Geological Survey of Estonia

YEARBOOK 2018

RAKVERE 2019

GEOLOGICAL SURVEY OF ESTONIA
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Geological Survey of Estonia

2018

GEOLOGICAL MAPPING AND GEOLOGICAL DATA

APPLIED GEOLOGICAL STUDIES

HYDROGEOLOGICAL AND ENVIRONMENTAL GEOLOGY

Foreword

Geology is a very old field of science. It was formed and developed more than thousand years ago, dictated by the demand for Earth's resources. It has been existing in different forms during different regimes and with various levels of success. An analogical institution dealing with geological information operated in the region of Estonia already when it was a part of the Russian Empire. A geological survey as a state agency has been operating in Estonia during the periods 1937–1940 and 1957–1997. For some twenty years before now, geological services were provided in the format of a company, which distanced us considerably from successful colleagues in Europe.

The Geological Survey of Estonia as a national authority was re-established under the administration of the Ministry of Economic Affairs and Communications on 1 January 2018. In its background were national understanding, and the desire to explore possible future mineral resources, studying them through the principle of sustainability and environmental friendliness. Another task of the survey will be to put the geological information in order, transforming it into an understandable form available for the whole society. The majority of our geological data is still preserved in the form of manuscript reports. Finding relevant information in them is a time-consuming effort.

Without doubt, any activity on the ground surface or underground changes the environment. It is still possible to mitigate the consequences of human action with skilled and careful operation. For this, modern knowledge has to be applied when dealing with questions related to groundwater, environmental geology, geochemistry or other technical issues. Geological mapping of the Estonian subsurface has to be accomplished, with a particular focus on regions of general economic interest. New information collected with geological mapping has to become public domain. Its use has to be easy both for a decision maker and an entrepreneur, and particularly for an average person, who wishes to get familiar with the environmental conditions or existence of mineral resources in his own locality. Doubtless, our sea bottom resources and environment have to be mapped in the near future. We do not need to reinvent the wheel, as geological surveys of all the developed countries in the world deal with these topics. It is certainly a challenge to reach a new level in a very short time and with limited resources. We are confident that we are able to tackle the obstacles on this road, in cooperation with Estonian ministries and leading universities, and shall reach the group of successful European geological surveys both in regard with quality and importance.

Our yearbook provides an overview of activities, research, projects, and hopefully of many other intriguing geological issues during our first year of operation.

Enjoy the reading!

Prof PhD
Alvar Soesoo

The director
of the Geological
Survey of Estonia

A national geological survey – an investment for the future

Riigikogu, the Parliament of Estonia approved on 6 June 2017 the foundation for the Estonian Earth's crust strategy until the year 2050. The long-term goal of the framework strategy "General principles of the Earth's Crust policy until 2050" is to secure management of geological resources that is science-based, environmentally-friendly and oriented to boost the growth of national economy, as well as to increase resource efficiency and to diminish the dependence on raw material and non-renewable resources. The approval of this document was an exceptionally important step for the research of the Estonian subsoil.

Proposals for changing the hitherto valid regulation for using the subsoil were pointed out in the framework strategy: bringing about the capacity for strategic planning of the economic and socio-economic development of the field, and establishing a national geological survey under the administration of the Ministry of Economic Affairs and Communications. By taking this step, Estonia went ahead with its development after a standstill of tens of years. The wealth of a state is directly correlated with its capacity of knowing and using its resources well and wisely, including the mineral resources.

Three global trends can be observed in the world economy: 1) constantly increasing demand on mineral resources; 2) increasing demand on energy resources; 3) need for balanced means for environmental protection. Economic growth is an obvious interest of the Ministry of Economic Affairs and Communications. For reaching it, science-based production using the national resources have to be developed in the context of everything else, together with reasonable environmental investments and well considered planning.

The Geological Survey of Estonia started its operation on 1 January 2018. The fields it deals with are geological mapping, geological investigation, preserving geological information and ensuring its availability, counselling governmental agencies and informing the public on geological issues.

When Estonian mineral resources are discussed, two views are typically expressed: some claim that our geological resources are not significant, others rather consider that we have an immense potential. A conclusion can be drawn that, in fact, we do not know the actual value of our subsurface.

The Estonian geological resources can be divided in two: the known ones (including local construction materials and peat) and the less known, future mineral resources. The latter ones may even not be called as mineral resources in the current context. A natural resource is a mineral resource, if it is profitable and sought after.

There is enough or almost enough geological information on the known mineral resources. But it is obvious that this is not the case with the so-called future mineral resources. Oil shale, graptolite argillite and phosphorite can be considered as strategic Estonian mineral resources. It is likely that the deposits of iron ore and polymetals in north-eastern Estonia (the region of the Jõhvi magnetic anomaly), as well as deep geothermal heat, may turn out to be similarly important. These resources are intrinsically very different, and it is not possible to assess their exploitation potential adequately with the current knowledge. Also glauconite (raw material of potassium used in chemical industry and environmental technologies) and mineral waters in many regions could be added in the list of natural resources requiring investigation.

The expectations of the Ministry of Economic Affairs and Communications are above all related to the investigation of strategic geological resources:

- identification of mineral resources of high economic potential, with the goal of giving an overview on these resources as sources of complex raw material (rare earth metals, ores, phosphorus). Existing information on these mineral resources does not allow developing of new fields of use, because of being insufficient and out-of-date regarding modern criteria;
- to continue collecting and systematizing geological information on all known, currently used geological resources and to develop the maintenance of respective databases;
- to continue comprehensive geological base mapping at the scale of 1:50 000, on the basis of which it is possible to make decisions on the use of mineral resources and groundwater, construction operations, land use and environmental conditions;
- strengthening the potential of coastal and marine geological research, which together with fostering the image of Estonia as a marine state makes it possible to increase national competence in international cooperation projects and applied investigations, e.g. in the fields of constructing, transport and logistics.

The Geological Survey of Estonia has been operating slightly more than for a year. Many developments and emphasis are still at the phase of forming. The interest of the Ministry of Economic Affairs and Communications is to secure national competence in the use of mineral resources and in essential decision-making processes influencing economic development. We are just heading towards our goals.

Above all, decisions in every field depend on the knowledge and the level of awareness of the actors. Wise decisions secure the functionality of a prosperous and developed state. Explorers of the Earth's resources face the challenge to ensure the trust of the people on their state and on the actions of its developers.

PhD Ene Jürjens,
Head of Mineral Resources Division,
Ministry of Economic Affairs and Communications

An interview with Alvar Soesoo, the director of the Geological Survey of Estonia

Why was the Geological Survey of Estonia established?

Every developed country has a geological organization that counsels the state on a scientific basis. A few European countries have had a geological survey for almost two hundred years. Since the state of Estonia regained its independence, geological survey has been a state authority only for a short period, and a commercial enterprise for a longer time. Unfortunately, the status of a company led to the circumstances that many functions necessary for the state were not accomplished. This led to the demand for creating a state agency Geological Survey of Estonia, administered by the Ministry of Economic Affairs and Communications that would also provide the financial basis. Both the state and entrepreneurs need a neutral advisory organization and an impartial assessor of resources, as the interest on Estonian geological resources is great. The geological survey explores mineral resources by internationally acceptable means and is not interested in mining.

How was the staff formed?

