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POSSIBILITY OF INJECTING CO_2 INTO THE UNDERGROUND BY BOREHOLES ON POTENTIAL LOCATIONS IN BOSNIA AND HERZEGOVINA

Šabović Almir[1], Isabegović Jasmin[2], Karadžin Zvjezdan[3], Delić Edin[4]

[1,2]*Mining institute Tuzla, e-mail:almir.sabovic@rudarskiinstituttuzla.ba*
[3,4]*Faculty of Mining, Geology and Civil Engineering Tuzla*

ABSTRACT

The paper presents the potential areas in Bosnia and Herzegovina (BiH) for injecting CO_2 into underground geological formations by boreholes. Areas are determined based on the geological structure of Bosnia ana Herzegovina, and development of Miocene formations which are the most prevalent in the northern and northeastern parts of the country, in the central part of country and southwest of Bosnia and Herzegovina. Furthermore paper gives an overview of potentials for injecting CO_2 into abandoned coal mines, and abandoned salt mine.

Key words: *CO_2 emissions, CO_2 injection, potential sites, suitable geological formations, Tuzla power plant, salt deposits, coal deposits*

INTRODUCTION

High concentrations of gases, especially carbon dioxide (CO_2), produced mainly through use of fossil fuels, create greenhouse effect causing a significant rise in temperature, and therefore climate change. In order to prevent further climate changes it is necessary to reduce CO_2 emissions into the atmosphere, which can be achieved through its injection through boreholes into suitable geological formations in deep underground. This could be achieved with the same or similar methodology used for injection of waste generated in research and exploitation of oil and gas [1]. In 2009 the European Union has adopted the so-called. "Climate-energy package," which includes a number of measures to encourage EU countries to achieve reductions in greenhouse gas emissions. Directive 31/2009/EZ on the geological storage of carbon dioxide (also called CCS Directive – „Carbon Capture Storage Directive") was adopted as part of the package and is one of the first legal framework for geological storage of carbon dioxide in the world.

AREAS FOR CO2 INJECTION

Capture and storage of CO_2 is a technological process that involves capturing carbon dioxide emissions from industrial installations, its transport to the facility for temporary storage and transport from temporary storage to injection sites and injection through boreholes into the appropriate underground geological formations (Figure 1). As the main application the Directive emphasizes the reduction of CO_2 emissions in the power plants that use coal and gas, as well as in industrial plants such as refineries, steel facilities, cement plants, etc. The aim of CO_2 injection into suitable geological formations is to isolate it from the atmosphere. Therefore, the purpose of the Directive is environmentally safe storage of CO_2, i.e. permanent preservation of CO_2 in a manner to prevent any risk to human health and the environment [2].

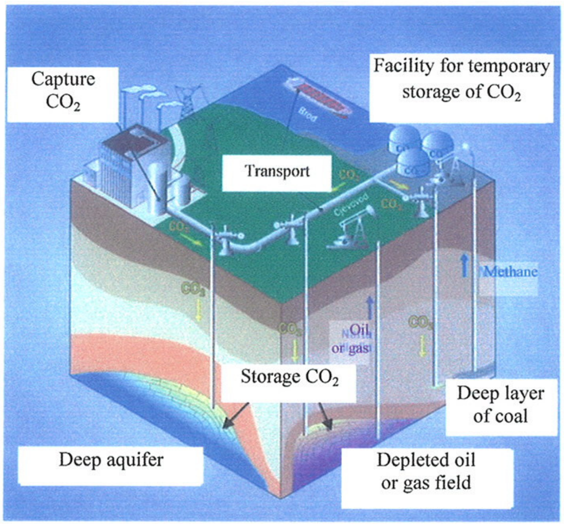

Figure 1 Capture, transport and storage of CO_2

CO_2 injection can be carried deep into the porous and permeable rocks which are positioned below impermeable formations (clay, clay stone) that prevents escape of CO_2 toward the surface. Figure 2 shows the three options for CO_2 storage [2]:

- Exploited oil and gas fields - well known based on the explorations of hydrocarbon reservoirs;
- Deep salt deposits - are not well explored, but have great potential for storage;
- The deep coal bed - well known, option for the future.

