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Geological and environmental pre-conditions for utilisation of the Maardu granite deposit, northern Estonia

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Abstract Efficient use of natural resources is a global goal. A specific way of improving resource productivity in Estonia is utilisation of Maardu granite deposit as a joint goal for producing granite aggregates and construction in the caverns of the granite mine and a pumped hydroaccumulation plant. The environmental impact assessment in connection with construction of a Maardu deep granite mine was accepted by the Estonian Ministry of Environment in 2009. The most challenging engineering task, causing also the biggest environmental risks, is safe penetration of aquifers and aquitards during construction of vertical and/or inclined tunnels for granite mine and/or pumped hydroaccumulation plant. A major problem is also the high radiation level in the Maardu area and in the planned deep mine. High radon concentrations up to 10 000 Bq/m^3 have been recorded on the outcrops of alum shale in the mine area and they can be dangerous to human health. Based on the hydrogeological modelling it was found, that under normal circumstances the construction and operation of the Maardu deep granite mine is environmentally safe. The territory of the former Maardu phosphorite opencast is highly polluted and damaged and therefore the foundation of the granite mine with overground buildings is the best way for the environmental improving of the area.

Keywords *• Granite mine • Jõelähtme commune • Maardu town • Radon emissions • Phosphorite opencast • Groundwater • Pumped hydro-accumulation station • Northern Estonia*

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INTRODUCTION

In nearest decades in the Baltic States will continue extensive construction of roads and railways supported by the European Union, requesting large amounts of granite aggregate. Presently in Estonia the latter is imported chiefly from Finland, Norway and Sweden. The imported aggregate is expensive and large-scale import deteriorates Estonia`s negative balance of foreign trade. Besides, the country fails to receive the tax revenues and the fringe benefits from employment. Taking into use the Maardu granite deposit located in the northern Estonia (Fig.1) on the territory of Jõelähtme commune and partly of Maardu town would allow to reduce the import of granite aggregate and would create new jobs in the region. At the initiative of the Ministry of Environment of the Estonian Republic, the State Development Plan for the use of natural construction materials for the years 2011–2020 has been accepted and it contains also the excavation of the local granite resources.

On 30 April 2007, Maardu Granite Mine Ltd. submitted an application for mining permit to the Ministry of the Environment requesting 30-year mining right on the mine claim with an area of 1167 hectares (Fig. 2). On the applied mine claim and in its nearest environs are located several environmentally vulnerable objects, e.g. Maardu town and lake of the same name, Port of Muuga, Kallavere, Rebala and Võerdla villages with several objects of national heritage, Iru

Fig. 1 Location of the study area (red rectangle). Compiled by Mait Metsur.

and Väo power plants, Tallinn-Narva Highway and Jõelähtme dumping ground. The deposit is situated at the northern boundary of the Baltic Artesian Basin and its overburden layer comprises the Ordovician aquifer, Ordovician-Cambrian aquifer and Cambrian-Vendian aquifer, also the groundwater in the weathering crust of the crystalline basement has to be isolated.

Published materials in English about the Maardu granite deposit are limited. Only a short review by K. Suuroja and V. Klein was published 15 years ago (Suuroja, Klein 1997). In last years several papers in Estonian language appeared from the print (Adamson *et al*. 2009; Raukas, Siitam 2009, 2009a; Suuroja 2012). The most valuable information is comprised in manuscripts stored in Estonian Geological Fund and referenced recently by Suuroja (2012).

Establishing a granite mine is not only a complicated technological task, but questionable is also the quality of the crushed intrusive rocks (Suuroja 2012). A small amount of material from the boreholes did not allow to test granite with industrial methods and therefore it will be difficult to predict the exact quality characteristics of the aggregate. Based on existing quality data from the site (Suuroja, Klein 1997) it can be presumed, that characteristics of the material of Maardu deposit are close to rapakivi, which is common aggregate material in southern part of Finland. Therefore it is reasonable enough to presume also, that aggregate produced from the Maardu granite deposit could meet better quality parameters as limestone aggregate used in road construction in Estonia today.