We recruited people from various institutions. The majority of the staff at the Department of Geological Mapping come from the liquidated company-type Geological Survey of Estonia. The Department of Hydrogeology gathered people from companies and universities. Building up the team for the Department of Geological Resources was most complicated, as for instance, the state of Estonia has not dealt with future mineral resources for 30 years or more. When forming the staff, we considered that the geological survey deals with applied research of mineral resources. We hope that the universities provide enough support for us in the form of basic research, which we could develop further into practical applications.

How has the geological survey advertised its existence?

We managed to discuss common issues together with all geological surveys in the European Union during the first year. Problems met in Estonia exist distinctly also elsewhere in Europe. Thus, we have introduced ourselves in those circles as a new Estonian national institution of applied geology. The Estonian universities supported us. We are not their rival but quite the opposite – a partner, and on the other hand, a becoming workplace for young specialists. We have accomplished a big task by introducing our activities to ministries. We have not yet visited schools as much as we would have wished, as schools provide our next generations. Certainly, more advertising has to be done together with other state institutions, universities, schools and entrepreneurs.

What has been the greatest success during the first year?

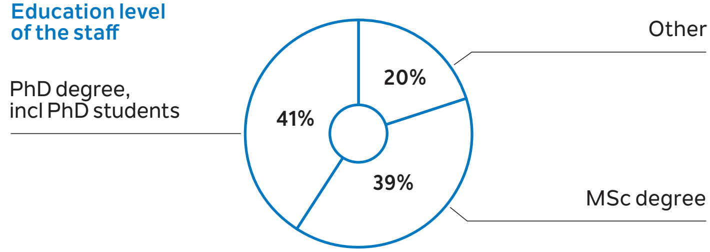
Without doubt, finding good people, creating a team and starting up the authority.

What are the challenges for the geological survey in 2019?

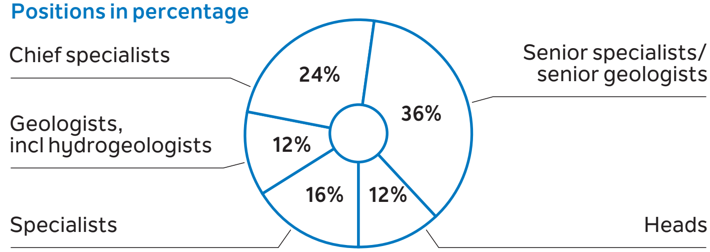
The state and the people expect from us trustworthy information on the possibilities for utilizing the subterranean environment. The state of Estonia and the society need to develop business activities and increase income. All our teams have to be manned until the end of this year and everybody has to get modern working conditions – this is the prerequisite for expecting productive teamwork from the staff. The majority of geologists live either in Tallinn or Tartu. As we are an institution that is placed outside the capital, many of us face challenges that have to be overcome.

Heli Suvi
Specialist of Public Relations, Geological Survey of Estonia

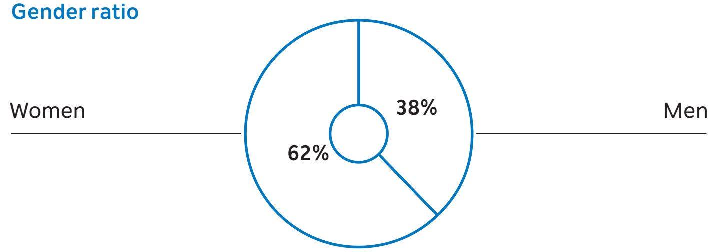
Education level of the staff



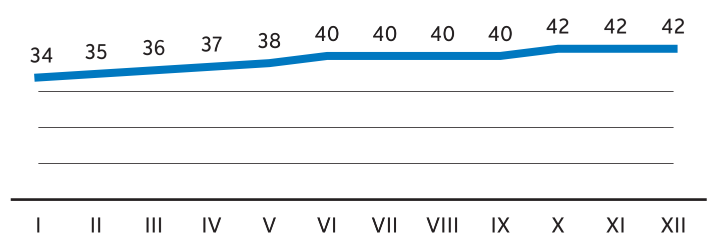
Positions in percentage



Gender ratio



Number of employees/month in 2018



Geological mapping of Hiiumaa at the scale of 1:50 000

The Geological Survey of Estonia completed digital geological maps of the Hiiumaa island and surrounding mainland areas at the scale of 1:50 000, with accompanying datasets.

Data from more than 2350 observation points, of which 721 were added during the 2018 control fieldwork, were used for compilation of five map sheets (6124 Kõpu, 6213 Kõrgessaare, 6214 Kärdla, 6211 Emmaste, 6212 Käina). The set includes maps of 1) Quaternary geology, 2) bedrock geology, 3) bedrock relief, 4) thickness of Quaternary deposits, 5) geomorphology, 6) aeromagnetic anomalies and 7) gravity anomalies. The set of Hiiumaa maps is soon to be complemented with digital maps of hydrogeology and groundwater vulnerability, as well as with an explanation to the maps.

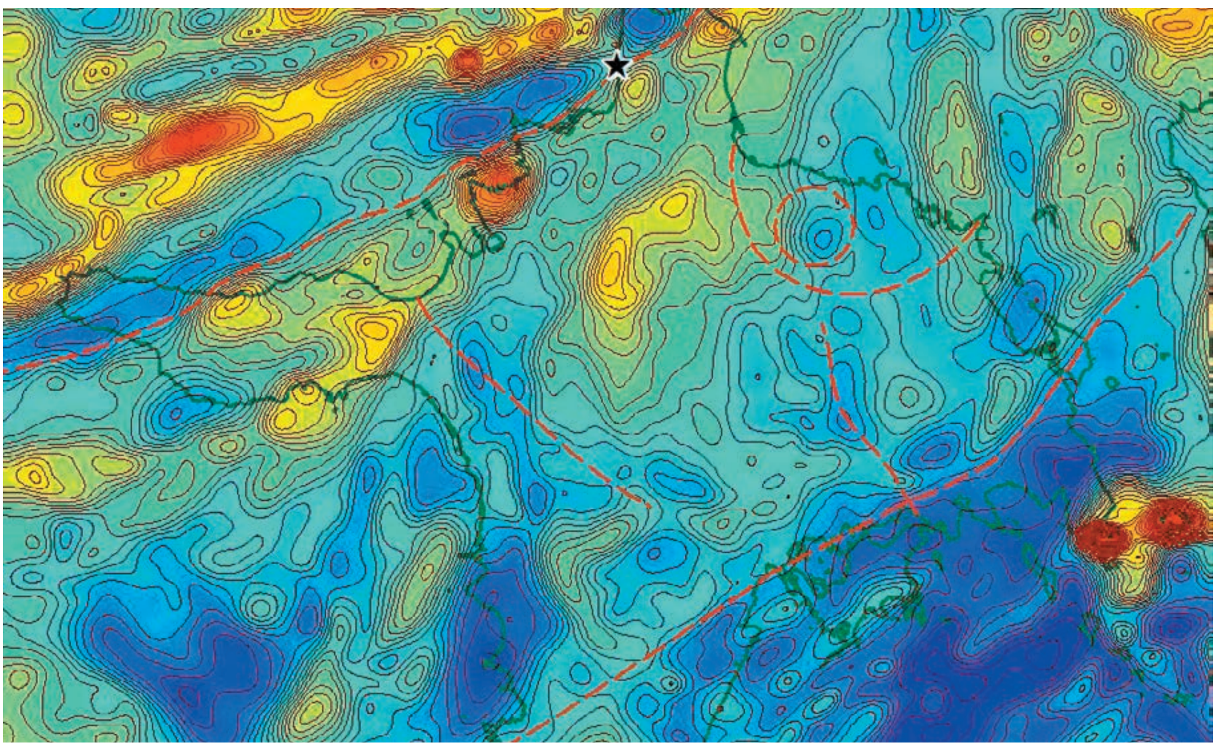
The geologists noticed several geological structures and features during field mapping, which deserve attention both from the perspective of studies on Earth's structure, as well as from the perspective of mineral exploration.