In addition to the above CO_2 could be injected in loosely bonded sedimentary, porous rocks, primarily sandstones and sand, and in fractures of carbonate rocks.

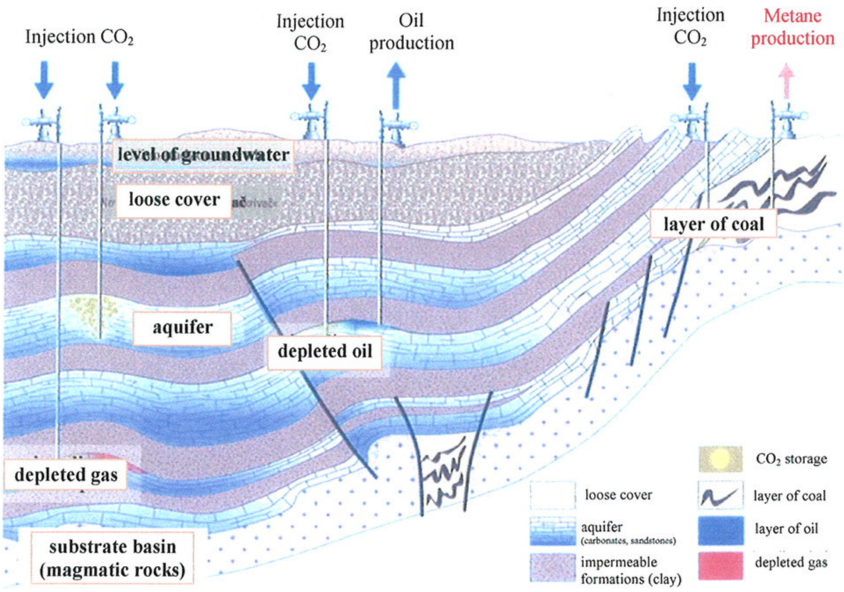

Figure 2 Options for CO_2 storage

Upon carbon dioxide is injected into a suitable underground geological formation it accumulates in the pores between grains and in the fractures by removing existing fluid, water, gas or oil. Suitable rock formations for injectiing CO_2 are mostly located in the sedimentary basins where rocks have high porosity. In order to assess the suitability of underground structures for long-term storage of CO_2, a detailed knowledge of the geological structure of the underground is needed. The basic criteria that artificial reservoirs of CO_2 have to fulfill are [3]:

- Sufficient porosity and permeability of the formation in which CO_2 will be stored,
- Sufficient capacity of storage space,
- Impermeability of the rock formations above the formations for storage, so it prevents raising of CO_2 to the surface,
- Absence of drinking water aquifers in the layers determined for CO_2 injection,
- Position of the layers for injection should be at greater depths where the pressure and temperature are high enough that allowes storage of CO_2 in the compressed liquid phase, which significantly increases the capacity,
- The existence of the structural traps that can keep the CO_2 within the formation.

POTENTIAL AREAS IN BOSNIA AND HERZEGOVINA FOR INJECTION CO_2 THROUGH BOREHOLES

Analyses of BiH geological structure, indicated that Miocene formation,s which are mainly developed in the northern parts of the country, partly in central Bosnia and Herzegovina (Zenica-Sarajevo basin), and further southwestern part (Fig. 3), can be potentialy suitable areas for CO_2 injection.

