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DEPOSITS AND MINING POTENTIAL OF BENTONITE IN CROATIA

LEŽIŠTA I MOGUĆNOSTI EKSPLOATACIJE BENTONITA U HRVATSKOJ

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Ključne riječi: odlagališta, nuklearni otpad, bentonit, eksploatacija, rezerve, Hrvatska

Abstract

Bentonite is one of the materials that is planed to be used for buffering and backfilling in spent nuclear fuel repositories, within deep crystalline rock. There are several locations in Croatia that bentonite deposits and occurrences are found on. Some were exploited in past, and others were more or less explored. This paper presents overview of bentonite deposits, basic properties and potential resources, and mining practices in Croatia. Largest exploited deposits are found in area of Poljanska luka, Gornja Jelenska and Bednja. Surface and underground methods (drift and fill, sublevel caving) were used during exploitation. In the area of Svilaja and Lika are found potentially valuable deposits that were never exploited. Montmorilonite content ranges form 20-50% to 57-89%. Most deposits contain bentonite beds with thickness 0,4-1,6 m, and have plunge 10°-30°. Few exceptions are nearly horizontal and thick more than 5 m and even 12 m. One is declined at 70° and up to 40m thick. Proven reserves are about 2,3 Mt with some level of uncertainty. Average production per mine during exploitation period can be assumed to be several thousands t/y.

Sažetak

Bentonit je materijal kojim se planira brtviti i zapunjavati podzemna odlagališta nuklearnog otpada u dubokim magmatskim strukturama. U Hrvatskoj postoji više lokacija ležišta ili pojava bentonita. Neka od njih su eksploatirana u prošlosti, dok su druga manje ili više istraživana. U radu je prikazan pregled ležišta bentonita, važnija svojstva i rezerve, te način eksploatacije u Hrvatskoj. Najveća ležišta nalaze se u područjima Poljanske luke, Gornje Jelenske i Bednje. Primjenjivale su se površinske i podzemne (stupno uz zapunjavanje, podetažno otkopavanje) metode eksploatacije. U području Svilaje i Like nađena su potencijalno vrijedna ležišta, koja nisu iskorištavana. Udio montmorilonita se kreće od 20-50% do 57-89%. Većina ležišta čine slojevi bentonita debljine 0,4-1,6 m, i pada 10°-30°. Iznimno su horizontalna i debljine veće od 5 m, pa čak i 12 m. Jedno ležište pada pod 70° i debljine je do 40 m. Dokazane rezeve čini otprilike 2,3 Mt bentonita, uz određenu razinu nesigurnosti. Prosječna proizvodnja po rudniku za vrijeme eksploatacije pretpostavlja se oko nekoliko tisuća tona godišnje.

1. Introduction

The concept of spent nuclear fuel repositories in deep crystalline bedrock employs multiple barrier system (Gunnarsson et al., 2007). Spent nuclear fuel is enclosed in water-tight and load bearing canisters. Canisters are then placed into deposition holes at 400-700m depth and surrounded with buffer material. All cavities, shafts, deposition and access tunnels are then backfilled and sealed (Figure 1).

Purpose of the buffer is to isolate canister from geosphere, providing protection from groundwater flow and other detrimental processes, and to limit the release of radionuclides in case of damaged canister. Purpose of the backfill is to keep mechanical stability of the tunnels and provide sealing to prevent water flows.

Because of its properties, bentonite is one of the materials that is planed to be used for buffer and backfilling. Thus, objective of this paper is to provide overview of deposit locations, estimated reserves, basic properties data, and mining practice and potential of bentonite in Croatia.