The Kärdla meteorite crater (discovered in 1974) is a central element of geological maps of Hiiumaa. Most of the mineral resources and their manifestations in

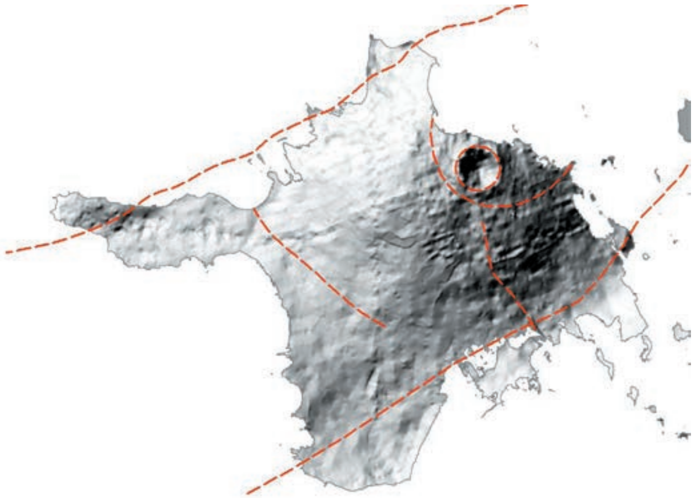
Hiiumaa are related to the crater region, to a greater or a smaller extent. Together with deposits of crystalline building stone, there are deposits of industrial and building limestone at the slopes of the crater ring wall. Deposits of ceramic clay and gravel can be found at the crater bottom. Mineral water named "Kärdla" was tapped from the Soovälja K18 drill hole in the central part of the crater during 1985–1993. Enterpreneurs have still not lost their interest on this water. An up to 6 m thick interval of dolomitized limestone has been discovered at about 40 m depth at the contact of carbonatite rock and sandstone, located in Paluküla by the Lennuvälja road at the NE slope of the ring wall. Here the concentration of Zn is up to 20% (0.5% in average), of Pb up to 2% (0.2% in average) and of Cu up to 0.6% (0.05% in average), respectively. Unfortunately, the diameter of this ore body is less than 50 m. Thus, it remains as an intriguing manifestation of a geological resource, similarly to petroleum found in the crater area.

The Gotland–Hiiumaa uplift was formed under the Baltic Sea during the Middle Ordovician Kunda age (460–470 Ma ago) and is related to the origin of Kõpu–Tahkuna ja Kassari tectonic fracture zones.

These tectonic fracture zones at the distance of 28 km from each other are more or less parallelly aligned in the SW-NE direction (azimuth 40°–50°) and stand out clearly on the aeromagnetic anomaly map. Geological and geophysical evidence, e.g. many structural characteristics of the Quaternary cover and bedrock, point to their existence.



The Kõpu–Tahkuna (NW) ja Kassari (SE) fracture zones (red dotted lines) on the aeromagnetic anomaly map. Magnetic anomalies of Kaevatsi and Heinlaid are prominent at the SE corner, but the Kärdla meteorite crater at the NE part of Hiiumaa does not stand out. The area of sandy limestone boulders at the Meelste beach is marked with a star.



The Kõpu–Tahkuna (NW) ja Kassari (SE) frature zones (red dotted lines) on the gravity (Bouguer) anomaly map.

The Kõpu–Tahkuna fracture zone is marked on the aeromagnetic anomaly map as a clear 2–3 km wide zone of negative anomalies (up to 1300 nanotesla, abbreviation nT). The fracture zone is expressed on the gravity (Bouguer) anomaly map as a variation of about 1 milligal (mGal). The NE flank of this fracture zone with the length of up to 0.9 km is related to sandy limestones (brownish grey sandy limestone of the Pakri Formation of the Kunda Stage with weakly kerogenic interlayers of lime sandstone) existing in the Meelste (earlier named as Kauste) region. This is expressed by boulders and cobbles found at the Meelste beach. Such sandy limestone debris have been found nowhere else in Hiiumaa or its surroundings. However, rocks similar to this sandy limestone (about 4 m thick Pakri Formation) are found near this fracture zone in the Kauste drill hole F351, where the thickness of Quaternary sediments is 24 m, but the depth to these rocks is 73 m.

Boulders of greenish grey limestone with thin wavy layers (similar to limestone of the Keila Stage), with sizes of several square metres, have been found by the shoreline to the south of the southern boundary of the area of sandy limestone and of the Meelste brook. It is highly likely that both of the described rocks originate from a submarine terrace at the bottom of the Meelste Bay and have been ended up to the shore by glacial transport.

In order to define the region of origin for the sandy limestones and limestones found at the Meelste beach and to find supplementary signs for the Kõpu–Tahkuna fracture zone, seismoacoustic profile measurements should be made at the Meelste, Reigi and Luidja bays.

The Kassari fracture zone is marked on the aeromagnetic anomaly map as a 400–500 nT change in the geomagnetic field. The fracture is manifested at the bedrock surface as a up to 30 m high gently sloping terrace. The height of the terrace decreases to 20 m at the structural boundaries of sedimentary rocks. The general outlines of the fracture zone are indicated by atypical distribution of sedimentary rocks of different ages, which can be traced in the cross-section of Lower and Middle Ordovician rocks. Evidence of later crustal movements in the fracture zone have been found in the cross-section of younger rocks. For instance, the thickness of the cryptocrystalline limestone deposit of the Upper Ordovician Saunja Formation decreases in the fracture zone from the typical 4–6 m down to 0.8 m.

Geophysical anomalies of the Kaevatsi islet. The intensity of magnetic anomalies in Hiiumaa is from -540 to 1800 nT, and they are mainly aligned in the SW-NE direction. Present-day seismic activity takes place within structures having this direction of anomalies, including the 1976 Osmussaar earthquake.

The two most intense magnetic anomalies of Hiiumaa are located next to the Sarve peninsula at the Kaevatsi islet (to the west), with the intensity of 1800 nT and at the Heinlaid islet (to the east), with the intensity of 1425 nT. Magnetic anomalies of such intensity are pretty common in Estonia, but few of them are so small in diameter that the exciter would be located at a depth accessible for drilling. On the gravity anomaly map, these islets are located along a gradient zone following the SE coast of Hiiumaa. Geological map of the crystalline basement shows amphibolites and amphibole gneisses at both islets, i.e. rocks that are more magnetic and more dense than rocks in the surroundings. A local gravity anomaly with the intensity of 1.66 mGal is found at the Kaevatsi islet.

