Activity Report of WP3.3 **12|2021**

SITE DESCRIPTION AND DATA OF THE RUSKEALA UL

Site services, Characteristics and Data

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1 Aim and Introduction

This report provides an overview of the features, properties and services of the Ruskeala UL for external users and site managers.

The aim is to support marketing, project planning/execution, business, and innovation development. General site information, including current use and access to the Ruskeala UL, is followed by information on research, innovation and cooperation possibilities, and on-site support, including the database. The bedrock geology, hydrogeology, and hydrochemistry data and properties are described in detail.

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2 Overall description of the Ruskeala UL

2.1 Location

2.1.1 Geographical settings

Ruskeala Underground Laboratory is located in the now-closed marble mine in Ruskeala Mining Park. The Ruskeala area is located in the Sortavala District (municipality) in Karelia (30 km to the north from Sortavala), southwestern Republic of Karelia, Russia. The mine has numerous large underground spaces.

The Underground facility's coordinates are 61° 56' 51.6" N 30° 34' 48.4" E. A 3D visualization of the Ruskeala UL can be found at https://sketchfab.com/3d-models/ruskeala-9907829a3d894485a44d6cbfce67f965. Fig.1. shows a 3D Sketchfab model of the Ruskeala UL.

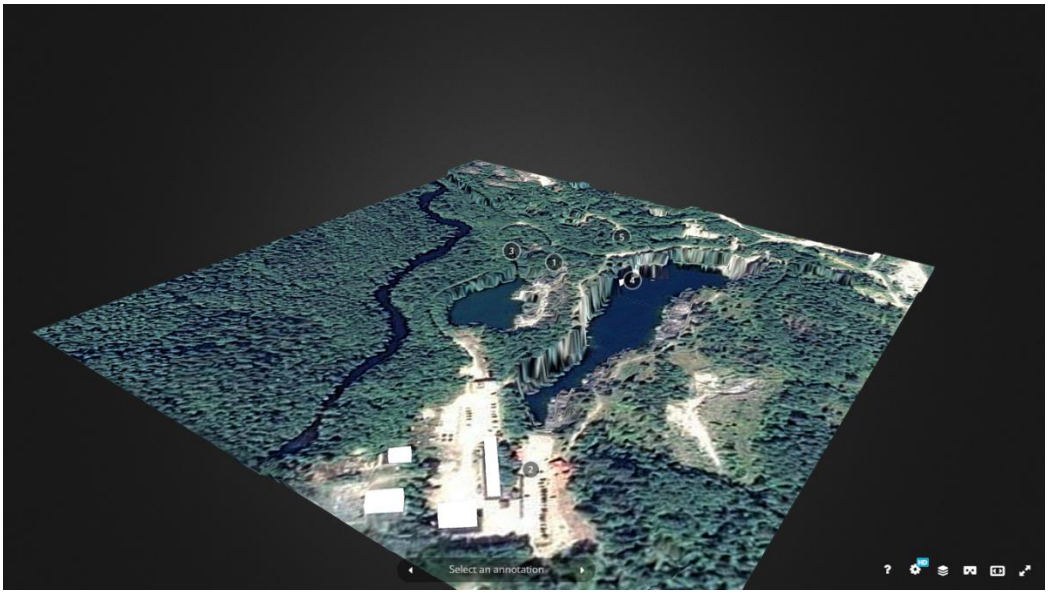

Figure 1. 3D Sketchfab model of the Ruskeala UL.

2.2 Use and Access

2.2.1 The original purpose and current use

Currently, the underground laboratory is engaged in testing, designing, and building tourist facilities in old quarries and mines. The current use is for other methodological and technical development of the roof control, investigation of weak zones – which could pose a danger for visitors and the environment, conducting geotechnological studies, and photogrammetry of the underground space. This is a now-closed marble mine.

2.2.2 Available infrastructure

The underground laboratory includes several extensive tunnels, a lake, and a larger area with underground chambers (Fig.2.). One of the chambers has an area of about 15 m^2; there is also a space with dimensions of 2.5 m × 2 m × 300 m. There is no internet connection, power, or ventilation in the underground laboratory.