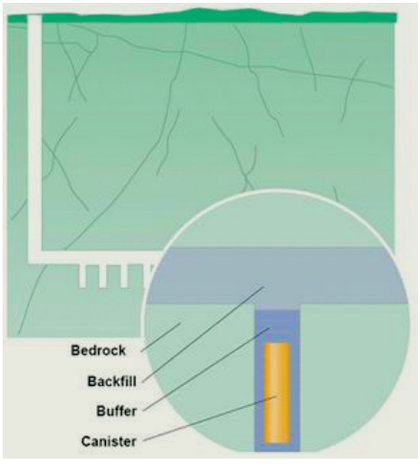

Figure 1 Buffer and backfill in multi-barrier system (Rautioaho et al., 2009)

Slika 1. *Brtvljenje i zapunjavanje u sustavu više barijera (Rautioaho et al., 2009)*

2. Bentonite exploration and mining in Croatia

There is more then fifteen sites in Croatia that exploration or mining activities were conducted on (Figure 2). These locations can be divided in several areas.

2.1. Area of Svilaja

In the area of Svilaja exploration in Štikovo and Maovice was done in period from 1947. to 1967. Two beds of bentonite were found. In Štikovo, upper bed has thickness of 0,2-1,2 m while lower bed is 2,5-6 m thick and outcrops extent is found to be around 200 m. Upper bed has thickness of 1,5-5,5 m in Maovice, and outcrop is more then 300 m long. Bentonites in this area were never extensively explored, nor exploited.

2.2. Area of Lika

Divoselo is the only larger deposit found in the area of Lika. Exploration during 1980.-1981. showed composition of three beds of bentonite. The thickness of lower, middle and upper bed is 0,3-0,5m; 1,6-2,2m and 2,0 m respectively. Lateral extent of deposit was not determined, but it was concluded that economically significant quantity of bentonite is found and further exploration is needed to estimate full potential of this deposit. It was never exploited.

2.3. Area of Poljanska luka

Area of Poljanska luka was first explored in 1952. Soon Poljanska luka mine was developed and bentonite clay was exploited till 1968, with intermission of several years in 1950's. Production rate was 6.000-7.500 t/year. During 1966 development phase of Bratkovec mine was started on other location, and this mine was active until 1980's.

Deposit composes three beds of bentonite, with angle of dip around 30°-40°. First (lower) bed is 0,6-1,0m thick and second bed with thickness of 0,8 m is found 9-12 m above. These two beds, that can be followed for 1.800 m on outcrop, were exploited by underground methods. Third bed is located about 20m above second and it's 0,7 m thick only in one section, were it was exploited by open pit.

In Bratkovec, mining of second bed was developed with main declined adit from the surface. From this adit deposit was divided in several levels by horizontal drifts that were connected to declined ventilation drift on the opposite side of deposit. Variant of drift and fill method on retreat was used, with excavation face that was driven inclined from horizontal drifts. After first excavation drift was done, subsequent was started and spoil material was backfilled in void of the first drift.

2.4. Area of Gornja Jelenska

Deposits of bentonite in the area of Gornja Jelenska can be found in two stratigraphic sequences. One is composed of three bentonite layers that were exploited by underground mines in locations called Draga, Krč and Široki jarak. The other is deposit of lenticular shape that was mined by open pit Murinski jarak.

According to exploration reports, most exploration and exploitation activities in this area were taking place in period from 1960's to 1980's. Furthermore, the only active bentonite pit during last two decades in Croatia is Murinski jarak, where recent production ranged from 0.0 to about 3.000 tons annually.

Area of Draga, Krč and Široki jarak is characterized by high tectonic disturbance. Therefore beds of bentonite along with hoist strata are broken into blocks. This caused mining approach with several separate underground excavations. The three beds of bentonite, from lower to upper have thickness of 0,15-0,9 m, 0,2-1,2 m and 0,9 m, respectively. Mining method used in Krč was similar to Bratkovec mine. Deposit was developed in several levels by horizontal drifts that were driven from main adit in direction of bed strike. Main adit was declined from the surface to the deposit. Drift and fill excavation was driven to both sides of horizontal drifts, one inclined and one declined. Bentonite was transported from excavation face by drag chain conveyor to the horizontal drifts, and then by rail wagons to the surface. Hard mining conditions were reported in this area. Host rock contains sand layers which are permeable and act as aquifer. Clays are susceptible to expansion in contact with water and cause high stresses. Also, great number of faults is found in deposit.