When considering the intensity of the anomaly, iron ore formation cannot be excluded at this location. The Hiiumaa anomalies are located at the axis of the anomalous zone, extending to the NE from the Soela Strait, and being particularly intense at the Soela Strait. High concentrations of iron, up to 6.29%, have been discovered in the Hiiumaa parent rock samples of soil along this zone. The sample with the highest value was taken at the location closest to the mentioned islets (Petersell *et al.* 2000).

The gravity field in Hiiumaa varies between -28 and +17 mGal. An extensive gentle positive anomaly with the intensity of more than +7 mGal is seen in central Hiiumaa. The local anomaly of the Kärdla crater, leading to the discovery of the crater, stands out at the eastern slope of this anomaly. Gravimetric intensity at the bottom of the crater is 2.6 mGal and at the crater wall it is up to 8.1 mGal.

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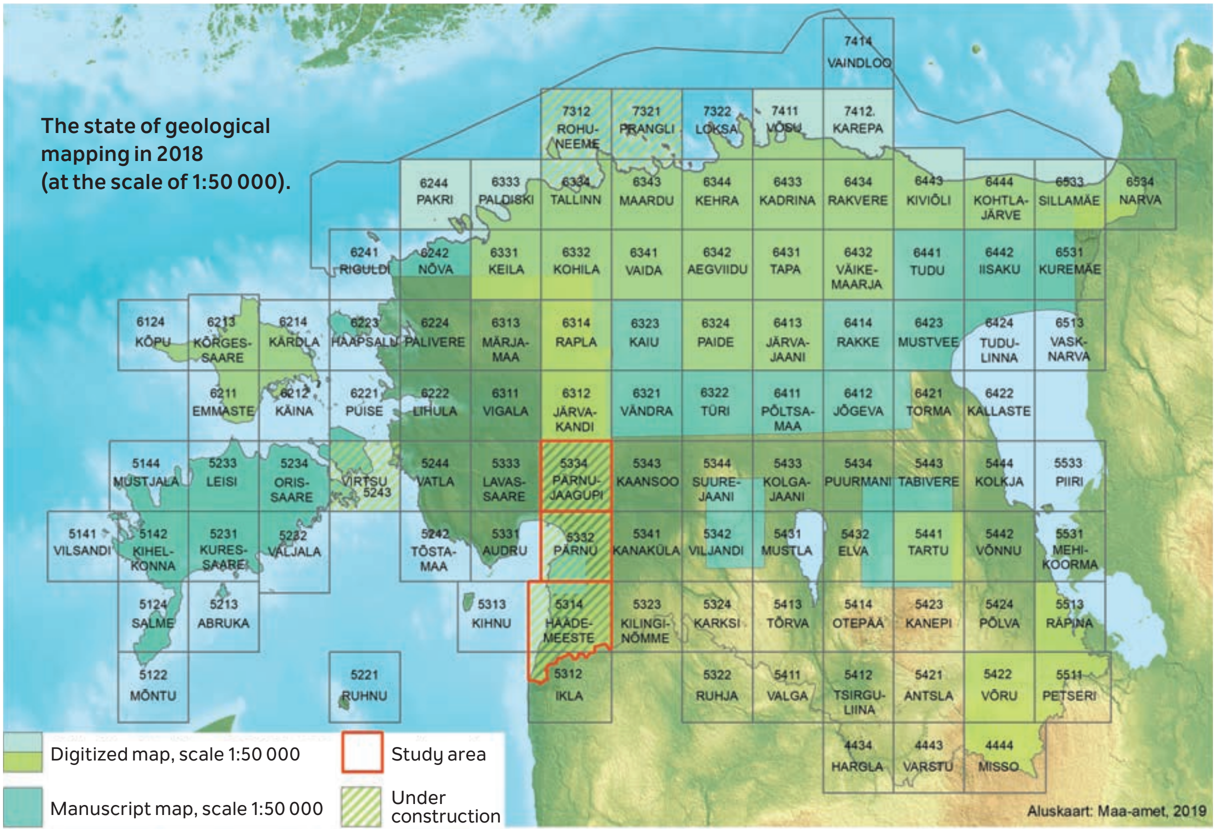
Sandy limestone boulders of Pakri Formation at the Meelste beach.

A geological map provides information for:

1. **managing efficient investigation, use and protection of rocks, sediments and groundwater resources;**
2. **knowledgeable planning of constructing, agricultural and environmental activities;**
3. **raising awareness of the existence of geohazards, such as avalanches, earthquakes, tectonic fracture zones or harmful elements, and preventing related damage;**
4. **comprehending events that have taken place in the geological history of the region, which assists in better understanding of the likelihood of existence of geological resources (mineral resources, groundwater, geothermal heat) and hazards, and to analyse the course of the processes taking place at the planet Earth, their extent and meaning for the mankind.**

FOR WHAT TO USE GEOLOGICAL MAPS?



The state of geological mapping in 2018 (at the scale of 1:50 000).

Geological mapping in the Pärnu County

Geological mapping provides the society comprehensive subterranean information, a decision-making basis for the use of groundwater and mineral resources, land use and environmental conditions.

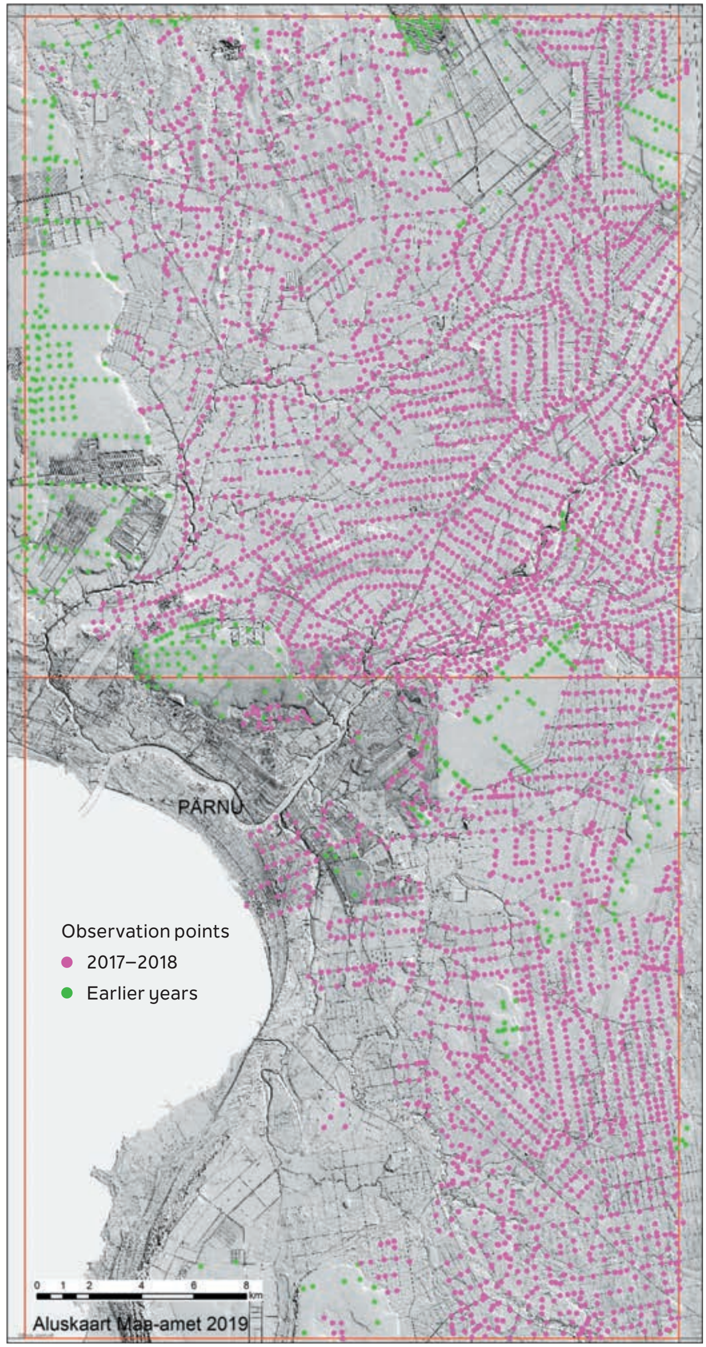
One of the goals of the Geological Survey of Estonia in next few years is to accomplish large-scale (1:50 000) geological mapping of Estonia as a whole.