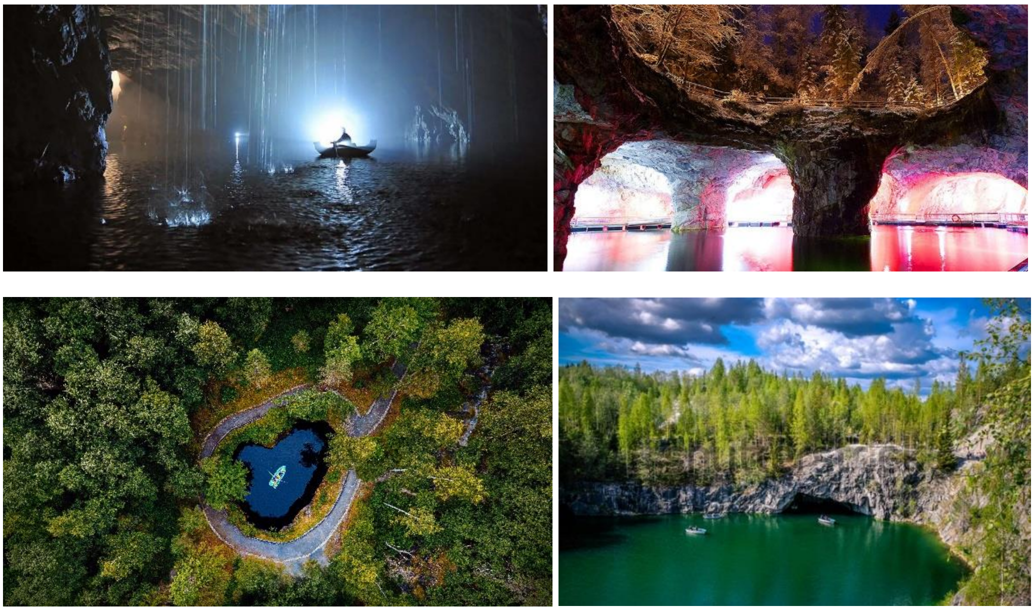

Figure 2. Ruskeala Underground Laboratory.

2.2.3 Current ownership and organisation

The initiators of the Ruskeala underground laboratory are the tour operator JSC Kolmas and the Karelian Research Centre of the Russian Academy of Sciences. The UL acts as a pilot facility for innovations in the mining heritage research.

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2.2.4 Underground access

The underground laboratory is reached from the surface via a gently inclined tunnel. There is no elevator or stairs in the underground lab. Therefore, there is no limit to the maximum size and weight of goods transported underground. The only problem is the dimensions of the entrance, which may limit the size of the equipment and goods that can pass through.

2.2.5 Commuting

The trip to the Rusekala underground laboratory takes some 30 minutes by car from Sortavala (30 km), about 3 hours by car from Petrozavodsk (250 km), or about 1.5 hours from Joensuu, Finland (110 km). The nearest airports are in Joensuu, Finland (120 km from the UL), in Petrozavodsk, Russia (250 km from the UL), and in Saint Petersburg (Pulkovo, 320 km away). Another option is to take a train to Sortavala from Ladozhskiy Railway Station in St. Petersburg (ca. 5 h trip), then take a taxi or bus to Rusekala. There is a train from Petrozavodsk to Sortavala (No. 680-Ch via Kaalamo). It may also be a good idea to go by a tourist bus from St. Petersburg.

2.3 Research, innovation and cooperation possibilities

2.3.1 Innovation and research

The following tests are carried out in the underground laboratory:

a) Geological exploration - Study of the geological structure of the massif.
b) Tectonophysical research - Investigation of the problems of fracturing in the rock mass.
c) Modeling - making underground space simulations, virtual tours, augmented reality.
d) Physical and mechanical tests of rocks. Invasive and non-invasive research methods.
e) Geophysical studies of underground space.
f) Hydrological and bacteriological research - Study of the hydrological regime of the underground space. Study of the impact of climate change. Microbacteriological analysis.