That to be sure about the profitability of the mining the developers of the Maardu Granite Mine Ltd. joined their efforts with the biggest renewable energy producer in Estonia AS 4energia to construct the mine together with the construction of the Muuga pumped hydro- accumulation plant (PHAP). Simplifying the business model of the Muuga PHAP it is assumed, that aggregate originating from Neeme granite deposit could be sold at reasonable price. Additionally, the developers of Muuga PHAP have investigated several other options, mostly offshore constructions, for utilising the granite, originating from Maardu deposit. As the territory of the former Maardu phosphorite opencast is highly damaged (Fig. 3), one of the main tasks of this paper is to find out the best solutions to use the highly polluted territory near Tallinn in the coming future.

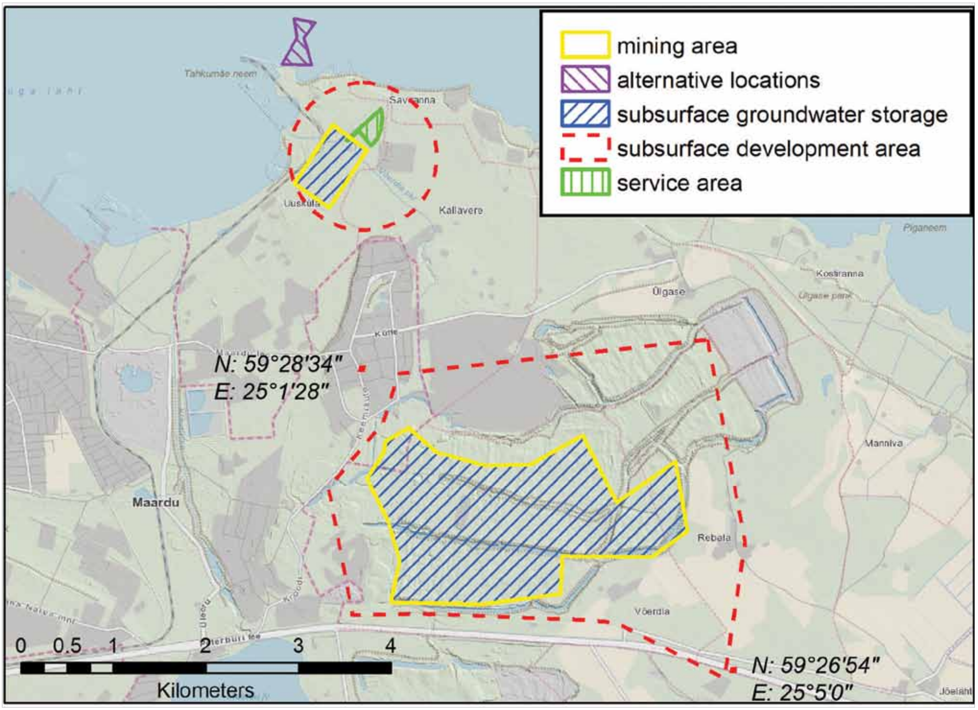

Fig. 2 Map of the Maardu granite mine claim (south area) and planned hydro-accumulation station (north area). Compiled by Mait Metsur.

ENVIRONMENTAL PROBLEMS

Establishing a granite mine is complex mining undertaking, without any counterparts in the Baltic States presently (Adamson *et al*. 2009; Raukas, Siitam 2009, 2009a). The facilities will include administration building, overground complex of shafts, terminal crushing junction of aggregate and fractionation, block-stone processing department, and storage grounds for raw material, aggregate and block stone.

Fig. 3 Maardu phosphorite opencast over 20 years after mining. Radioactive elements are leaching into the water bodies. Photo by Madis Metsur (2010).

The mining would be performed by sublevel stopping in large rooms with design height 65 m, width 45 m and length 500 m. The drilling and explosive operations, loading of mined material, transport as well as primary crushing and sorting would take place underground, which would considerably reduce the noise and dust emissions. The mine is designed in with non-breakable pillars, due to which at least half of the granite reserve would remain nonextracted, supporting the workings and ground surface. The subsurface rooms will be isolated to exclude possible risks. When establishing the mine, the aquifers systems would be penetrated either by freezing method or preliminary grouting of soil, thus excluding contamination of groundwater and inflow of large amount of water into the working face.

The mine claim is located on technogenous topography of the former Maardu phosphorite opencast dissected by some 20 m wide trenches with steep rocky slopes or taluses (see Fig. 3). In west–east direction the ground surface elevation changes from 30 to 47 m (difference in elevation 17 m), and in north–south direction from 25 to 47 m (difference in elevation up to 22 m). During the opencast mining of phosphorite at Maardu the radioactive alum shale (uranium content 80–120 ppm, maximum 300–450 ppm) was deposited in waste dumps. In 1989 opencast mining at Maardu was carried out in the area of 6.36 km^2. Waste hills at Maardu contain at least 73 million tons of alum shale (Veski 1995). Developing of a mine and an accompanying industrial complex would facilitate gentrification of the area and assure its safety.

