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Geological and engineering geological settings of the radioactive waste repository Novi Han, Lozen Mountain, Bulgaria

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Abstract. The Repository for Radioactive Waste (RAW) Novi Han of the Russian "Radon" type was built in the middle of 60-es, last century, in the Lozen Mountain near Sofia. Unconditioned wastes from medicine, military sources and scientific research activities are stored in it. The repository site has not been selected after detailed geological, hydrogeological and engineering geological investigations including safety assessment procedures. Such investigations were realized in the early 90-es by institutes of the Bulgarian Academy of Sciences. Later, in 2000–2002 the studies of the site have been enlarged with the authors` participation. These newly performed investigations have taken into account the requirements of the International Atomic Energy Agency (IAEA) documents. In the paper the results concerning the engineering geological and hydrogeological settings of the site are presented. Its geological and tectonic conditions are discussed as well. The data will be used for future analyses of impact of the Novi Han repository over the environment including radiological safety assessment.

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Key words: radioactive waste repository, engineering geology, hydrogeology, geology, tectonics, Lozen Mountain.

INTRODUCTION

The storage facility at Novi Han is the only one existing repository in Bulgaria for radioactive waste disposal. Waste materials from the medicine, military sources, and scientific research activities in unconditioned form are stored there. The gross volume of the wastes up to year 2010 was around 670 m^3 (Nuclear Regulatory Agency, 2011). It is indicated in the Strategy for Spent Fuel and Radioactive Waste Management (SSFRAWM) that the complete volumes in Novi Han facility could reach 2 440 m^3 till year 2030 (Council of Ministers, 2011). The radioactive wastes (RAW) are of solid, biological and small quantities of liquid types. Mainly low and intermediate radioactive wastes are stored in the repository but also some amounts of long-lived radionuclides of high activity are disposed. Those are spent sources from the technologies for nondestructive equipment, different types of level measures, static electricity instruments and smoke detectors.

The construction type of the disposal units depends on the type of wastes and their activity and includes concrete trench, concrete containers for temporary storage, tanks for liquid RAW, disposal unit for biological RAW, for spent sealed sources and solid RAW. The different units of the repository present the multibarrier engineered facilities constructed from reinforced concrete and additional engineered barriers such as steel layer, bitumen layer and brick wall (Mateeva, 2001). According to the Bulgarian SSFRAWM, the storage facility for RAW at Novi Han, further noted as RAW–Novi Han, will be subject to closure after the New

National RAW Repository will be in operation to accept the respective wastes there.

The choice of the RAW–Novi Han site was made in the early 60-es on the basis of expert assessment between several sites. The official exploration of the repository started in 1964. After long years of use, a complex assessment of the geological and geotechnical conditions of the repository site was conducted in 1992; it was followed by a detailed investigation of the geological, engineering geological and hydrogeological conditions on and around the repository site (2000–2002). The last two studies were undertaken according to the documents of the International Atomic Energy Agency IAEA, *e.g.* IAEA 1994, IAEA 1995, and IAEA 1999, and the international practice and national regulations and legislation (Evstatiev et al., 1993, 1994; Evstatiev, Kozhukharov, 2000; Kozhukharov et al., 2002).

The current study is focused on two goals: (*i*) to represent in retrospection the performed engineering geological investigations and (*ii*) to describe in details the engineering geological setting of the RAW–Novi Han site. These conditions are relevant to the long-term stability of the facility. In addition, regarding the documents dealing with the safety of the RAW–Novi Han “Radon” type of repository, the geoenvironment around the site should be considered as a main barrier against unanticipated radionuclide migration in the future decades (Stefanova, 2003). The geological, engineering geological, hydrogeological and geomorphologic settings are here described being in relation to the safety of the repository site.

CURRENT STATE OF THE ENGINEERING GEOLOGICAL INVESTIGATIONS

The engineering geological investigations in the period 1991-1992 were represented in a report, followed by some publications. The main results of these investigations are as follows:

- presentation of 1:25 000 scale geological map of the eastern part of Lozen Mountain;
- engineering geological mapping (of scale 1:1 000) of the repository site and surrounding area;
- analyses of the data obtained from 6 boreholes, 250–790 m deep, drilled during the period 1984-1988 and located at 80 to 1500 m around the site;
- hydrogeological analyses of all water sources in the region and hydrogeochemical testing (including determination of radioactive elements) of the water;
- rotary core drilling of three boreholes, two of them inside the repository perimeter, and the third one outside the perimeter;
- determination of density, specific gravity, particle size distribution, plasticity and unconfined compressive strength of the borehole samples;
- field pumping permeability test in one of the inside boreholes;
- determination of the chemical composition of the underground water in the boreholes;
- gamma-ray log in the boreholes.