Geotechnological and photogrammetry investigations are also conducted in the underground space. The aim is to transfer the experience to other historic mines and quarries in the territory of the Russian Federation.

2.3.2 National and international cooperation

The Ruskeala UL was organized by the Institute of Geology of the KarRC RAS and the Kolmas Karelia company.

The Ruskeala UL belongs to the European Underground Laboratories Association.

2.4 Support at the site and available database

2.4.1 Project handling, competencies and quality control

The UL team is willing to provide assistance in the implementation of various projects by partners. Some spaces or the entire underground route can be rented for research and creative purposes provided that this does not interfere with tourism activities. The facility as a whole can be rented for the evening and night, in the 20.00 to 10.00 interval.

If applied in advance, the project team can rent out different sorts of equipment and gear (camping, electrical, photo and video, lighting, vessels, life-saving equipment). Catering services can be provided. The park has experience of collaborating with filming teams.

Personal diving gear, roping equipment for industrial mountaineering activities can be rented from the park's local partners.
Support can be provided with transport, meals, and accommodation.
Ruskeala Mining Park has experience in hosting and organizing thematic scientific events (seminars, conferences) and specialized excursions.

2.4.2 Database

Up-to-date cartographic information can be provided on spot or upon preliminary request:

- detailed topo survey of the surface in the study area;

- detailed topo survey of the entire Underground Ruskeala cave route.

3 Site description data and data properties

3.1 Bedrock geological data and properties

3.1.1 Geological data and tectonics

The Ruskeala deposit area is composed of rocks of the Pitkaranta suite rocks and lower suite of the Lower Proterozoic Ladoga complex, which form an overturned anticline with limbs dipping monoclinally south-westwards. The anticline core is formed of amphibolite schists, and the limbs – of carbonates and mica schists. Ruskeala 1 deposit lies in the south-western limb of the anticline, and Ruskeala 2 in its north-eastern limb. The sites are discrete lenticular sheet marble deposits lying in the same horizon and having similar petrographic and geochemical parameters.

Ruskeala 1 is a larger deposit, exploited for over 180 years. The marble deposit is known to stretch along the strike for over 1700 m and its maximum thickness is 500 m. The deposit has been drilled down the dip to 160 m. High-quality marble grades and calcitic varieties occur as isolated lenses. Some of them have been extracted from the surface by quarrying. Calcitic marble varieties stretch for some 700 m and have a maximum depth of up to 60 m. Where they pinch out, the marbles are enriched with dolomite. Phosphorus content is elevated, reaching 0.15%, which is the threshold for the marble to be applicable as low-grade fluxes. The deposits has been largely exhausted and removed from operation.

3.1.2 Major rock type(s)

The deposit's marble is dense, crystalline, scarned, highly heterogeneous. Four marble varieties are distinguished by the mineral composition: calcitic, slightly dolomitic, dolomitic, and heavily dolomitic. There are gradual transitions between these varieties. The latter two varieties are more heavily scarned. There are areas of heavily scarned amphibolized mottled dolomite segregations. Marble varies in color from white to dark gray and greenish. Banded varieties are widespread. The rock is a fine facing material.

3.1.2.1. Mechanical properties and conditions

There is no up-to-date data on the mechanical properties of Ruskeala marble. The physical and strength properties of the Ruskeala deposit marble have not been specifically studied. The reference cadaster of rocks, however, contains the information that the compressive strength in samples of similar marble varieties from other deposits of Karelia (Kivinpurja, Spassogubskoe, Mramornoborgskoe, Raiguba, Perguba, etc.) is quite high, ranging from 2120 to 2610 kg/cm^2 (212–261 MPa). It is safe to say that the sample compressive strength of Ruskeala marble is at least 212 MPa.

3.1.2.2. Thermal properties and conditions

Microclimate in the underground workings.