Geological mapping has proceeded from northern and central Estonia to the Pärnu County, where investigations were made in an area of 1126 km^2 within two map sheets (5334 Pärnu-Jaagupi, 5332 Pärnu), i.e. from the Pärnu-Jaagupi town to the Võiste village near the Uulu village. The decisive factor for choosing this study area was the need to gain comprehensive information on geological

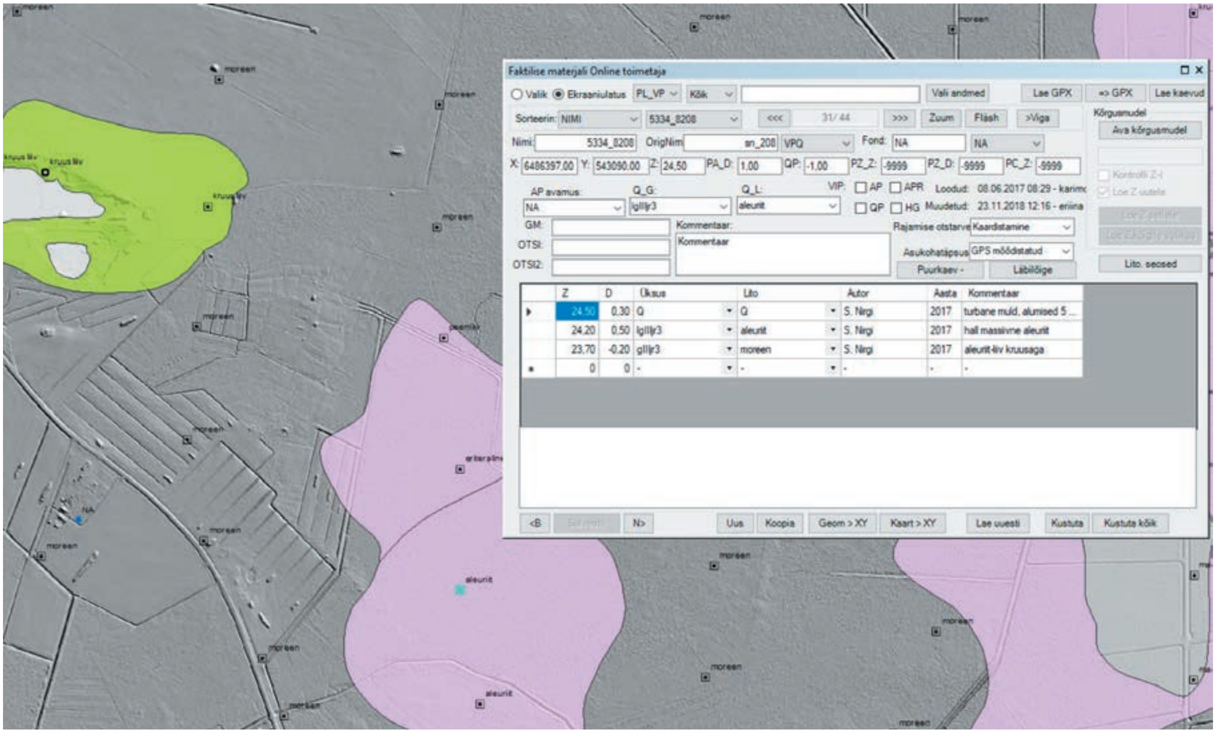
„The truth and justice“ of a geologist – Devonian marl cropping out at the side of a ditch.

structures along the planned route of Rail Baltic and and its vicinity.

Numerous investigations for mineral exploration, engineering geology and hydrogeology have been made through the years. A good basis for elucidating the geological structure of the region is the comprehensive set of maps at the scale of 1:200 000 and accompanying explanatory notes of the sheet O-35-XIII Pärnu, which was accomplished in 1969. After controlling, updating and unifying, the data on drill holes from various endeavours during earlier years were added in the geological database.



Observation points on the map sheets 5334 Pärnu-Jaagupi ja 5332 Pärnu.



A map of Quaternary cover under construction.

The areas that have so far remained unmapped at the scale of 1:50 000 were covered with a network of 4190 observation points, where data were collected. For a better overview of the thickness and structure of Quaternary sediment and bedrock material layers, 54 drill holes with different depths were made. Map applications of the Estonian Land Board, such as relief shading, orthophotos, a soil map and a mineral deposit application are used as supplementary tools.

Data from approximately 5000 study points were collected and entered into a database. The plan in 2019 is to compile a set of geological-hydrogeological maps by using this database, and supplementary information from a borehole database. The set consists of four base maps: 1) bedrock geology, 2) Quaternary geology, 3) hydrogeology (a model) and 4) groundwater. Additionally, there will be maps on bedrock relief and on the thickness of Quaternary deposits, and other auxiliary maps. A collective explanation to the maps will be compiled for describing the geological structure, prospects of natural resources and the conditions of their use regarding the map sheets 5334 Pärnu-Jaagupi, 5332 Pärnu, 5314 Häädemeeste and 5312 Ikla.

Geological maps provide somewhat generalized information on the geological structure of a certain region. Databases supply the user with information on specific data points.

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Borehole drilling for geological mapping

Extensive drilling operations for geological mapping took place in the Pärnu County along the becoming route of the Rail Baltica track. Altogether, 62 drill holes with the total length of 500 m were bored in an area covering four map sheets (at the scale of 1:50 000).

One of the pillars of Estonian geological research is bored drill cores that are described and sampled for gaining reliable information on the properties of sediments and rocks. The network of drill holes in north Estonia has been shaped up during more than 150 years, and is tight enough for outlining the geological structure of this region. In the southern parts of Estonia, however, there are still too few drill holes with sufficient depth or preserved data about them for making essential conclusions.

Altogether 62 boreholes with the total length of 500 m were drilled with a snail auger in the Pärnu County. The material remaining in the twist of the auger characterises the geological cross-section, and is described and sampled. The borehole is liquidated after drilling operations and its surroundings are tidied. Data are collected in this manner on the uppermost subterranean section (down to the depth of 20 m) of Quaternary sediments. If possible, the boundary between the Quaternary cover and bedrock is defined.