As the area is covered by dumps of alum shale, rich in uranium and thorium, we studied the radioactivity level and radon emissions in mine claim (Fig. 4) and surrounding area (Jüriado *et al.* 2012). The concentration on Rn was determined simultaneously by two methods: with a portable gamma ray spectrometer eU (ppm) as calculated from analyses of ^{226}Ra (Bq/kg) (RnG), and by direct measurements of Rn (kBq/m^3) in soil air with MARKUS-10 emanometer (RnM) (Petersell *et al.* 2005). By direct measurements, the Rn content in the soil air of the heaps in the former Maardu phosphate mine is varying between 25–34 kBq/m^3. The Rn content computed after the U(Ra) content is nearly 12 times higher than by direct measurements, and varies between 218–625 kBq/m^3 (Jüriado *et al.* 2012). This indicates that the aeration conditions in the heaps are very good and risk from radon is high.

Fig. 4 Bird-eye view of investigation area showing the mine claim (red line) and area to be mined (yellow line). Compiled and photo by Mait Metsur (22 April 2012).

The extreme leaching of several components by the water filtrating through the heaps, and their dispersion in the mine and in the groundwater, is also connected to the oxidisation of shale. Per one square kilometre of the Maardu heap, an average of 1646.4 t of dissolved minerals was leached and dispersed in surface and groundwater. Of that amount, 72.9% was made up of ion SO_4^{-2}, 12.8% Ca^{+2}, 11.3% Mg^{+2}, 1.1% K^++Na^+ and the rest were various micro-components. The leaching from the heap is not directly dependent on the amount of water flowing through the heap, but rather on the intensiveness of the oxidisation process of the rocks. The Maardu heaps are a source of pollution, which will keep polluting the surface and ground water for a very long time. The effluent of the Maardu mine and plant, which was directed into the sea via Kroodi Brook, delivered up to 20.18 million m^3 of water with very different levels of pollution into Muuga Bay each year. The amount of dissolved minerals delivered into the sea reached up to 38.4x10^3 t annually (Pihlak 2009). Establishment of overground buildings, places for the deposition of the end production and paving the territory with asphalt will minimise the pollution of the territory.

MATERIAL

The data on the granite deposit are based mainly on the prospecting works, carried out by the Geological Survey of Estonia in 1979–1982 (Suuroja 2012; Suuroja, Klein 1997). In the process of mentioned investigations 36 boreholes were drilled in the granite massif, altogether 8 412 m, including 2 130 m in granites. In 1992 the Geological Survey of Estonia approved the reserves of granite, on the grounds of which on 25 October 1994 (resolution No. 221) the Estonian Commission of Mineral Resources confirmed the proved reserves of crystalline building stone between elevations -160...-225 m 1,3 billion cubic meters. The reserves can be considerably extended.

The data on hydrogeology of the area are based on long-term investigations carried out by the Geological Survey of Estonia and during last years by Maves Ltd. under the leadership of the first author. The authors performed radioactivity analyses (the radionuclide concentrations and gammaspectrometric measurements) of rock samples in Research and Environmental Surveillance (STUK) in Finland.

GEOLOGICAL BACKGROUND

In geostructural terms the Neeme rapakivi massif, in which is connected Maardu granite deposit, is located at the north–western border of the Russian Plate. Two distinct complexes can be distinguished in the bedrock: underlying crystalline basement made of magmatic and metamorphic rocks, and sedimentary bedrock, overlying the latter. The bedrock is covered with thin layer of soft Quaternary deposits. The crystalline basement is the continuation of the southern Finland Svecofennian orogenic belt, and one can distinguish the metamorphic and magmatic rocks from the Palaeoproterozoic Jägala complex as well as the late Palaeoproterozoic intrusive porphyry-like potassium granites (piiterliite rapakivi) of the Neeme pluton there (Klein *et al.* 1997). The basement`s upper surface lies at 125–135 meters below sea level. The majority of metamorphic rocks consist of biotite, quartz-feldspar and mica amphibole gneisses and amphibolites. The basement's upper part has suffered chemical weathering, forming a clay-like weathering crust. The average thickness of the weathered part of the Neeme intrusive is 5 m, while the areas of fracture zones it reaches 32 m (Suuroja, Klein 1997).