Microclimate observations have been studied in adits and the Great hall a few times. The first measurements were made in February 2011, before creating the underground tour and the system of doors, which now enable zone-by-zone regulation of the microclimate along the route.

At that time, e.g., temperature in the adit early in May was around 0 degrees, and there was no active thawing. Owing to the ice formed in adit #1 during the winter, the spring temperature there long remained around 0 ˚C. Because of such freezing, tours of the adit in winter and, especially, in spring were not safe.

Construction of the door system has helped stabilize the temperature in adits at 6-7 ˚C. Their roofs and walls do not get frozen over.

The temperature patterns of watercourses are more conservative as they are significantly correlated with the temperature of the rock massif, which is around 6˚C. In September, the temperature in the lake in the Great hall (on the surface) was 6.6˚C, and that of the stream in the middle section of adit #2 was 5.8˚C.

Thus, the microclimate parameters in Ruskeala underground spaces prior to the making of the caving route varied substantially among seasons and depending on the weather on the surface. Installation of doors along the route to maintain a constant microclimate in the adits has produced long-term positive effects. The microclimate of the Great pillar hall, on the other hand, is not regulated and experiences substantial seasonal fluctuations.

As a result, seasonal ice features form in the Great pillar hall every year. The ice cover on the lake in winter can be up to 40 cm thick. Numerous speleothems form on the ice, where water drips from the roof. Stalagmites prevail, but stalactites and stalagnates are also present. Sublimation crystals form locally. Some of them curve, but do not break. This must be due to the presence of calcareous matter in the speleothems. Speleothems are known to have high plasticity. There are three major areas where ice drip features form. Two of them are situated in the north-eastern part of the hall, and the third one in the westernmost site. The largest pillar-like feature resembling a stalagnate is found in the western site.

Sublimation ice crystals form in areas with abrupt temperature change, usually near entrances, in frosty weather. They occur in the entranceway of the first adit on the Great hall side and in the oval cul-de-sac in the north-eastern part of the Great hall.

In the middle of the winter, ice in the Great hall reaches 30 -40 cm thickness. Sometimes, however, there form thinner areas. Test drilling of the ice is done in mid-February, before the traditional underground ice sculpture festival “Mystery of the Depth”.

3.1.2.3 Radionuclide data

Data is not available.

3.1.3 Data sources

3.1.3.1 Surface data

Topographic and geological maps of the area are available, they can be provided by UL agents upon request.

3.1.3.2 Borehole data

No boreholes have been drilled.

3.1.3.3 Underground data

The prolonged period of marble mining in the Ruskeala deposit has resulted in the formation of an extensive network of underground workings. Two vertical and one inclined shafts, a substantial number of adits and several large chambers (halls) with room and pillar structure have been driven. Quarries and underground workings form four horizons. The lower horizons of the deposit are flooded to 92.6 m level.

Of greatest interest for the research and excursion purposes are the Great pillar hall, the Main pit (Great marble quarry), and the adits connecting them.

Sketch map of the Underground Ruskeala cave tour is attached. More detailed cartographic material can be provided upon request.

3.1.3.4 Petrography, geochemistry, rock mechanics, petrophysics and thermal properties

The Ruskeala deposit’s marble is dense, crystalline, scarned, highly heterogeneous. Four marble varieties are distinguished by the mineral composition: calcitic, slightly dolomitic, dolomitic, and heavily dolomitic. Marble varies in color from white to dark gray and greenish.

The physical and strength properties of the Ruskeala deposit marble have not been specifically studied. The reference cadaster of rocks, however, contains the information that the compressive strength in samples of similar marble varieties from other deposits of Karelia (Kivinpurja, Spassogubskoe, Mramornoborgskoe, Raiguba, Perguba, etc.) is quite high, ranging from 2120 to 2610 kg/cm^2 (212–261 MPa). It is safe to say that the sample compressive strength of Ruskeala marble is at least 212 MPa.

The adits in the site were driven through marble.

The marble of different types and grades is broken by several natural fracturing systems. The prevalent rock weakening surfaces are roughly spaced 1.5–2.0 m apart.