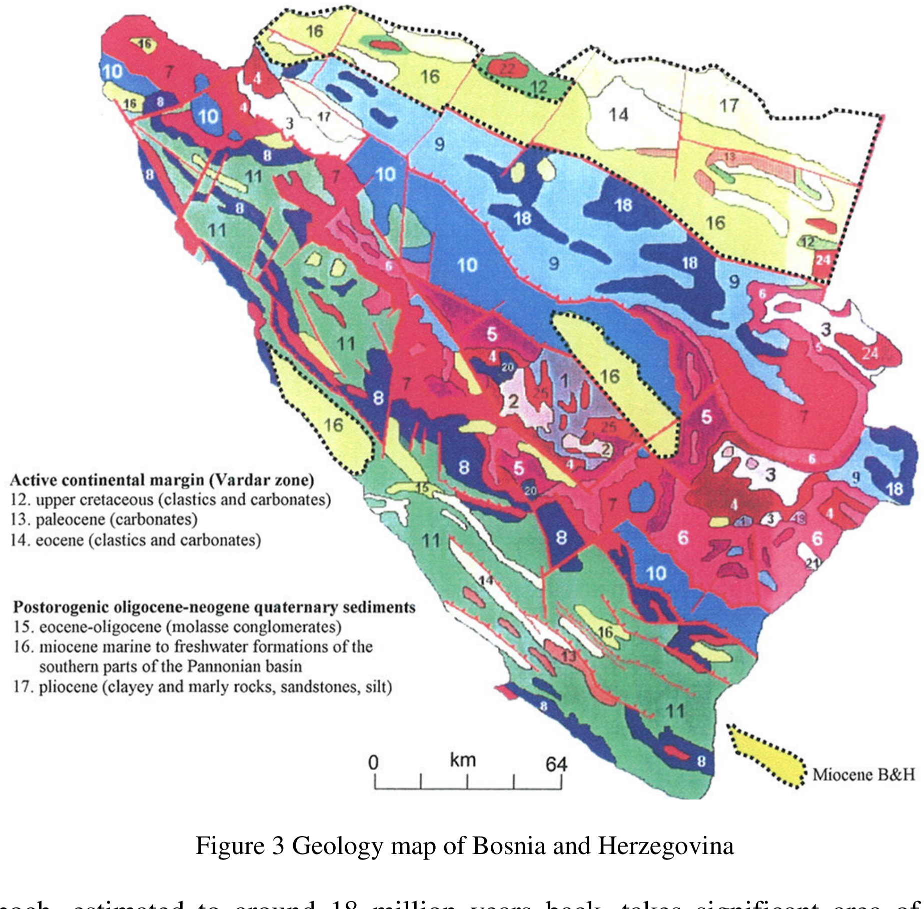

Figure 3 Geology map of Bosnia and Herzegovina

Miocene Epoch, estimated to around 18 million years back, takes significant area of Bosnia and Herzegovina, and the Miocene formations represent a considerable part of the geological structures covering large areas. Their deposition was done in a variety of structural conditions, which resulted in genetically diverse types of series and formations. The characteristic of this epoch is formation of the Paratethys, the sea which has existed along the Tethys. These two seas were linked with straits. Allocation of Miocene formations on the northern territory of Bosnia in shown on Figures 4 and 5.

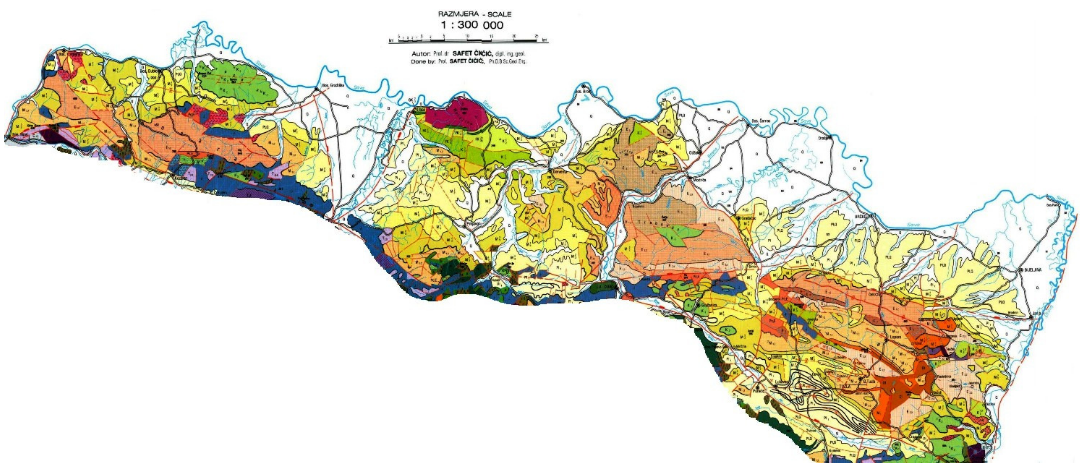

Figure 4 Distribution of Miocene northern Bosnia

Characteristic of Miocene is that deposition took place in two distinct paleogeographic belts. In northern Bosnian belt marine and brackish sedimentation occured in the Paratethys. Inside the Dinarides out of reach of Paratetis, many isolated freshwater ponds existed with normal sedimentation taking place during late Miocene. Some of these ponds appeared in the early Miocene, but continued existence in the late Miocene. This is the case with the basins: "Zenica – Sarajevo", "Livno", "Duvno", "Banja Luka" and "Kamengrad".