It is complicated to define the boundary between the Quaternary cover and bedrock in the area of Devonian sandstones and clays in south Estonia. Firstly, the parent material of the loose sedimentary cover might be the same Devonian clay or sandstone. Secondly, as one of the surprises of these investigations, the Devonian rock older than 380 million years is often so weathered that it exists widely in the form of loose clay and sand. Widespread existence of a plain of such atypically soft Devonian clay and sand under the less than one-metre-thick Quaternary cover was also somewhat unexpected, as the Treimani buried ancient valley, the deepest one in Estonia, goes apparently through the southern part of the Pärnu County. In comparison with the northern cross-sections where the lower part of the Quaternary cover consists mainly of till formed during the latest Scandinavian glaciation, sand and gravel underlying the till were discovered in the western part of the Pärnu map sheet, even in flat areas lacking particular relief features.

The information collected with drilling operations is used for compiling geological maps of the Pärnu County (at the scale 1:50 000). Decisions on using groundwater and mineral resources, building activities, land use and environmental conditions are made on the basis of these maps (5334 Pärnu-Jaagupi, 5332 Pärnu, 5314 Häädemeeste, 5312 Ikla).

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Profiling the Rukki Channel.

Geological studies of the sea bottom

The interest on marine areas and on the use of their resources have drastically increased. The work agenda consists of compilation of a spatial plan of Estonian marine areas. This comprises many projects related to e.g. offshore wind parks, gas pipelines and communications cables, construction of the FinEst Link (Tallinn–Helsinki tunnel) and the Saaremaa permanent link, mineral resource exploration under the sea floor, planning of pumped storage hydropower plants or designing and maintaining harbour areas and waterways.

One of the objectives of the Geological Survey of Estonia is to compile a comprehensive overview of the Estonian sea floor in regard with geology (the extent and composition of sediments), environmental status and dataset of mineral resources. This action is motivated by the desire to contribute in reaching goals set in the national development plan „Estonian Marine Policy 2012–2020“ by creating knowledge-based prerequisites for using and maintaining the Estonian marine resources.

Two research vessels are in use at the geological survey for the research of coastal seabed. During the first navigation season, applied research was carried out for solving problems faced in marine areas (waterways, harbours) and for planned usage of marine areas (fish farming, a sea cable route). Monitoring for assessing coastal changes and trends of development is regularly performed at 26 monitoring areas. The methodology of this research was upgraded during 2018 with underwater surveying on the coastal slope.

Geologists use modern geophysical equipment and software for marine research. Vertical profiling of sea bottom is carried out with sediment profilers (Boomer, Chirp, Pinger) operating at different frequency bands. A side-scan sonar is used for studying the seabed surface. Sediment cross-sections are studied with a two-tube Gemax corer and interval cutter. A Van-Veen type grab bucket is used for seabed sampling. Diving equipment and sets of two types of underwater cameras are in use for visual inspection of sea floor.

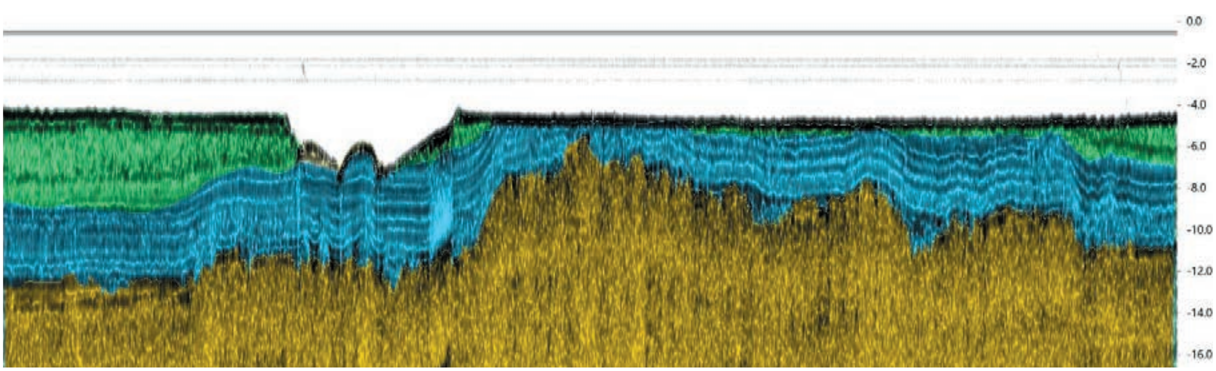
The geological survey compiles seafloor maps and data layers for **the integrated European marine data portal EMODnet** (*European Marine Observations and Data Network*). The target of this project is to assemble geological data and metadata of European marine geological organizations into easily accessible databases. The dataset being collected and maps consist of wide-ranging information on the sea bottom: the substrate and the amount of its sedimentation, seabed geology (at the scale of 1:250 000 and larger), geological events and the likelihood of their occurrence, distribution of mineral resources. The types of coastal areas are presented together with the data on coastal processes (e.g. rates of erosion and accumulation). The dataset is continuously published in the EMODnet Geology Portal: http://www.emodnet-geology.eu/.

Geophysical investigation of the Rukki Channel was ordered by the Maritime Administration of Estonia on the basis of the need for deepening the channel. Sediment profilers operating at different frequency

Sediment profiler Chirp on board of the research vessel „Mare“.

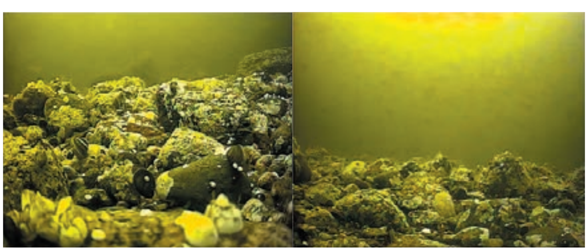
Profiling of seabed sediments at the research vessel.

An interpreted sedimentary cross-section across the Rukki Channel



Measurements of retreating coastal terrace at Kakumäe.

Contaminated sediments in the sedimentary cross-section of the Hundipea Harbour.



bands and a side-scan sonar were used for geophysical studies. Samples for interpreting the geophysical data were taken with a rotary corer and a grab bucket.

The studies revealed that mud, clay, varved clay, till and fluvioglacial sediments are found at the sea bottom in the Rukki Channel region. In the central area of the channel, where till and fluvioglacial sediments are present, currents generated by ship propellers carry coarse debris away from the till. This material accumulates along a wall in the middle of the channel. Finer material (silt and sand) is transported away from the channel by waves and currents. Water flow evoked by ship propellers erodes the sea bottom in the eastern and western parts of the channel where mud, clay and varved clay are present. Also this fine material is carried away from the channel by waves and currents.

An investigation along the route of the submarine communications cable of the Gulf of Finland was made along a 51 km long stretch from the Kakumäe Peninsula to the boundary of the Estonian exclusive economic zone. Two sediment profilers with different frequency bands and a multi beam echo sounder were used in this study.

An investigation of the seabed sediments of the Hundipea Harbour was carried out in the context of deepening the harbour. Concentration of heavy metals and total petroleum hydrocarbons were determined in sediment samples taken with a hand drill sampler. The study revealed that in the northern part of the harbour sediments are contaminated down to the lowermost soft layer. The concentration of heavy metals and total petroleum hydrocarbons mostly exceeds the target value and the residential area threshold value in this layer.