In Murinski jarak deposit has shape of lens that is 12 m thick. Bed is approximately horizontal and has thin overburden of several meters. Thus, it is exploited by open pit.

Similar deposit in Ognjilo was found to be 7 m thick.

2.5. Area of Bednja

Two major deposits were explored and mined in the area of Bednja. Šeprun, which was explored in 1959. and exploited till 1979., and Šaša which was first opened in 1926., then extensively explored in 1975. and exploited till 1990's. Both deposits were exploited combining surface and underground mining methods.

The deposit of Šeprun composes one bed of bentonite clay, that has thickness of 1,1- 2 m and angle of dip up to 20°. At first it was exploited by open pit and afterwards it was entered underground at other location. Two inclines 700 m long were excavated, from which deposit was divided in several levels by horizontal drifts. Mining method was probably drift and fill similar to Bratkovec mine.

Šeprun mine was abandoned after activation of Šaša, but still one location in proximity of the mine was explored in 1988. Bed of bentonite 0,9-1,3 m thick was found at depth of 30-56 m.

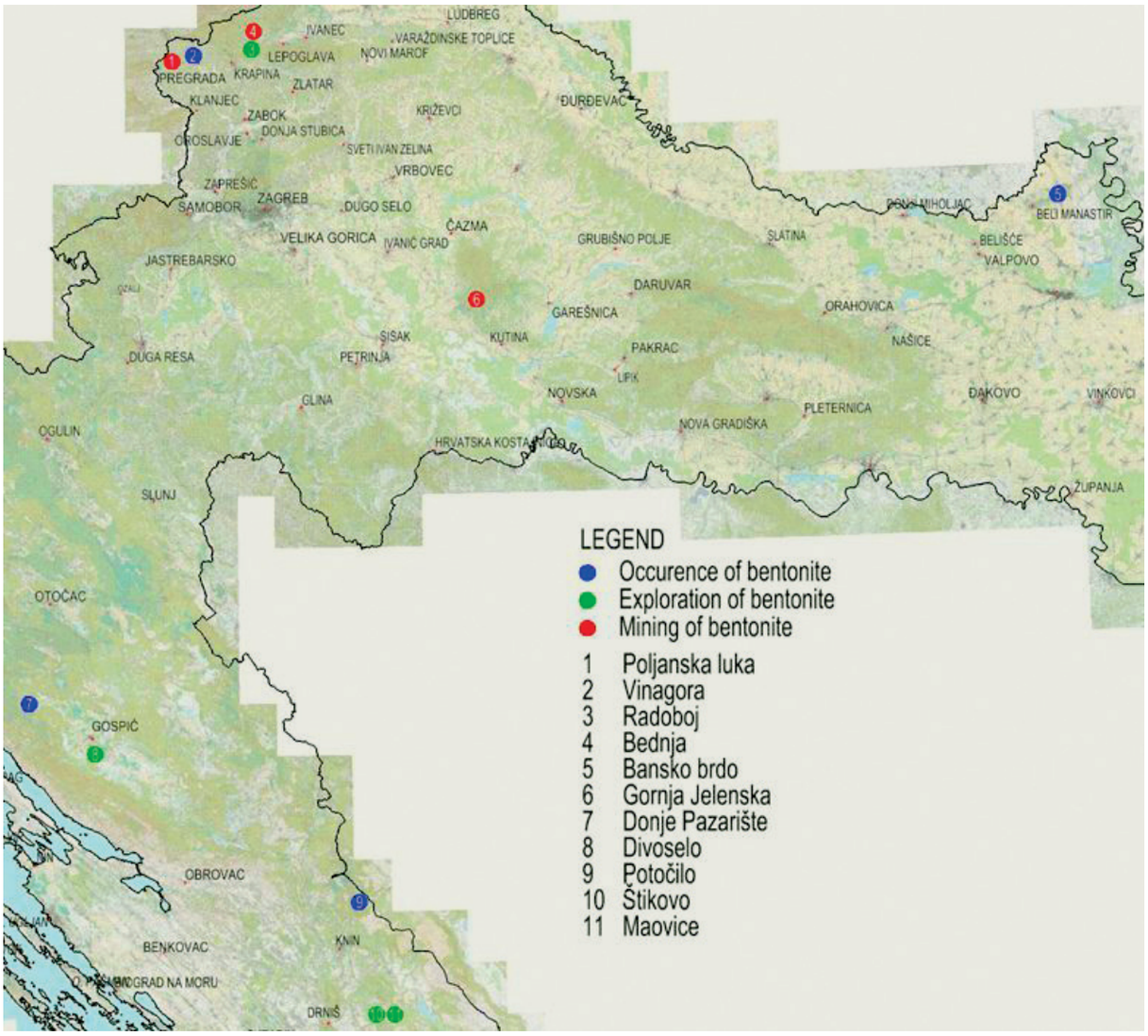

Figure 2 Exploration and mining sites of bentonite in Croatia (Marković, 2002; RGN, 2008)

Slika 2. *Istraživanje i eksplotacija bentonita u Hrvatskoj (Marković, 2002; RGN, 2008)*

A deposit of Šaša is composed of bentonite bed with 10-35m of thickness and angle of dip more then 70°. It was first opened at outcrop by open pit, with production rate around 7.000-10.000 t/year.

Afterwards, underground mine was developed by main adit, which follows the hanging wall contact and main drift on the same level, which follows the footwall contact. These two passageways were connected by transverse drifts at every 30-50m. Similar development work was made on several levels that were connected by blind shaft. One main drift at every level had connection with surface for ventilation and safety purposes. Development phase provided exploration data and preparation for production phase of mining. Variant of sublevel caving method was used with retreat from the end of the deposit. Excavation, with face 4 m wide and 2,5m high, was starting