The conclusions from the investigations were that there was no radioactive contamination in the rock massive and in the ground waters. At the same time, however, it has been established that the geological and hydrogeological conditions in the investigated part of Lozen Mountain cannot secure reliable natural barriers against the migration of radionuclides in case of extreme events of the geological hazard in the future. Moreover, the natural settings were describes as “too complex” for modelling of eventual radionuclide migration pathways. At that time, the existing data from the survey could not be implemented in some radioactive pathways and models/codes.

The next more detailed complex geological investigation of the RAW–Novi Han site and the surrounding area was performed in the period 2000–2002. The both field (*in situ*) and laboratory engineering geological, geotechnical and geophysical investigations which were much more focused and concentrated on the geoenvironment setting included:

- execution of 450 meters borehole length (15 as a number of boreholes); during the drilling works, the parameter Rock Quality Disintegration (RQD) was determined in order to quantify the quality of the rock base;
- standard penetration tests at eleven localities along the repository site;
- engineering geological mapping was made in a zone with radius 1 km around the RAW–Novi Han in order to understand the spatial distribution of the rocks depending of their engineering geological classification, to determine the zones of expressed erosional forms and hazardous geodynamic processes such as landslides, rock falls, etc.
- geophysical survey comprising a range of geophysical methods: vertical electrical sounding, seismic tomography, reflected seismic wave method, gamma logging/borehole sounding method.

Laboratory tests included particle-size distribution, Atterberg limits, unconfined compressive strength, etc.

GEOLOGICAL SETTING

Stratigraphy

As the geological setting of the area in its complexity is important to the long-term stability of the repository, a broader area around the RAW site has been investigated. The geological structures of the area consist of Upper Proterozoic, Lower Paleozoic, Upper Paleozoic (Stephanian–Permian), Lower Triassic, Neogene and Quaternary deposits and several magmatic bodies of granitoids and lamprophyre dikes (Fig. 1) (Dimitrov, 1937; Katskov, Iliev, 1993; Evstatiev et al., 1993, 1994; Kozhukharov et al., 1980, 2002, 2003); Vassilev, Kozhukharov, 2004).

Vendian-Cambrian rocks in the region are represented by the so-called Diabase-phyllitoid complex. Dismembered rocks falling within tectonically formed block structure consist of the green rocks of diabase and its pyroclastics, amphybole schists, chlorite schists, and phyllitoids (Dimitrov, 1937, Vassilev, 2004). The whole complex is metamorphosed up to green schist facies.

Ordovician. The Krushovitsa Formation of Kozhuharov et al. (2003), i.e. the former Phyllitoid schist and phyllite formation, builds up the terrain of the repository site (Fig. 2). The formation thickness is about 300-500 m. It consists of basal conglomerate and thin layered semi-crystalline phyllites, phyllitoids and quartz-sericitic phyllites. They are of grayish green to dark-gray colour, locally with glancing and finely undulated surface. Due to tectonic deformations they were transformed into ocher yellow or rusty brown clayey mylonites. The weathering zone of phyllites reaches 5-7 m. They have a fine laminated parallel fabric and lepidoblastic texture. The phyllite cleavage is of E-W orientation (80°-90°) and the steep inclination is to the North (74°-80°).

Upper Paleozoic (Stephanian and Permian). The Upper Carboniferous (Stephanian) in this region is represented by the Chervenigrad Formation (Kozharov et al., 1980). It consists of breccias-conglomerates and alternating conglomerates and sandstones with small siltstone and shale intercalations. The red colour is characteristic for the rocks. The Permian sediments are divided into three formations: the Gabra, Tarnava and Ravulyan formations (Kozhuharov et al., 1980). The Gabra Formation is built up of sandy siltstones, shales and marls. Carbonate strips and carbonate binders have been established among the sandstones. The Turnava Formation is represented by unsorted breccias-conglomerates and gravel sandstones. The Ravulyan Formation is situated at the northern slope of the mountain and is built up of sandstones with siltstone and shale intercalations.