An investigation of seabed sediments was done in the Saaremaa region for establishing the **planned Kesknõmme fish farm**.

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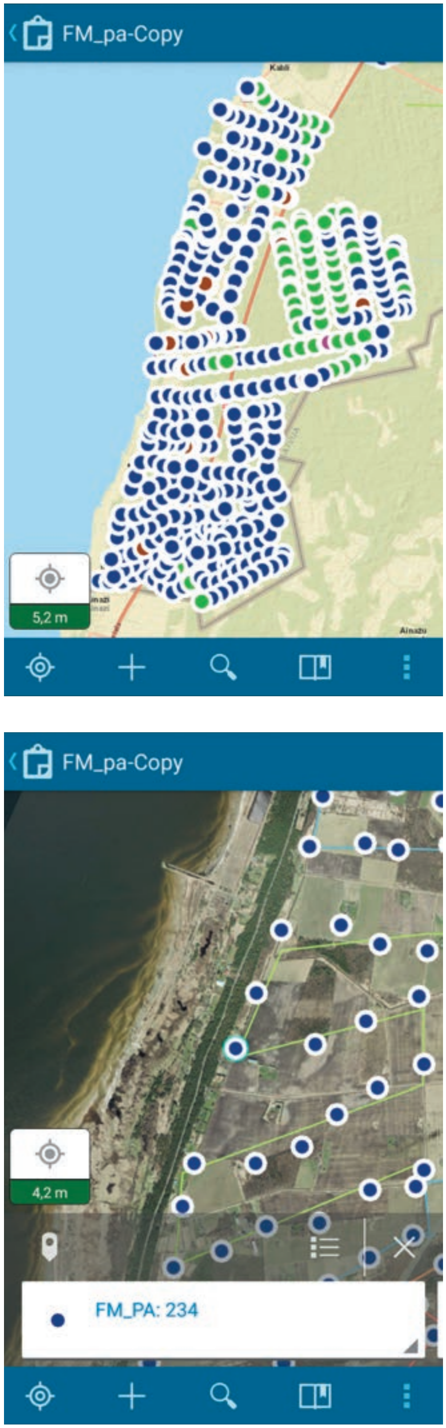
Smart devices and a mapping application being tested in the field.

Geologist's smart field notebook

As modern information technology helps people everywhere to work more efficiently, it is only natural that also field geologists start taking advantage of smart solutions.

Satellites and mobile stations have been used for years to determine geographic locations, and for better precision, together with a reference station. Reaching centimetre-level precision still requires expensive equipment. However, an accuracy of a few metres is already achieved with common smartphones and tablets, which besides positioning can also take photos and record video or audio material. Until these days geologists have written down geological mapping observations into field notebooks, marking also coordinates from a GNSS receiver and references to pictures taken with a camera. Later on, a geologist had to manually enter all collected information into a database. This is not the case with modern devices – smartphones can store all your observations together with pictures and geographical data, and enter them correctly into a database. There are very few advantages in using a classical field notebook.

We learned of the use of smart devices in geological mapping for the first time from our partners at the Geological Survey of Finland. The possibility of using a regular smartphone in the field, rather than a notebook, sounded appealing to our specialists. Hence



the work towards our own geological mapping application was started.

Our primary geoinformatics software partner, AlphaGIS introduced us the highly customizable fieldwork application Collector for ArcGIS, which is compatible with the ArcGIS software that is in daily use at the survey. The Department of Hydrogeology and Environmental Geology led the first trial run of using smart devices at fieldwork, in cooperation with geologists from other departments and trainees from universities. Various types of smartphones and tablets were tested in the field near the Häädemeeste municipality and Ikla village during a week-long period. Despite a few setbacks, the overall feedback was positive and our geoinformation specialists continue to work towards even more satisfying experience next summer. An application tailor-made for our needs is expected to improve the quality of observational data and make geological mapping easier for inexperienced geologists or trainees. Smartphones are also used for collecting observational data in radon monitoring and hydrogeological fieldwork. It is a major improvement, when all photos have been geographically referenced to points of interest and all data are available in the database for further processing already by returning to the office from field.

Standardization of geological data is one of the most important challenges for us. Introduction of such information technology solutions promotes the fulfilment of this objective. Upgrading our fieldwork to a higher level with smartphones and tablets was acknowledged at the Geological Survey of Estonia with the “Deed of the Year 2018” award.

◀ **Overview of geological mapping observation points in a tablet.**

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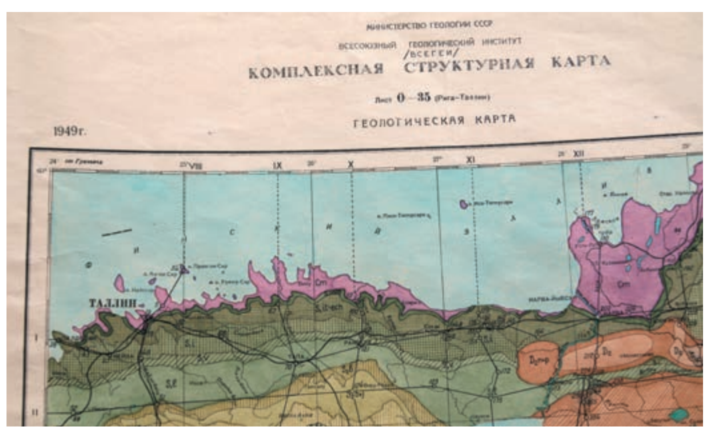
Depository of Geological Manuscript Reports

The task of the manuscript depository is to collect and preserve material on geological investigations (such as manuscripts, electronic reports or fieldwork data) and provide adequate circumstances to researchers for using the stored material. Important data available in the archival documents reduce the extent of planned exploration, leading to a cutdown in expences of new investigations.

According to the assessment of the Estonian National Archives in 2018, documents of archival value are reports of geological investigations, balances of mineral resources until 2006, registry cards of the list of mineral deposits and mining areas of old surface mines.

An agreement between the Geological Survey of Estonia and the Estonian Land Board launched mutual exchange of ar-

The Depository of Geological Manuscript Reports of the Geological Survey of Estonia files pure and applied geological science reports since 1957 and other material related to earlier geological investigations. They are accessible for institutions, companies, organizations and private citizens dealing with studies on mineral resources.



15
INTERESTING FACTS

In total, 9015 open and 144 limited access manuscript reports are filed.

More than 13000 volumes and more than 1200 copies on CD/DVD discs are deposited.

The electronic database "FOND" contains data on geological investigations from the year 1923 on.

In total, 85 new reports were received during one year, mainly being geological investigation reports.

During one year, 344 information requests were made and the depository was visited by 256 persons (97 from the geological survey, 159 from other institutions).

Most frequent visitors were experts from companies dealing with mineral resource exploration. Frequent requests came from private enterprises, state institutions and municipalities.

At times, depository services are used by building and real estate companies, architects and evironmentalists.

Most frequent requests and visits from universities came from the Tallinn University of Technology, and to some extent also from the Estonian Academy of Arts Faculty of Architecture and from the University of Tartu.

Most popular request objects are mineral resources and mine claims. Copies of water borehole records are being asked, also for drilled wells with no official record. Groundwater level and vulnerability in different regions are of interest. Descriptions of drill holes are being ordered.