The rock being quite stable, there was no need for structural support when driving the adits, and their contour has remained stable until today. Rock stability has been partially undermined by repeated freezing and subsequent thawing of the roof rock in winter and summer. At present, problematic areas have been taken under control to secure the excursion route.

The only short, some 6 m long, stretch with highly unstable rock is in the immediate vicinity of the southern wall of the Great pillar hall, at the northern end of adit #2. There, a sub-latitudinal tectonic zone crosses the adit. The marble is heavily fractured, broken into blocks. The site was supported by timber framing during driving. The framing has afterwards decayed and collapsed, forming large-block debris. In 2015-2017, a reinforced-concrete tunnel structure known as Cavers' Tunnel was built in the area, facilitating safe passage of the project staff and tour participants from the adit to the Great pillar hall.

3.1.3.5 Natural background radiation data

The background radiation in underground spaces of the Ruskeala deposit was measured on September 18, 2011. The measuring device was a combined radiometer RKS-107 Belvar. The measurement step in the adits was 10-20 m. The characteristics are averaged and maximum background radiation levels at specific spots expressed as μSv/h. The resultant data are presented in tabular form (Table 1).

Table 1: Results of background radiation measurement in Ruskeala adits.

	Space	**Material in the site**	**Radiation, μSv/h**	
			average	**maximum**
1	Southern debris of adit #2	Marble waste	0.07	0.08
2	Adit #2, 7 m north of debris	Marble waste	0.08	0.09
3	Adit #2, 18 m north of p.2, "the gate"	Marble waste, water	0.08	0.09
4	Adit #2, 16 m to the north	Marble waste, tall berm	0.04	0.05
5	Adit #2, 16 m to the north	Marble waste	0.06	0.06

6	Adit #2, 18 m to the north	Marble waste	0.05	0.06
7	Adit #2, 22 m to the north	Marble waste, clay	0.02	0.03
8	Adits fork	Marble waste, scree, clay	0.04	0.09
9	Adit #1, 26 m to the south	Marble waste, water	0.03	0.03
10	Adit #2, 19 m to the south	Marble waste	0.04	0.06
11	Adit #2, at the bend	Marble waste	0.05	0.05
12	Adit #2, 18 m to the south	Marble waste, water, clay	0.05	0.07
13	Adit #2, near-entrance room	Marble waste, clay	0.02	0.04
14	Adit #2 debris at GH	Clay, marble	0.05	0.05
15	Adit #2 exit to GH	Clay, water, scree	0.04	0.05
	Mean values		0.05	0.07

Thus, no elevated background radiation level was detected in Ruskeala underground workings. The values did not exceed 0.09 µSv/h, which is not hazardous for humans and not an obstacle for excursions.

Radon situation in the underground workings.

Radon is an inert radioactive gas with no odor or taste, which is hard to detect and is therefore measured by specialized devices. The radon radiation health guideline level is 250 Bq/m^3. Being heavier than the air, radon concentrates in the lower air flow. This is the radon-rich cave air in summer and the radon-poor cold air entering the cave from the surface in winter. Measurements were done by radon radiometer RGA-1.

Three measurements of radon activity per unit volume (VRA) were made in Ruskeala underground workings, showing the level to be relatively low. VRA in adits #1 & 2 was very low, and a notable rise to 179 Bq/m^3 was detected right after the debris in adit #1, at the entrance to the Great hall (Table 2).

Table 2: VRA in underground spaces of the Ruskeala deposit.

	Radon testing sites	**VRA [Bq/m^3]**
1	Adit #2, 10 m from the drilling station	26
2	Adit #2 southern part, 15 m from debris	12
3	Adit #1 at the junction with the Great hall, after the debris (Cavers' Tunnel area)	179

Hence, there is no hazard for human health from the radon factor in the adits and the Great hall.