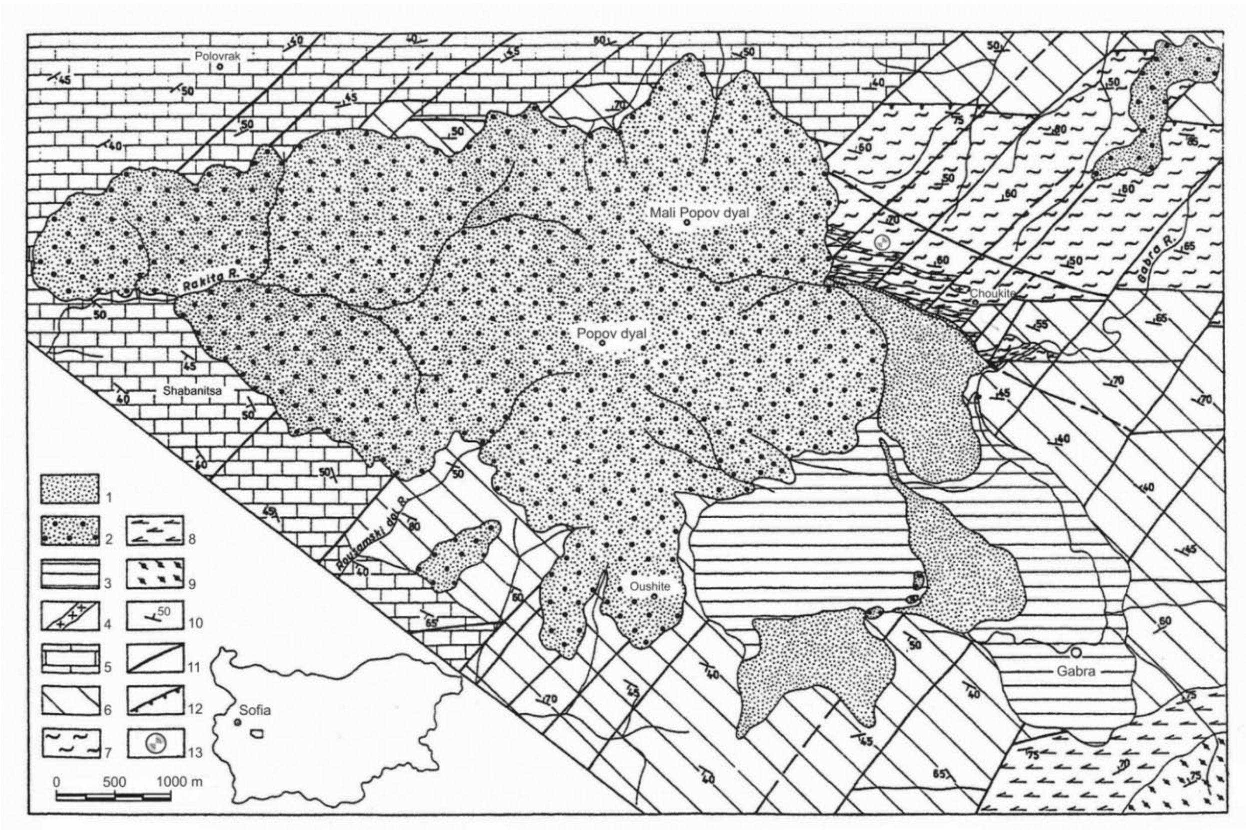

Fig. 1. Geological map of the RAW Repository Novi Han, Lozen Mountain (after Vassilev, Kozhoukharov, 2004). 1. Deposits formed by human activity; 2. Popov Dyal Formation – Late Miocene-Early Pliocene; 3. Formation of the clayey sandstones and clays with the Chukurovo coal layers – Miocene; 4. Upper Cretaceous dykes of syenite-granite porphyry; 5. Triassic sediments; 6. Upper Carboniferous and Permian sediments; 7. Phyllitoids of Krushovitsa Formation – Ordovician; 8. Diabase–phyllitoid complex – Vendian–Cambrian; 9. Proterozoic metamorphic rocks of Arda Group; 10. Bedding; 11. Faults; 12. Reverse faults; 13. Radioactive waste repository Novi Han.