The sedimentary cover represented by Neoproterozoic and Palaeozoic rocks follows the topography of basement surface. The Kotlin Regional Stage of the Vendian (Ediacaran) system (540–610 Ma old) is represented by 50–60 m thick clastic rocks (sandstones, siltstones, claystones). The Cambrian rocks (490–540 Ma old) are also represented mainly by sandstones, siltstones and claystones (Mens, Pirrus 1997). The Lower Ordovician rocks (470–490 Ma old) are diversified. One can find the phosphatic Obolus sandstone, including brachiopod bivalves and fragments, radioactive alum shale (graptolite argillite, Dictyonema shale), glauconite-rich grey bentonite claystone and glauconite sandstone. The Middle Ordovician rocks (ca 460–470 Ma old) in the area are represented by carbonate rocks.

Jägala Complex comprises strongly folded metamorphosed sedimentary and sedimentary-volcanic rocks occurring as fragmentary northwesterly–southeasterly belts. In Maardu–Jõelähtme–Neeme area the rocks of the Jägala Complex are penetrated by an intrusion of porphyry-like potassium rapakivi granites of relatively high radioactivity, with background radiation of 60-100 mkR/h according to the gamma-logging of boreholes, made by Geological Survey of Estonia in former Neva laboratory in St. Petersburg. The relatively high radiation level is probably due to the inclusions of accessory zircon, monazite and sphene in biotite. The average content of U in the granites is 5.6 ppm and that of Th 25–30 ppm, which is quite characteristic of the rapakivi granites (Suuroja, Klein 1997).

The pluton comprises two granite varieties: 1) porphyry-like potassium granites (piiterliite rapakivi) of medium– to coarse–grained groundmass and 1–5 cm plate-like potassium feldspar phenocrysts, and 2) aplitic potassium granites of fine–grained groundmass and small (2–5 mm) potassium feldspar phenocrysts. The latter rock type occurs in the granite massif as subvertical veins some tens of centimeters to tens of meters in thickness and is better suited for producing the crushed aggregate. The physical-mechanical characteristics of granites and crushed aggregates according to tests, presented in Suuroja and Klein (1997) demonstrated high quality of the material. Recently the Los Angeles crushing tests (EVS – EN 1097-L) gave less promising results (Suuroja 2012). It means that new tests will be necessary.

HYDROGEOLOGICAL CONDITIONS

Recently the hydrogeology in Tallinn area has been described by Marandi (2011) and Perens (2011) and this information will be not repeated here. It should be mentioned that in Maardu area are rather specific hydrogeological conditions and big pollution level, investigated recently by Maves Ltd.

On the granite mine's planned industrial site the sediments and rocks overlying the granite pluton host four aquifers: aquifer in the technogenous deposits of the Quaternary cover (dumps), or Ordovician aquifer in the area previously not disturbed by phosphorite mining, Ordovician-Cambrian aquifer, Cambrian-Vendian aquifer and aquifer in the crystalline basement's weathering crust. In order to reach the granite massif, all above aquifers should be passed and extensive modelling is needed to assess their impact (Fig. 5).

Aquifer in technogeneous deposits spreads in the dumps of the former Maardu phosphorite opencast (area 11.2 km^2). The dump deposits are mostly dry and due to the good filtration properties of the material (K=10–100 m/d) the groundwater level depends on the level of water in the trenches of the former mine field. In places perched groundwater may occur in the dumps. In spite of the thickness over 10 m the groundwater spreads only in the lower several metres of the dumps and forms a joint aquifer with the Ordovician-Cambrian groundwater.

In westernmost part of the area the outflow of mine water into the Kroodi Brook occurs through the tunnels of the former Maardu phosphorite mine (see Fig. 3). The groundwater in the technogenous deposits is contaminated by sulphates and high TDS (over 29 g/l). The groundwater of SO_4Ca-Mg type is acid (pH = 3.3 – 6.5), brackish or even saline, very hard and contains elevated amounts of heavy metals. In a radius of up to 1 km from the opencast spreads groundwater