3.2 Hydrological data and properties

3.2.1 Hydrogeological data and properties

3.2.1.1. Description of data

There are two flooded open pits in the Ruskeala Mining Park: the Great Canyon Lake and Montferrand's Lake, as well as the underground lake in the Great pillar hall. They are now flooded to about 90 m level. The area is mainly drained by the River Tohmajoki (Ruskolka), flowing in the near vicinity, to the south-west of the park, at 66-65 m elevations.

The main quarry is connected to the Great hall by large underground spaces – huge communicating vessels. The Great hall – Canyon system is drained via the Lesnaya (Forest) Adit. In February 2011, when research only started, this stream had a discharge rate of ca. 2 l/s in winter and its water level did not exceed 10-15 cm. The stream passed both debris areas with hardly any rise of the level. The walls of adit #2 bear clear traces of the water level at 40 cm to 1.5 m above the floor. It was at first unclear when these water (flood) marks had formed, but later we observed a major (more than a meter) rise of the water level in the stream during snowmelt and the spring flood. The stream now discharges into Montferrand's lake via the adit and the "Mine office". In winter, during the low-water period, the discharge rate through the stream is ca. 2-3 l/s. In the highest-water period, it rises to 20 l/s.

3.2.1.2. Description of properties

Date is not available.

3.2.2. Hydrogeochemical data and properties

3.2.2.1. Description of data

Hydrochemical samples from the Canyon lake. The results are given in the table below (Table 3).

Table 3: Hydrochemical data of the samples from Canyon lake.

	Ions	**g/l**	**mg-equiv/l**	**% equiv**
1	Dry residue	0.0210		
2	(Na+Ka)	0.0186	0,81	19,5
3	NH_4^+	not detected	-	
4	Ca_2^+	0.0511	2,55	61,3
5	Mg_2^+	0.097	0,80	19,2

6	Fe^{2+}	not detected	-	
7	Σ cations	4.16		100
8	Cl^{-}	0.0268	0,76	18,3
9	SO_4^{2-}	0.0161	0.34	8.2
10	No_2^{-}	0.00005	0.002	0.0005
11	HCO_3^{-}	0.1770	2.90	69.7
12	NO_3^{-}	not detected	-	
13	CO_3^{2-}	0.0048	0.16	3.8
14	Σ anions	4.16	4.6	100
15				
16	pH	8.22		
17	$Fe(OH)_3$	0.0002		
18	Permanganate index (oxidizability)	0.0004		
19	Total hardness		3.65	
20	H_3SiO_3	0.0010		
21	H_4SiO_4	0.0064		

Table 4 presents the metal content in the Great Canyon lake water.

Table 4: Metal content in the Great Canyon lake water.

Metals	**Content, mg/l**	**Lower threshold, mg/l**
Cd	below 0.0.0001	0.0001
Cu	0.011	0.001
Pb	0.0056	0.001
Zn	0.036	0.001
Ba	0.064	0.03
Sr	0.16	0.03
Al	0.044	0.001

The hydrochemical formula:

$$M \; \frac{HCO_3\, 69.7 - Cl\, 18.3 - SO_4\, 8.2}{Ca\, 61.3 - (Na+K)29.5 - Mg\, 19.2}$$

Water is of the calcium and magnesium bicarbonate type, potable.

Thus, at the time of the measurements, water in the quarry was pure, uncontaminated, and could be used in water supply.

3.2.2.2. Description of properties

Data is not available.

4. Summary

The Ruskeala Lab underground laboratory was created on the basis of the first cave tour route in the Republic of Karelia – Underground Ruskeala. The laboratory offers unique opportunities for integrated monitoring of the underground space at the air-water interface. In winter, diverse glacial features form in the Great pillar hall, and observations thereof can form a special area for research. The laboratory can offer a wide spectrum of support services to partner teams. Owing to the high-quality infrastructure and the experience gained through participation in international projects, the Mining Park can proficiently host international multidisciplinary scientific excursions, seminars, and conferences. Another favorable factor is the site’s geographic location: near a border-crossing checkpoint (25 km), with good road and railway connection to St. Petersburg and Petrozavodsk.