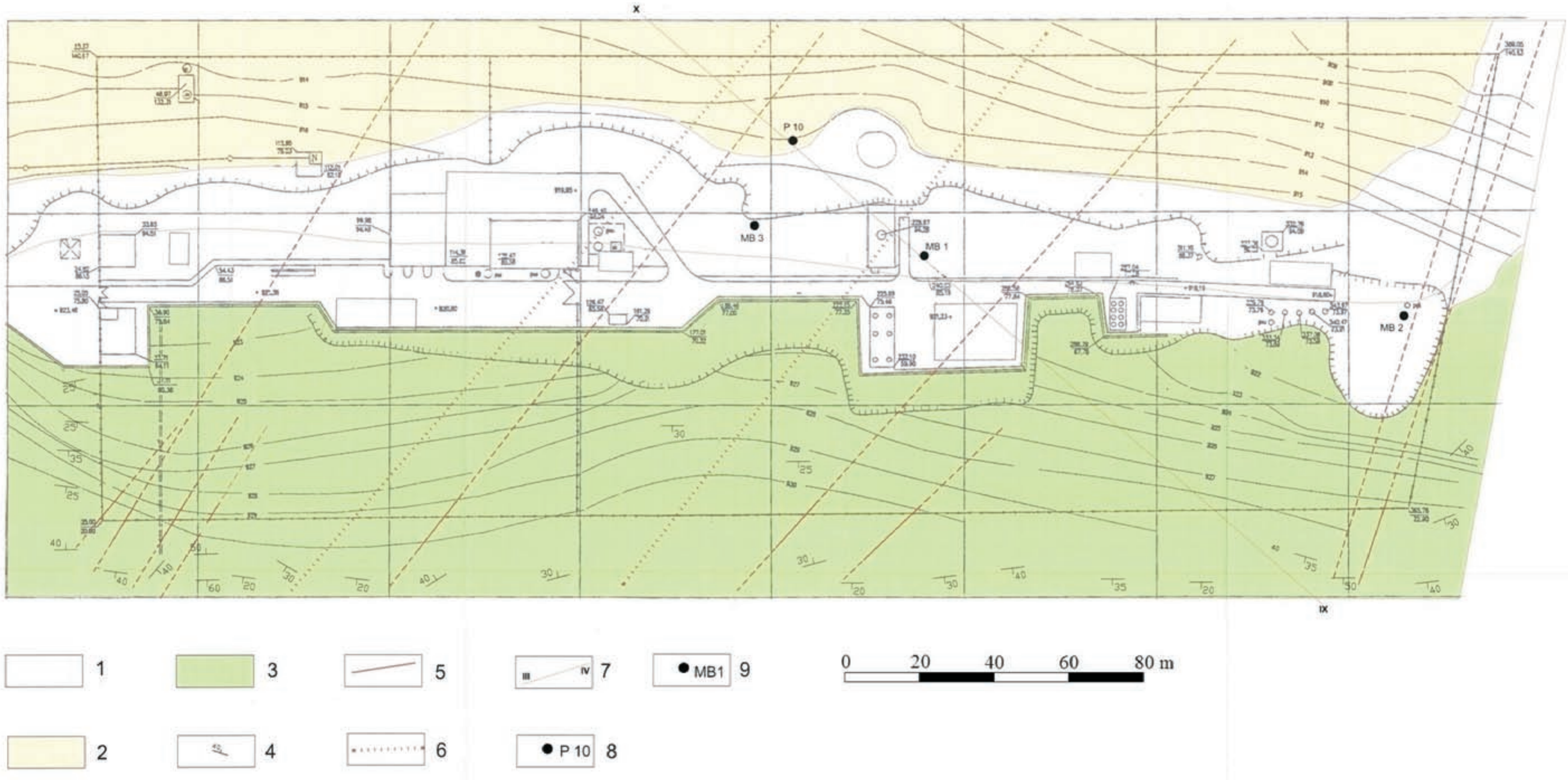

Fig. 2. Geological map of the RAW Repository Novi Han site. 1. Anthropogene – technogenic embankments; 2. Quaternary – alluvial–diluvial deposits; 3. Ordovician – Phyllitoids of Krushovitsa Formation; 4. Elements of rock bedding; 5. Fault; 6. Fault distinguished by geophysical surveys; 7. Profile line; 8. Prospecting motor borehole set as piezometer; 9. Prospecting motor borehole.

Triassic in the region is shown by the Lozen Formation (Tronkov, 1981). It is represented by the typical for the Buntsandstein red quartzitic conglomerates, sandstones, and siltstones. They are deposited over the Upper Paleozoic sediments. The Lozen Formation is denoted in the studied region by its Rusamski Dol Member consisting of variegated quartzitic sandstones.