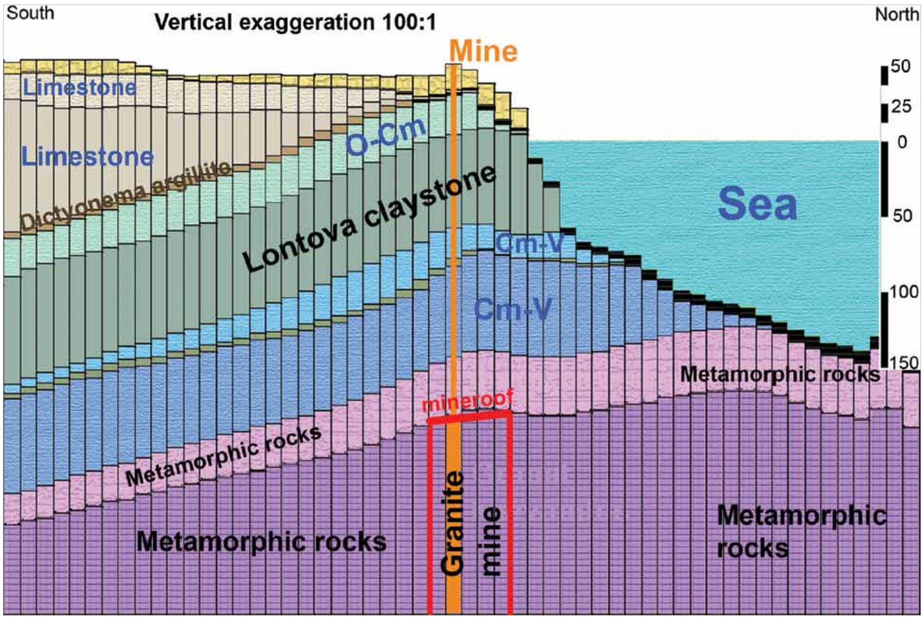

Fig. 5 Cross-section of the groundwater model for simulating the impact of the mine (modified by Mait Metsur using own materials of Maves Ltd.). Modelling network grade is 1 km.

of HCO_4SO_4Ca-Na type which is hard and with TDS ~0.5 g/l. Generally the increase in the concentration of sulphates is due to the oxidization of pyrite, but on the territory of the Maardu opencast this is mostly due to self-combustion of the excavated alum shale (graptolite argillite) in the dumps. Sulphates have accumulated in soil also in the result of aerial contamination from the sulphuric acid department of the former Maardu chemical plant.

Ordovician-Cambrian aquifer is in average 20 m thick; it spreads directly beneath the dump and is hydraulically connected with the water in dumps. Filtration properties of the aquifer are consistently similar: lateral K prevailingly 1–3 m/d and specific yield of wells 0.1–0.4 l/s×m. Exceptionally, on the territory of the Mähe buried valley over the Lake Maardu (Miidel *et al.* 2010) and in the Maardu opencast K reaches up to 10 m/d. The groundwater of HCO_3Ca-Mg type is fresh (0.3–0.4 g/l); when mixed with contaminated mine water it is of HCO_3SO_4Ca-Mg type and has TDS 0.5–1 g/l, and in abandoned workings even of SO_4HCO_3Ca-Mg type and with TDS 2 g/l. The content of iron in natural groundwater is frequently high and in places in the fore-klint area the concentration of ammonium exceeds 0.5 mg/l.

Lükati–Lontova aquitard (Є1$_{lk}$–Є1$_{ln}$) spreads in the entire area and is represented by argillite-like claystone ("blue clay") and in the top 5-m part in places by silt- and sandstones. This is the thickest (up to 75 m) aquitard in the sequence and has the highest isolation capacity, its transversal permeability coefficient reaching 10^{-7}–10^{-5} m/d. The basal ca 10 m thick part of the Lontova Formation, where are sandstone with blue clay beds (Sämi Member), belongs to Cambrian-Vendian aquifer.

Water–bearing rocks of the *Cambrian-Vendian aquifer* are the sand- and siltstones of the above systems. On the territory of the planned granite mine the clayey aquitard (Kotlin Formation) separating the upper part of the aquifer (Voronka) and lower part (Gdov) is missing. This aquifer is the main source of water supply in the region. The concentration of chlorides is high (200–350 mg/l) and the content of radionuclides is above the standard, requesting purification of raw water from radium. The aquifer is confined, the piezometric head in Maardu is at an elevation of 6 m below sea level. Permeability coefficient K of the upper portion of the Cambrian-Vendian aquifer (Voronka) is 1–5 m/d on an average, and the specific yield of wells (q) generally does not exceed 1 l/s×m. The groundwater of this aquifer is of HCO_3Cl-Ca-Mg type and has TDS 0.4–0.9 g/l. The permeability coefficient of the lower part of the Cambrian-Vendian aquifer (Gdov) is on an average 5–6 m/d and specific capacity of wells is 1–2.5 l/s×m.