Besides the above mentioned, a whole range of lakes where sedimentation took place existed in that period. Those basins are: „Cazin", „Bihac", „Drvar", „Krupa", „Barac", „Sipovo", „Jajce", „Bugojno", „Glamoč", „Konjic", „Prozor", „Nevesinje", „Gacko", „Ulog" and „Rogatica".
Mostly coal deposits had been formed in these basins. Since a large number of these coal basins are active mine areas nowadays, and taking into account the depth and thickness of favourable clastic formations the coal basin "Kreka" in the NE of Bosnia and Herzegovina was taken out as potential for injection (Figure 6).

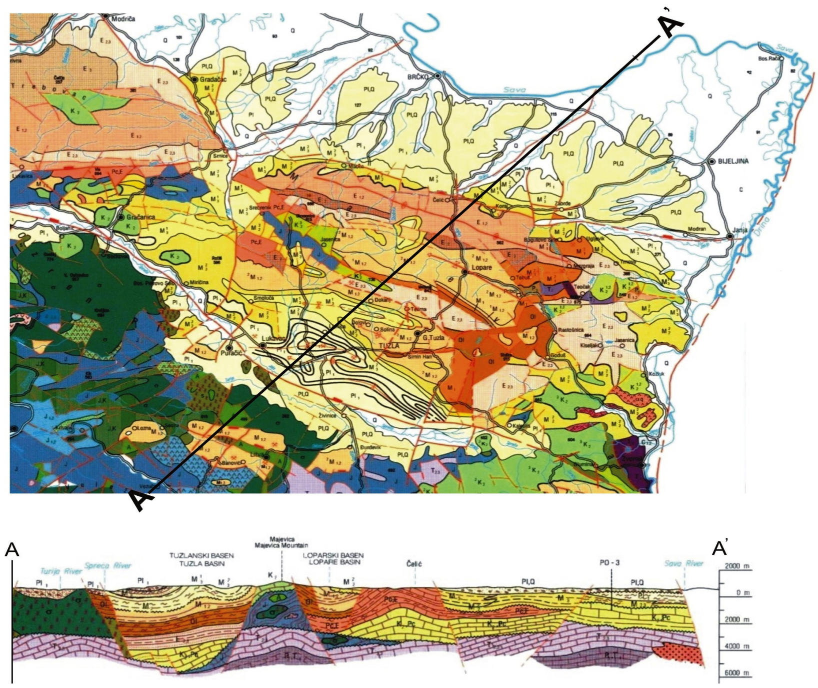

Figure 5 Distribution of Miocene in northeast of Bosnia and Herzegovina

The largest surface and in depth distribution of clastic sediments are in sedimentary basins.

Significant research results are related to the eastern part of NE Bosnia and Herzegovina: “Brcko” and “Bijeljina” where deep drilling on oil and thermal water were conducted. The results of these studies were used for a study of potential sites for CO_2 injection.

The geological composition of the “Semberia” terrain was interpreted based on the findings of oil investigations because this area represents a depression filled with Tertiary and Quaternary sediments, and with no outcroops of lower beds. Therefore four deep boreholes were drilled.within the scope of conducted studies.
As for the region of the “Sarajevo-Zenica” basin, as potential sediments for CO_2 injection were considered so-called “lasva alteration series”, with thickness of series varying from 400 to 800 m.

This series is positioned above the coal bed. Second and more favorable sediments for CO_2 injection are deposits of “Oligocene - Miocene multi-colored series”. Lithological composition is dominantly represented with conglomerates and sandstones with frequent lateral alteration with clay and marl. This series is underlying the coal bed of this basin, with thickness between 300 and 500 m. Detailed data are shown in Table 1 and in Figure 6.