Upper Cretaceous. The Upper Cretaceous is revealed by different in size magmatic bodies and by sediments of the Sandstone formation. The latter is observed to the south of Novi Han village and is built up of evenly grained sandstones with single intercalations of quartzitized sandstones and dark limestone lenses (Karagyuleva et al., 1974).

Neogene. The Neogene sediments in the region are marked as sediments of the following lithostratigraphic units: the Popov Dyal Formation introduced by Vassilev, Kozhukharov (2004) (former Conglomerate-sandstone-clay formation), the Clayey sandstone and clay formation with the Chukurovo coal layer, the Novi Iskar and Lozenets Formations. The Popov Dyal Formation within its greater part is represented by pieces of breccias-conglomerates of various sizes and in lesser extent by variegated, differing in particle size polymictic clayey sands (Vassilev, Kozhoukharov, 2004). The lower parts of the formation are built up of clayey sands and small-piece breccia-conglomerates and in the upper parts are presented almost entirely block and boulder breccias-conglomerates. The Clayey sandstone and clay formation with the Chukurovo coal layer is represented by clayey sandstones, fine-grained sandstones, sixteen coal seams, plastic clays and conglomerates of total thickness of about 200-250 m. The Novi Iskar Formation (Kamenov, Koyumdzhieva, 1983) is observed in the vicinity of the Novi Han village and is represented by uniform gray and gray-bluish layered clays. The Lozenets Formation (Kamenov, Koyumdzhieva, 1983) is represented by irregularly alternating yellowish sands, sandy clays, gray-green siltstones and clays with thin layers of lignitic coal in its lower part that are designated as the Novi Han Member.

Quaternary. It is represented by talus, eluvial, eluvial-talus, and alluvial deposits. The Quaternary sediments are of limited distribution and are not thick, with grain size varying from rock pebbles and gravel to clays.

Thus, the future models of the potential migration pathways from the repository to the surrounding geoenvironment of the RAW–Novi Han and the connected safety assessment analyses should specifically consider the lithological composition and the structure of the rock layers in order to have a reliable prognosis of unforeseen radionuclide spread.

Tectonics

The area of the RAW–Novi Han belongs to the Maritsa fault zone which is more than 20 km wide. This is a complex tectonic structure which includes rocks of broad age range from Precambrian to Quaternary. They were subjected to Paleozoic, Mesozoic and Neozoic tectonic deformations (see Vassilev, 2004 and references herein).

The contemporary tectonic structure of the region is dominated by the fault network of the Maritsa fault zone where two main systems predominate: longitudinal (100-130°) and transversal (15-45°) ones. The complex block structure of the region between Novi Han and Gabra villages is formed by these systems combined with some smaller faults of other directions. The complexity of the faults is presented in Fig. 1.

The more important faults of the longitudinal system are the Novi Han fault dividing the Neogene lithostratigraphic units from the Mesozoic and Paleozoic units, the Mogilene fault, the Yazdirastovo (Krushovitsa) fault passing to the North in immediate proximity of the RAW-Novi Han, and the Chukurovo fault.

The transversal faults of greater importance are Gola Mogila, Soposh Mogila, and Preko Mogila ones. They divide differing in age lithostratigraphic units and play an important role in the formation of the block structure of the RAW repository region.

The data presented so far show unambiguously that the RAW–Novi Han site is located in a very complex tectonic structure with intensive tectonic activity continuing after the Neogene. In consequence, the mountain massif has been greatly deformed and divided by faults, and the rocks that built it are broken, fissured and in some zones turned into mylonite. The width of these zones varies from 0.30-0.50 m to 10-15 m.

In connection with the tectonic structures, the seismicity risk on the facility should be taken into account and reliably evaluated. According to the seismic zonation of Bulgaria over a period of 1000 years, the region possesses seismic intensity of the 9^{th} degree on the MSK-64 scale and seismic constant K_c = 0.27 (Ministry of Regional Development and Public Works, 2007). It should be noted that due to the newest recommendations by the IAEA, the potential for fault displacement and the rate of fault displacement that could affect the feasibility of the site or the safe operation of the installation at that site should be evaluated (IAEA, 2010). At the moment such type of investigations are absent.