from two main drifts and was driven toward centre and supported by timber, until encounter. After encounter, roof was controllably collapsed while retreating toward main drifts, and thus bentonite clay form sublevel was extracted. Bentonite was transported by rail wagons to the blind shaft, through the shaft to the main level, and again by rail wagons out of the mine.

Beside these two well-known mines, bentonite was found and somewhat exploited in proximity of Vrbno. Beds of thickness from 0,6 to 1,6 m, and surface area from 35×50m to 120×360 m are determined.

3. Common world practice in bentonite mining

The most common method of mining bentonite is the open pit method. This involves removing overlying ma-

terial to expose the bentonite. Bulldozers, scrapers and excavators, and often a combination of these equipment, are used to remove the overburden. In a typical bentonite pit the topsoil and subsoil are first removed and stockpiled for redistribution during pit closure and land reclamation, then overburden is removed. Mining sequences can vary in different cases depending on deposit shape and complexity, but typical mining process involves several stages similar to strip or terrace mining methods. After the bentonite is removed from first section of deposit, the overburden from subsequent section is placed in void left by removal of the bentonite and this sequence continues toward end of the deposit. Equipment for extraction of bentonite often includes scrapers, front-end loaders or excavators. Trucks are used, along mentioned equipment, for transport of bentonite to the processing plant.

Table 1 Basic mineralogical, chemical and physical properties

Tablica 1. *Osnovna mineraloška, kemijska i fizička svojstva*

Location	Montmorilonite,%	SiO_2,%	CaO_2,%	Na_2O,%	Density, t/m^3
Štikovo, Maovice (area of Svilaja)	40-70	65,94-73,30	6,50-7,60	0,28-0,43	-
Gornja Jelenska	60-80	46,40-50,30	2,40-3,72	1,84-2,10	2,00
Poljanska luka	60-80	60,74-67,47	2,97-5,10	1,21-3,90	2,00
Višnjevica (area of Poljanska luka)	57-89	-	-	-	-
Bednja	20-50	57,53	3,30	1,84	2,00-2,20
Šaša (area of Bednja)	60-70	-	-	-	-

As opposed to cyclic machines, continuous excavation equipment can be used in clay like materials.