Table 1 Stratigraphic, thickness and petrographic of the Sarajevo-Zenica basin

Basic geological map	Stratigraphic symbol	Thickness (m)	Petrographic
„Zenica“	$M_{2,3}$	400-800	Lasva alternating series of conglomerate, sandstone, marl and limestone
„Vareš“	$^{2}M_{2}$	350-450	Transitional zones: thinly laminated marls and sandstones
	$^{3}Ol, M$	300-500	Multicolored series: conglomerate, sandstone, marl and clay
„Sarajevo“	$M_{2,3}$	600	"Lasva conglomerates": conglomerates, sandstones, marls

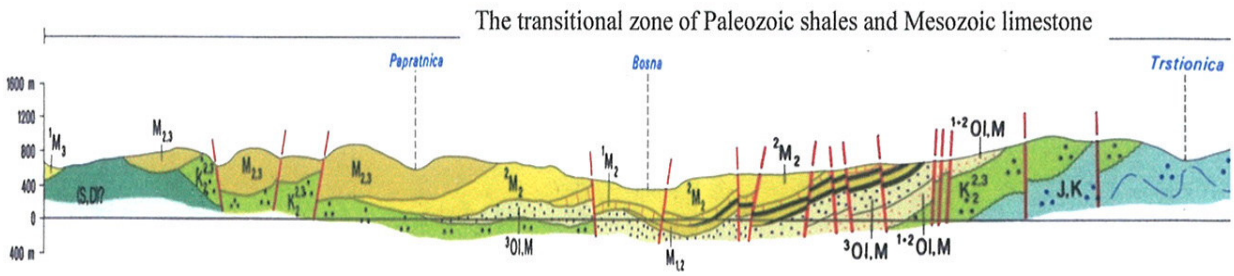

Figure 6 Distribution of Miocene clastics at Kakanj coal area

COAL BASIN „KREKA“

Coal basin „Kreka“ is situated between the southern slopes of the mountain „Majevica“ and valley of „Spreca“ river. Surface is over 200 square kilometers. Coal basin is developed from northwest to southeast from „Dobošnica“ (near Lukavac town) to „Caparde“ (west of Zvornik town). It is developed in length of 50 km, with four coal beds. Based on the generalized stratigraphic column given by the Institute of Geology of Sarajevo, a potential sediments for deep CO_2 injection are sands below coal layers of upper Pannonian ($^{2}M_{3}^{2}$), Figure 7. The thickness of this series is 360 m, lying at depth of about 1.050 meters below sea level. Given the orientation of the layers (synclinal bending) the high pressures are expected in this zones marked as suitable, but, further research regarding pressures are required.

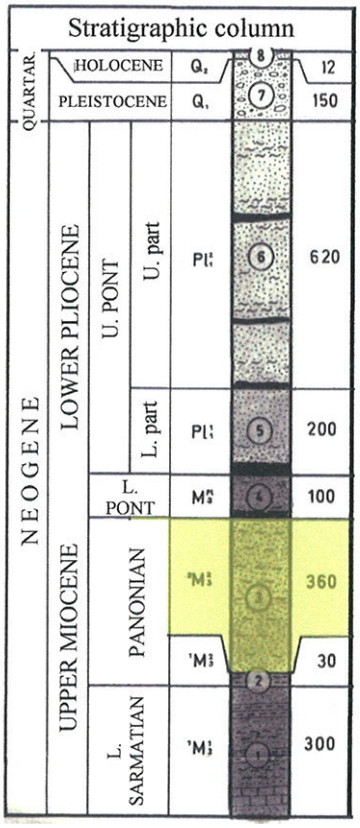

Figure 7 Stratigraphic column of Kreka coal basin

CO_2 EMISSIONS FROM POWER PLANT TUZLA AND POSSIBLITIES FOR ITS INJECTION THROUGH BOREHOLES

Coal fired power plants prime activity is production of electricity by coal combustion, that consequently cause release of large quantities of CO_2 into the air, and is therefore imperative to analyze possibilities for its collection and storage into suitable geological formations. As example, in papper are presented datas related to "Power Plant Tuzla" – „PPT" (Figure 9), the type and amount of coal that is combusted in a power plant, and the amounts of CO_2 resulting from that combustion [2].