Geomorphology

The repository is located under the ridge of the Lozen Mountain at an altitude of 920 m. The slope declivity is 13-16% in N-NE direction. The relief of the area was formed mainly due to plain denudation and gully erosion. There is no evidence showing hazardous atmospheric phenomena. Two gullies with variable water outflow in the vicinity of the site drain the shallow groundwater and surface water downward the slope which could conceivably transport radioactive contaminants.

Table 1

Physical and classification parameters of the soil samples

Layer №	Density, ρ_n	Bulk density, ρ_d	Liquidity index, I_c	Degree of saturation, S_r	Pore coefficient, n	Nomenclature according to the BSS*
	[g/cm^3]	[g/cm^3]	[-]	[%]	[-]	
1	2.17	1.95	2.17	80.0	0.370	Gravelly clayey sand
2	2.10	1.86	2.32	77.0	0.470	Gravelly sandy clay to ununiformed middle sand
3	2.27	2.10	1.65	91.7	0.343	Gravelly sandy clay to ununiformed middle gravel
4	2.09	1.88	1.84	70.0	0.430	-

* Bulgarian State Standard 676-85

ENGINEERING GEOLOGICAL SETTING

According to the performed surveys the following engineering geological types of the ground site are presented:

Layer 1. Embankment, heterogeneous, uncompacted/ loose. It occupies the central part of the site (Fig 2). Its thickness varies from 0.3 m (MB1) to 1.6 m (MB 3) (Fig. 3). By visual observations its thickness in the northern part of the site is about 2.0-2.5 m. It is made during the construction process in the landscaping stage and has never been machinery compacted. By visual observation the Layer 1 could be classified as clayey gravel to gravel clay depending on the percentage of the clay and gavel fractions. One sample was laboratory tested and then classified as gravel clayey sand (Table 1). The strength deformation moduli were determined from SPT measurements and are as angle of internal friction 30°30′ (characteristic) and 25°30′ (design); elasticity modulus is 47.9×10^5 Pa.

Layer 2. Weathered rock (eluvium). It is the upper near-surface layer of the bedrock complex. It is represented by weathered in different degree phyllites. The weathering processes transformed the original bedrock into gravel clay and clayey gravels with varying amount of original rock particles. The depth of the weathering processes is also different depending on the relief and occurrence of tectonic dislocations. Four undisturbed samples were tested and classified as gravel sandy clay to uneven middle-sized gravel (Table 1). Four SPT tests were conducted of the following strength-deformation parameters: undrained shear strength 2.66×10^5 Pa; modulus of total deformation 213×10^5 Pa, and bearing capacity of $6.98\sim7.0\times10^5$ Pa (Table 2). The design bearing capacity is 3.0×10^5 Pa. Although according to the Bulgarian State Standard 676-85 Layer 2 is gravelly clay, we think that the layer could be classified as bedrock with weak clay binder.

Layer 3. Phyllites broken and fissured. They have been found under the Layer 2 which just turns gradually into fissured and broken finely bedded rock intersected at some places by clayey zones. Six SPT tests were conducted and the following strength-deformation parameters were determined: undrained shear strength 4.32×10^5 Pa; modulus of total deformation 346×10^5 Pa, and bearing capacity 10.3×10^5 Pa. The design bearing capacity is 5.0×10^5 Pa.

Layer 4. Granitoid, hardly weathered. This is found in some boreholes mainly outside the repository site. Therefore, strength parameters were not investigated.

Layer 5. Granitoid, massive, with boulder type texture. It was found only in one motor borehole at 14.7-27.0 m depth intersected by phyllites. The fissures are with 45° declination.

Layer 6. Phyllites, weakly to medium weathered. The rock possesses boulder type texture. The layers are with 45 to 50° declination and the fissures are with about 80° declination. The following strength parameters were determined in the laboratory tests: unconfined compressive strength is 298×10^5 Pa under air-dried condition, and 117×10^5 Pa under 24-hours water saturated condition; tensile strength in air-dried and water saturated conditions are 125×10^5 Pa and 75×10^5 Pa, respectively (Table 2).

According to the geological setting and engineering geological characteristics, four engineering geological zones have been established (Fig. 4). The first engineering

Table 2

Strength-deformation parameters of the layers of the Repository Novi Han site determined by Standard Penetration Test procedure.