Groundwater in the weathering crust and fissure zone of the crystalline basement is confined. The groundwater table is 1–5 m under sea level and in eastern part the specific capacity does not exceed 0.05 l/s×m. In the Neeme rapakivi pluton the groundwater occurs only in the basement's upper part – in the 0,5–5 m thick weathering crust, its TDS is 1–5 g/l. In the single fissure zones the water may be deeper.

In the environs of the planned granite mine the groundwater reserves for municipalities have been approved for the Ordovician-Cambrian and Cambrian-Vendian aquifer, there are no significant groundwater reserves in the Quaternary and Ordovician aquifers. The proved reserves of the Cambrian-Vendian aquifer more than thrice exceed the factual groundwater consumption. Very likely the groundwater consumption in Tallinn and Maardu will decrease due to extended utilisation of surface water.

The groundwater level of the Cambrian-Vendian aquifer is some tens of meters below that of the contaminated water in the dumps. It is obvious that mine shafts and tunnels must not cause additional contamination of the Ordovician-Cambrian groundwater by the water flowing via the trenches. The Cambrian-Vendian and Ordovician-Cambrian aquifers are separated by the Lükati and Lontova claystone, which isolates the above aquifers. Thereby the construction technology is of crucial importance – the water–conducting terrigenous material from upper beds must not be left between the wall of the facility and the natural claystone bed.

Surface water. The water from the granite mine is planned to be conducted to the Kroodi Brook, which is in poor condition due to the residual contamination originating from the former chemical industry; Kroodi Brook is also the receiving water of the precipitation of the former phosphorite opencast. The pollution load of heavy metals in the bodies of water was worrisome already in 1979 (Hütt *et al.* 1979; Lippmaa *et al.* 1979) as well as in the process of preparing the Jõelähtme dumping site in 1989.

Review of the groundwater quality on the opencast's territory in the 1980s is presented in the manuscript reports compiled at the Estonian Environmental Research Centre. Before 1991, the TDS level in the water of opencast IV (southern opencast) was approximately at the same level. Considerable increase occurred in 1991–1996, when the water level in opencast IV rose. As compared to the northern opencasts, the increase took place much later since opencasts IV and V were operated longer and pumping was completed later. The concentration of fluorine continuously increased until 1992. The latter year became a turning point when the concentration of fluorine started to decrease simultaneously in all mine and opencast waters.

The content of heavy metals has been determined since the 1990s and their dynamics is similar to that of fluorine – until year 1992 the concentrations increased, but started to lower later on. The majority of heavy metals in the water of opencasts is the result of burning of alum shale (graptolite argillite). The highest concentrations of heavy metals were the following: As – 23 µg/l, Sb – 127 µg/l, Se – 407 µg/l, Cd – 0.45 µg/l, Co – 59 µg/l, Li – 88 µg/l, Ni – 419 µg/l, Pb – 13 µg/l and Zn – 557 µg/l. Supposedly in mid-1980s when the burning was more intensive also the concentrations of heavy metals were higher. The concentration of biogenous components (both phosphorus and nitrogen) in the water of opencasts was the highest in 1980s. Heavy metal contamination is observed until present, according to our recent studies especially high is Ni and Zn content.

DISCUSSION

EC Water Framework Directive and Water Act establish an aim for attaining good groundwater status of all Estonian groundwater bodies. According to the water management plan of the West-Estonian catchment area, Harju sub–catchment area the following must be followed at extraction of mineral resources:

applying technology economizing groundwater,

favouring application of mining and reclamation technologies economizing groundwater as well as surface water.

The mines should be designed keeping in mind sustainable water consumption, not causing unreasoned expenses to water consumers of neighbouring areas at assuring water supply, and taking into account the ecological systems depending on groundwater. These requirements must be met also when establishing the Maardu granite mine.

In Maardu the rapakivi massif is planned to be reached by shafts from the technological complex to be established on the mine claim's service area. One shaft will be for lifting up the broken rock, granite blocks and mining machinery, and the other for transporting the staff and ventilating the mine. The shafts will be established using the technologies restraining the inflow of groundwater into the workings – preliminary freezing of the massif or grouting.