Bucket chain excavator is common machine used in clay open pits. In conjunction with conveyors, they can provide large capacities and lower transportation costs. Also, one major advantage of bucket chain excavator is instant homogenization of material being excavated.

Mineable bentonite beds in western U.S. range in thickness from less than 1 m to up to 2 m. Overburden thickness is up to 10 m. General rule of economic recovery of bentonites requires that the ratio of overburden to clay thickness be less than 10:1 (Eisenhour et al., 2006).

Although open pits are most common method of bentonite extraction, underground mining practices can also be found, especially in Mexico and China.

4. Quality overview

Materials that are planed to be used for backfilling can be divided in to three categories: High-grade natrium and low-grade calcium bentonite clays with montmorilonite content form 60% to 85%, smectite-rich clays with montmorilonite content from 20% to 66%, and mixtures of high-grade bentonite with crushed stone and sand (Gunnarsson et al., 2007). By this criterion, bentonite from all explored locations in Croatia could be, to some extent put in use for nuclear waste disposal systems.

Since montmorilonite content and type are major properties that define quality in this case, mineralogical and chemical composition with emphases on montmorilonite, SiO_2, CaO and Na_2O content is summarised in Table 1. Data is obtained from several sources and represents range of values compiled from all sources for corresponding locations (Braun, 1980; Marković, 2002; Exploration reports).

5. Bentonite resources in Croatia

With exception of Murinski jarak, most deposits of bentonite that were exploited are abandoned and not further explored since 1980's or earlier. Thus, data on proven reserves is very scarce. Still, some data could be obtained from old exploration reports for major mining and exploration sites of bentonite. Data is summarized in Table 2. There is greater portion of reserves under sub-economic category. Most of them were probably transferred from economic category after mining of bentonite ended, because of questionable rentability or lack of interest for this commodity. Proven reserves are around 2,3 million tons, although this can not be claimed with great confidence. Some deposits were not included and there is uncertainty that latest exploration reports are obtained for all locations. No estimation on overall bentonite resources in Croatia was found. Considering that larger deposits were mined, and so well defined to some extent but not further explored, and that bentonite is found on many locations, some of which have greater potential, inferred resources could be several times greater than proven reserves. Geological expertise is needed for confident estimation.

Table 2 Proven reserves

Tablica 2. *Utvrđene reserve*

Location	Economic	Sub-economic
Draga	-	445.000 t
Bednja	-	248.420 t
Murinski jarak	691.480 t	413.170 t
Poljanska luka	49.220 t	13.650 t
Krč (Gornja Jelenska)	-	404.000 t
Šaprun	70.500 t	-
Divoselo	66.490 t	20.785 t
∑	877.690 t	1.545.025 t

6. Conclusion

Majority of bentonite deposits in Croatia are composed of one to three beds with thickness range 0,4 to 1,6m, and plunge form 10° to 30°. Few exceptions contain beds thicker than 2 m or plunge other then stated above. This includes Šaša deposit, which is dipping at angle more than 70° and has determined thickness of 10-35 m and increasing with depth. Deposit in Murinski jarak is nearly horizontal, it has thickness of 12m and relatively thin overburden. Exceptions are also three deposits that were never exploited, but are potentially valuable. One is Divoselo, with determined three beds thick up to 2,2 m and shallow overburden. Other two are Štikovo and Maovice that contain bed thick more then 5m in places.

Practically, declined deposits can be excavated using surface methods till overburden reaches its economic limit. Using the simple rule of approximately 10:1 as limit ratio of overburden to bed thickness, relatively small amount of bentonite can be economically recovered from thin declined deposits by surface excavation. Eventually, underground mining must be employed. This can be seen from applied mining practices briefly described in previous chapters. Most bentonite mining activities in Croatia started as open pits, while few of them continued by underground methods, of which drift and fill was most convenient for thin deposits, and sublevel caving for thick deposits.

Naturally, bentonite recovery increases with greater bed thickness and lower plunge of deposit, thus surface mining methods on deposits under shallow overburden are preferred around the world.

Data on production rate is scarce, but it can be assumed that each mine averagely produced several thousands tons annually, on average.

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