Layer №	Tensile strength	Elasticity modulus	Bearing capacity
	10^5 Pa	10^5 Pa	Pa
1	-	47.9	-
2	2.66	213	6.98 – 7.00
3	4.32	364	10.3
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	125*	-	-

* Value determined by laboratory test

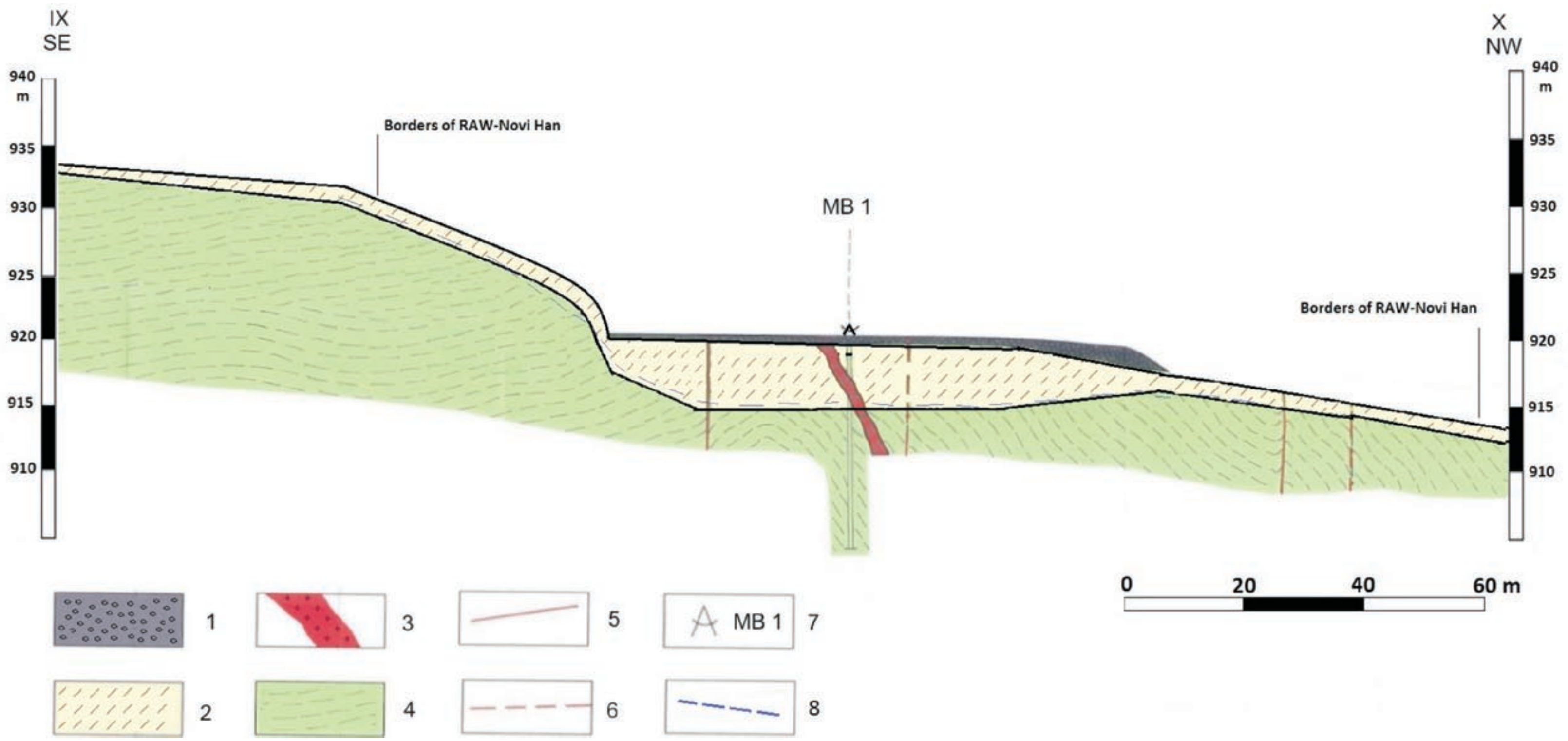

Fig. 3. Cross-section through the RAW Repository Novi Han. 1. Anthropogene – technogenic embankments; 2. Quaternary – alluvial–diluvial deposits; 3. Granitoids; 4. Ordovician – Phyllitoids of Krushovitsa Formation; 5. Fault; 6. Fault distinguished by geophysical surveys; 7. Motor borehole; 8. Ground water level.