The most difficult task is safe penetration of aquifers and aquitards**.** To assess the impact of this procedure, the model of Maves Ltd. has been used which simulates the impact of groundwater abstraction at the intakes on the water tables of the aquifers. The same model has been used for assessing the proved reserves of Harju County and Tallinn. To simulate the impact of the mine, the estimated expected losses of groundwater from the groundwater into the mine have been included in the model, and its structure in the environs of the mine has been customised.

An inescapable environmental impact is the leakage of the Cambrian-Vendian groundwater into the tunnels in the process of mine construction. Penetrating the artesian aquifer is technically intricate since the inflow of groundwater into the tunnels under construction has to be controlled. The authors assume that the amount of groundwater leaking at establishing a shaft or tunnel should not exceed 500 m^3/day. Proper isolation measures at penetrating the aquitards exclude the hazard of groundwater contamination.

Significant negative environmental impact can come with an accident in the process of drilling shafts in sedimentary rocks. However, such accidents are unlikely since at drilling the strength of the riser shaft and water proofness increases with depth due to the added constructional protective layers. Namely, at grouting the primary action is preceding grouting of soil, followed by drilling the grouted soil/rock, and finally building the reinforced concrete or steel shaft construction.

The main risk for emergency groundwater inflow is in the process of drilling before building the final construction. Maximum 15 m shaft can be drilled without the protection of final construction, which is also the maximum extent of emergency zone. The simplest way to exclude undesirable impact of such emergency zone is temporary filling of the failed shaft section with impermeable material, e.g. concrete. A possible way of fast and cheap transportation of granite aggregate to the Port of Muuga is building a 5-km tunnel section with a cross-section area up to 70 km^2 and total volume 350 000 m^3. The main technical risk at building such tunnel is, similarly with the riser shafts, drifting of sedimentary rocks within almost 1 km. Considering the groundwater, the risks are similar to those at establishing the riser shafts.

Impact of operating granite mine on the Cambrian-Vendian aquifer

In case of normally operating mine the possible leakage from the Cambrian-Vendian aquifer into the shafts must not exceed the amounts established by the permit of use of water. The granite body is practically waterproof, according to the model the calculated inflow of water on 1-km^2 mined area may reach 200 m^3/d. When the leakage from possible fissure zones is more extensive, they must be additionally isolated with grouting technology**.**

In the result of grouting the rock massif of the inclined tunnel between the designed granite mine and the Port of Muuga the probable leakage of the Cambrian-Vendian groundwater within the tunnel section penetrating through the aquifer is up to 100 m^3/d. Total leakage of groundwater into the two vertical shafts is expected not to exceed 100 m^3/d. To be on the safe side, when assessing the impact of water removal of the granite mine the authors have applied much bigger value of total volume of groundwater pumped out of the mine – 500 m^3/d. Even then the impact on the Cambrian-Vendian groundwater is not considerable, being comparable with the impact of one bored well (Fig. 6).

In case of the worst scenario when the mine's roof loos its water proofness on an extensive area the inflow of groundwater into the mine may reach 1 m^3/s. To handle such (extremely unlikely) situation filling the entire mine with groundwater must be avoided since this would be accompanied by extensive lowering of the water table of the Cambrian-Vendian aquifer. In accordance with the modelling results, the workings should be established as separable units, their volume reaching up to 2 million m^3, which is technically executable. The results of modelling show that in case of theoretical extensive failure of the mine roof the maximum total inflow of the Cambrian-Vendian groundwater into the mine during the first 15 days is 1.75 million m^3, 20 days – 2.2 million m^3, 30 days – 3.2 million m^3, and in one year – 30.5 million m^3. Such scenario is highly unlikely, but should be, however, considered in accordance with the precautionary principle. Surely filling of the entire mine with water is unacceptable for the consumers of the Cambrian-Vendian aquifer as source of drinking water and therefore in the construction process it is important to assure that in case of accidents the inflow of groundwater into the mine does not exceed 2.2 million m^3.

In the last couple of decades the total extraction of water from the Cambrian-Vendian aquifer has decreased and as a result, its surface has risen to an elevation of 5–7 m below sea level. On 15 January 2009, the groundwater level in bored wells was at an elevation of 6.3 m below sea level in Maardu town and at 5.9 m below sea level in Loo settlement.