„PPT" (Figure 8) is located approximately 7 km from Tuzla town and is situated along the main regional motor road „Tuzla" – „Doboj", and covers an area of 85 ha. Lignite from coal mines „Kreka" („Dubrave", „Sikulje, „Mramor" and „Bukinje" mines) and sub-bituminous coal from the mines „Banovici" and „Djurdjevik" represent the basic energy source used by PPT. Average daily quantity of coal received at PPT amounts to 8.000-10.000 tonnes. The PPT annually consume between 3.0 and 4.0 million tons of coal, depending on the power balance. The average heating value of lignite is 8.000-10.000 kJ / kg, and of sub-bituminous coal 12.500-15.000 kJ / kg with ash content of 15-25%. Annual emissions of CO_2 in the air (data for 2008) from the PPT is 3.579 tonnes, or 998 kg/MWh [4].

LITHOLOGICAL STRUCTURE OF POWER PLANT TUZLA AREA

Geological structure of the area where PPT is situated are formed partly from the Quaternary sediments (recent alluvial deposits consisted of clay, fine grained sand with clay, fine grained sand with clay and organic matter, medium sand with pieces of rock, fine and medium grained gravel with clay and gravel with sand) and the complex of Tertiary sediments or Pliocene formed during sedimentation in Pannonian lake (slate, coal and fine grain, medium and coarse sand). Lithological characteristics of the terrain at PPT area, is determined on the basis of the exploration boreholes, as follows [5]:

Figure 8 "Power Plant Tuzla" (photo: Sabovic, 2012)

Medium well compacted quartz sands which is under the coal bed. Thickness of sand sediments is approximately 90 m;

Lignite with interstratification of low plasticity, dense clay. Coal and clay layers alternating in series and with depth, the thickness of the clay material increase;

Marly clay and slate represent final litological sediments of Neogene sedimentary series. The thickness of these layers has not been identified but their presence was determined in area of water accelerator and cooling tower. These sediments are above the coal bed;

Alluvial deposits representing the youngest sediments in surrounding terrain of "Power Plant Tuzla". They were deposited by the river Jala, and consists of fine and medium sand and gravel with variable thickness. Over a layer of gravel lays fine to medium grained sand with also variable thickness. Alluvial series ends with a layer of clay sediments with thickness, in some areas, over 4,0 m.

Lithological structure of area at PPT indicates that this area has potential for underground injection of CO_2 generated in power plant coal combustion process. Prospect of CO_2 injection must be proven with drilling of borehole that should be deeper than the ones done earlier, and confirm existence of layers suitable for CO_2 injection.

Except of area at PPT site, potential location for CO_2 injection represent a narrow area of the former open pit mine, and future landfill of ash and slag "Sicki Brod", whith clay-marl sediments and dominant sand formations. Coal deposits are present within these structures. The following lithological units [6] were identified at this location (top to bottom):

- Burned clay (remains of eroded upper coal seam)
- Sand - thickness 60 m,
- silt (grain size 0.06 mm) - Thickness 3 - 15 m,
- clay - thickness 13 - 20 m,
- main coal seam - thickness of 10 m,
- Sand - thickness 18-26 m,
- clay - thickness of 2 to 8 m,
- lower coal seam - thickness 3 - 13 m and
- sand.

Analysis of lithological units indicate that, lithological units (clay and sand) are often interchanged, the thickness of sand layers are favorable for CO_2 injection, the thickness of the clay sediment are also favorable and represent a natural barrier above and beneath the sand layers, but deeper drilling should be performed to confirm the composition of the sediments underlying the deepest sand layer.

GEOLOGICAL INFORMATION ON AREA OF SALT DEPOSIT „TETIMA“

After the transgression of the sea from the Central Paratethys on area of „Tuzla Basin“lagune sedimentation enviroment and subtropical climate existed thus allowing deposition of salt formation. At least two salt deposits had been formed in „Tuzla basin“; salt deposits localy called "Tusanj" in the central part of the „Tuzla basin“ and salt deposit „Tetima“ in the eastern part of basin. Conditions of sedimentation can be characterized as shallow-marine where deposition of salt in „Dokanj“ syncline ends with the formation of breccias that are position above the salt deposit.