Fig. 4. Engineering geological map of the RAW Repository Novi Han site. 1. First engineering geological zone: anthropogenic embankment; 2. Second engineering geological zone: highly weathered rock-core; 3. Third engineering geological zone: phyllites (shales), fissured; 4. Fourth engineering geological zone: rock-core, phyllites; 5. Fault distinguished by geological mapping; 6. Fault distinguished by geophysical surveys; 7. Fault supposed by geological mapping; 8. Geological boundary; 9. Prospecting motor borehole set as piezometer; 10. Prospecting motor borehole.

geological zone includes the embankment of the site (Layer 1). In fact, it occupies approximately 40% of the functional area and 20% of the total area of the RAW–Novi Han. The embankment is uncompacted and it is unsuitable for direct foundation activities. It would play a significant role not only in future construction works but also in the safety assessment analyses. The second zone presents the spatial distribution of the weathered rock basis (Layer 2) where it is thicker than 1.0–2.0 m (Fig. 3). As there is a relation between the hydraulic and the physical-mechanical properties of the medium, a detailed characterization of the latter in future analyses for the needs of the contaminant migration predictions is indubitable due to the presence of a groundwater horizon in it. The third engineering geological zone marks the broken and fissured bedrocks along the faults. Hence the textural and mechanical properties of the zone are worsened in a high degree, and construction works in it are unadvisable. It is still questionable whether this zone possesses highly variable hydraulic properties from the surrounding medium. The fourth zone includes the outcropping or covered by thin layer of forest soil phyllites. The zone is a solid medium and the only measure that should be performed from the view point of the safety is to be covered in respect to future weathering processes.

HYDROGEOLOGICAL CONDITIONS

The Paleozoic rocks in the region represent a low water bearing and low permeability medium. Their permeability is higher in the strongly fissured and faulted tectonic zones and in the upper layer of the secondary weathered fissuration. The ground water in the Paleozoic rocks circulates in rock fissures and is recharged only by precipitation. The surface water outflow in the gullies was not observed to be permanent and hence depends on precipitation running dry during the hot seasons (Evstatiev et al., 1994). The only larger spring which drains the phyllitoids is located at an altitude of 850 m to the north of the repository and is captured for its water supply. The maximum debit varies about 0.2 l/s. The water has a hydrocarbonate-sulphate-sodium-calcium composition with a total salts content 0.08 g/l and a slightly acidic reaction, pH=5.6.

The cleavage of the Ordovician phyllites determines their anisotropic water permeability. Around the site of the RAW–Novi Han a relatively thick unsaturated zone (from 7 to 10 m) exists in the weathered part of the phyllite massif in which a part of the rain waters infiltrates (Fig. 3). Therefore, the formed groundwater horizon is low abundant and the medium possesses weak hydraulic properties and the flow has a strict direction to the north. The annual infiltration for the area is 29.3 mm, the total groundwater recharge – 0.7 l/s, hydraulic gradient – 0.095, and average aquifer transmissivity – 0.3 m^2/d (Galabov et al., 2003).

In general, the hydrogeological setting of the RAW–Novi Han is not very favorable. The tectonically fissured and faulted massif represents one of the most difficult for prediction and modeling geoenvironment concerning the pathways of water and the migration of radionuclides.

CONCLUSION

The study compiles the geological, hydrogeological and engineering geological investigations on both the repository for radioactive waste Novi Han (RAW–Novi Han) site and a broader area around it. The main lithostratigraphic formations, tectonic fault and mylonitic zones are described. As a result of the "*in situ*" and laboratory tests of the layers under the repository, four engineering geological zones concerning the long-term stability of the foundation of the facilities are distinguished, and the main hydrogeological elements and parameters of the RAW–Novi Han site are pointed out from the view point of the transport modeling. On the other hand, a detailed analysis of the engineering geological zonation shows the zones one and three as unfavorable from construction point of view. The tectonic situation of the Lozen Mountain is too complex and precise conclusions for the development of the area could not be drawn at that stage. Furthermore, a future safety assessment of the facilities, regarding the latest IAEA safety requirements at the site would need additional data about the infiltration and groundwater flow and pathways in the fissured medium.

The performed so far inspections and investigations have not shown groundwater contamination and other unfavorable for the local environment alterations. However, due to the very complex geoenvironmental settings, the authors stand by the forthcoming, according to the National Strategy, closure of the RAW-Novi Han and the projected allocation of the wastes to the National repository near the town of Kozloduy which will be built up during next years.

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