Under normal circumstances the operating granite mine does not influence the Ordovician-Cambrian aquifer. The technical solutions applied must assure that the Ordovician-Cambrian aquifer is safely penetrated and the aquifer is not drained. Temporarily limited accidents have little impact on the Ordovician-Cambrian aquifer. Estimated inflow of groundwater from the Ordovician-Cambrian sandstone into the vertical shaft would be 1000–2000 m^3/d, but the actual inflow could be twice as big due to the additional inflow of surface water, since first the bodies of water in the former phosphorite opencasts will be drained off. Their area is some 60 hectares and calculated volume of water 150 000–200 000 m^3. In case of accident during the first 50–100 days the inflow will occur mostly from the opencast bodies of water, and only after that the inflow from the Ordovician-Cambrian aquifer would take place, which would influence the consumption of drinking water, but the above period of time is sufficient for liquidating the accident. Cracking the roof of granite mine does not considerably influence the Ordovician-Cambrian aquifer, since the aquifer is isolated from below by thick bed of the Lontova blue claystone.

CONCLUSIONS

Utilisation of Neeme granite deposit serves different socio-economic and environmental interests. Construction of the Muuga pumped-hydro accumulation plant (PHAP) within the deposit is an important prerequisite for implying renewable energy sources into electricity and heat production capacities in the Baltic region. The central issue of constructing Muuga PHAP or Maardu deep granite mine is reaching the granite body, lying several hundred meters below the groundlevel.

Important will be the risk to the groundwater, but our complex studies show, that this risk can be mitigated. If the environmental requirements are followed the extent of the impact on groundwater will be limited to some

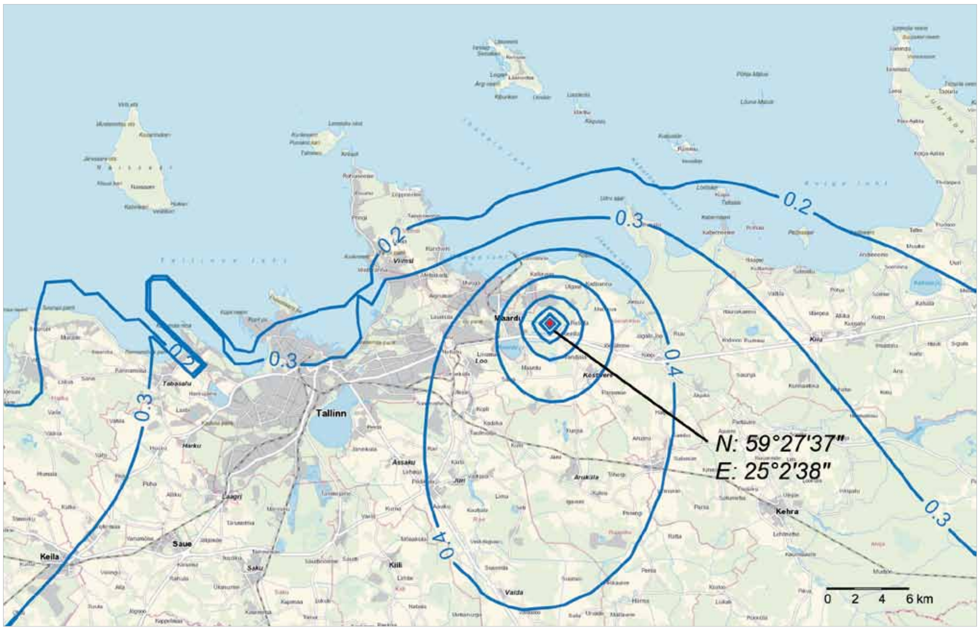

Fig. 6 Possible impact of the groundwater removal (500 m^3/day) of the operating granite mine on the Cambrian-Vendian aquifer system. Blue line indicates the drawdown of groundwater piesometric level in the Cambrian-Vendian aquifer system influenced by the granite mine. Modified by Mait Metsur using own materials of Maves Ltd.

1-m lowering of groundwater table near the facilities (at a distance of up to 0.5 km). In the case of extensive accidents (e.g. filling of mine with water) the extent of impact is bigger and may influence the water supply from the Cambrian-Vendian aquifer within a radius of up to 10 km. However, the probability of such accident according to our calculations is very small.

Former Maardu phosphorite opencast is highly damaged and dangerous to the surroundings. Establishment of the model industrial territory of the Maardu deep mine will improve the environmental situation in the whole area.

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