This breccia indicates a very shallow depositional environment with strong hydrodynamic conditions. During less severe transgression of sea water, on the area of synclines „Dokanj“massive dark gray sandy marls were created. This suggests that the marine sedimentation continued without interruption and today's massive sandy marl were formed from clayey-calcareous-sandy-muddy bottoms. It is assumed that after calm waters occurred certain hydrodynamic alternation with marl and interbeds of sandstone.
Deposit of salt "Tetima" is located in the eastern part of synclines „Dokanj“ that spreads under very hilly, and very diverse and mostly forested terrain. Salt is deposited mainly in the north section, in the top of the beaded series. Deposit represent one salt dome, with the direction of NW-SE.

The deposit is significantly deformed by faults during tectonic movements and development of synclines „Dokanj“. The faults are normal, younger, and intersect all sediments. Form of the deposit and its internal tectonics suggest movement of salt masses under the influence of tectonic forces towards the shallower part of syncline which resulted in the highest concentration of salt. On the basis of detailed geological mapping of core derived from the earlier investigation and exploitation boreholes and sedimentological and paleontological analysis, sediments were determined occurring above the salt dome and their relationships, as well as sediments under the salt body.

Deposit is covered by Miocene sediments, represented by marls, sandstones and conglomerates whose deposition took place in continuity, because of which the borders of individual stratigraphic units in lithologic manner are vague and are generally determined based on the fossile remains, mostly microfauna. Maximum thickness of the upper sediments and salt deposit is 900m.

Beneath these layers are sediments of beaded or salt series whose upper part include salt. This complex reveals three significant lithological units [7]:

- overlying breccias
- salt, and
- underlying dolomitic marl

Overlying breccias have an average thickness of 30 m (maximum of 50.8 m and minimum of 8 m). These are compact breccias composed of fragments of linearly marl, rearely anhydrite, limestone, marl and the binder is marl in lower part, occasionally, anhydrite.

Anhydrite content increases towards the south-western part of the deposit, and is especially significant in the peripheral boreholes (to the west and south of the bay) that didn’t found salt, and where anhydrite occurs in the layers 1-2 meters thick. These data suggest that the anhydrite southwest of the deposits appears as a lateral equivalent of salt.

Under the salt series a characteristical layer of anhydrite exist with thickness of 10-20 cm. Existance of breccias are associated with short emersion during which drain cracks are created in the clay-carbonate mud and in gypsum-anhydrit sediments.

Salt, is related to a beaded or salt series. In the structure of deposit exist salt rock or sodium chloride salt (halite), anhydrite and other clay-carbonate sediments. Structural and textural characteristics, and color of salt is varible. It appears in a wide limits: from fine grained to coarse grained aggregates but also in crystals characteristical for halite. Coarse aggregates prevail. Although the salt is usually gray, its color ranges in a wide range, from colorless, white, gray, dark gray to brown. Coarse crystals are dark gray and fine grained are light colors (to white).

Dolomitic marls and clay rocks under the salt can be generally divided into three levels. Immediately below the salt body is distinctly laminar level of dolomitic marls of about 30 meters, continuated with the level of alterated massive laminated marls with thickness around 70 meters on which bottom is layer of massive light gray tuff. The deepest level is gray and dark gray, massive or laminar marl and clay stone. These marls and clay stones laterally change into red and green marl and sandstone known as “colored” series.

CONCLUSION

Capture and storage of CO_2 is a technological process that involves capturing carbon dioxide emissions from industrial installations, its transport to the facility for temporary storage and from temporary storage to the injection borehole, and then injection into the appropriate underground geological formations.
CO_2 injection can be performed using boreholes into deep porous and permeable rock overlied by impermeable formations. CO_2 can be stored in

- depleted oil and gas fields,
- deep salt deposits, and
- deep coal layers.

CO_2 can also be injected into sedimentary loose, permeable rock or sandstone and sand, as well as cracks in the carbonate rocks.

Based on analysis of the geological maps of Bosnia and Herzegovina, and geological structure, the potential sites for CO_2 injection in BiH suitable for injection are Miocene formations which are the most prevalent in the northern, north-eastern parts of the country, partly in central Bosnia and Herzegovina, and the southwestern part of BiH. In addition, CO_2 injection is possible in abandoned salt mine chambers, and deep into the well-known coal basins.

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