More than 50% of reports deposited at the depository are not yet available in digital form. The most extensive orders have been scanning of research material on hydrogeology and oil shale.

Request in electronic form are preferred. Visitors of the reading room use also catalogue cards and study archives material in manuscript form.

Balances of mineral resources are deposited from the year 1945.

Collections of drilled well record cards exist for the period 1945–2009.

Archival documents include also e.g. register cards of mineral deposits, files of mine claims, catalogue cards, copies of drilled well plans, inventory books, and geological maps.

One specialist is employed at the depository.

DEPOSITORY OF GEOLOGICAL MANUSCRIPT REPORT SERVICES

Service for the users of geological reports, balances of mineral resources, collections of drilled well record cards and geological archives documents.

Supplementing the electronic database "FOND".

Consultation with users of databases and geological information.

Registration of geological reports.

Organizing and archiving geological information.

Copying documents by order.

Compilation of statistical overviews and forwarding them in the Estonian Archives Register.

chive material. The Depository of Geological Manuscript Reports hands over about 1500 engineering geological reports to the Land Board and receives geological reports, respectively. In 2018, the Land Board gave more than 85 geological investigation reports to the Geological Survey of Estonia for permanent preservation.

The manuscript depository is located at the address Kadaka tee 82, Tallinn. The depository comprises the ground floor storeroom, a reading room for client service, staff working space and a storeroom of archive material. We are open for visitors during working days, excluding the summer holiday season. The electronic database FOND is available (in Estonian) via the web page of the Geological Survey of Estonia: https://www.egt.ee/et/fond-search

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The distribution, mining and use of construction minerals in the Harju County

Construction activities have been livening up in Estonia during the latest three years. For instance, the volume of building construction increased about 21%. Accordingly, the demand on local construction minerals has grown considerably. The amount of construction minerals mined in the Harju County forms 37% of the total mined volume (approximately 3.6 million m^3 in 2017). This fact is the motivation for a special investigation on the distribution, mining, use and security of supply of construction minerals in the Harju County, carried out by the Department of Geological Resources on the order of the Ministry of Economic Affairs and Communications.

The study aimed at providing an overview of the resources of construction minerals in the Harju County, and of their use. The current situation was assessed on the basis of security of supply. Possibilities for securing the supply of construction minerals are described more in detail until 2030, and in more general perspective by 2050. The influence of legislation and environmental protection for managing the use of construction minerals was reviewed and suggestions for applying alternative options are provided.

Considering state interest, the task was to highlight such regions where the properties of natural resources indicate that it is justified to anticipate mining of those construction minerals that fulfil the criteria for raw material in construction, including road construction. In addition, there was the

The reserve of construction minerals (thousand m³) in the Harju County in the record of deposits by 31.12.2017

Construction mineral	Number of deposits	Economic proved reserve	Economic probable reserve	Potentially economic reserve	Mined volume in 2017
Limestone	16	104 355.0	123 747.3	206 017.0	1097.5
Building stone of crystalline basement	1	1 245 062.0	1 723 932.0	–	–
Sand	Total 53	115 922.9	22 684.9	79 793.2	2232.2
Gravel		9078.5	4 065.0	447.0	249.9
Clay	4	1320.0	6 596.9	9698.0	–

need to assess the possibility of applying national regulations for solving problems related to increased consumption of mineral resources. This includes e.g. supplying the construction of state-owned infrastructure with a required amount and quality of filling material, taking into account economically reasonable transport distance.

The initial material of the study was the geological mapping data of the Geological Survey of Estonia, geological reports preserved at the Depository of Geological Manuscript Reports and the database of the list of mineral deposits in the Environmental Register (further on, *register of mineral deposits*) together with balances of mineral resources.

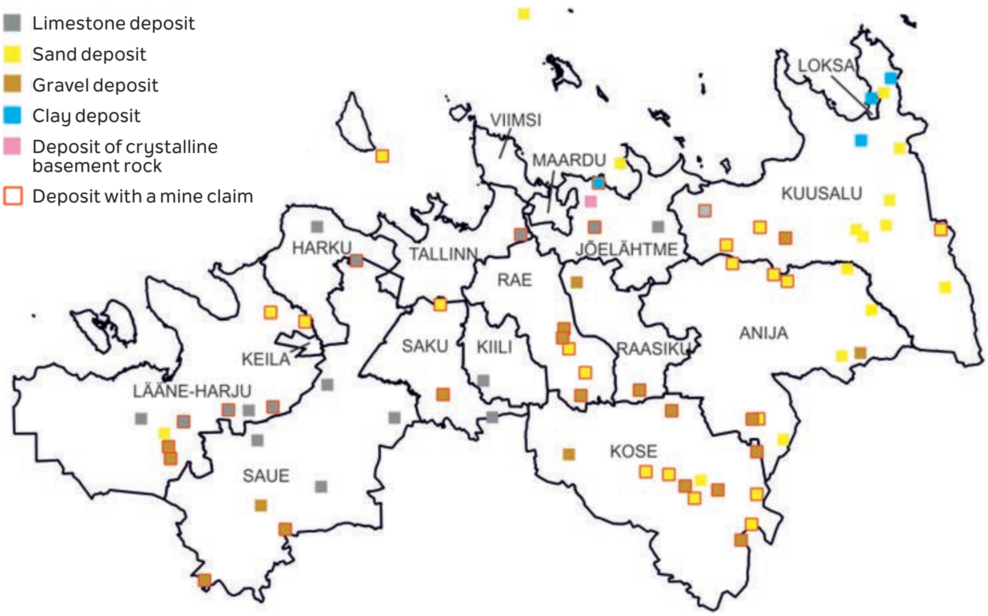
Construction mineral deposits in the Harju County listed in the register of mineral deposits are those of limestone, sand, gravel, clay, and one deposit of crystalline basement building stone. The area of these deposits (about 8 711 ha) forms 2% (approximately 4327 km^2) of the total area of the county. These construction minerals are mainly used for road building and maintenance.

During the analysis of the security of supply, several reasons were found why it is not straightforward to draw conclusions on securing the supply on the basis of the economic proved reserve recorded in the register of mineral deposits:

1) counted economic proved reserve in is not mineable because of environmental protection conditions. For instance, there are protected natural features, e.g. the Nabala mineral deposit as a whole, and to some extent the Väo and Kuusalu deposits. The reserve in such deposits is considered economic, although the Environmental Board does not proceed applications for mining permits;

2) there is no overview of sand and gravel reserve belonging to the state, as Quaternary mineral resources are possessed by the landowner, and it is not possible to plan to use privately owned mineral reserves for national infrastructures without the consent of the landowner;

3) possibilities for the use of a mineral resource cannot be assessed through the quality indicators of construction minerals recorded in the register of mineral deposits, as these indicators are not compliant with the requirements set for construction and maintenance work of roads and railways. There is particularly urgent need for re-evaluating the counted reserve of construction sand and gravel.



An overview on the locations of construction mineral deposits within the Harju County.

Suggestions by the experts of the Geological Survey of Estonia for securing the supply of construction minerals are mainly based on the geological structure of the Harju County, as mining is feasible only where resources are found and only in favourable mining technological conditions. For securing the supply of construction minerals of the Harju County, it is essential to prioritize the national interest in proceeding applications for geological exploration and mining. The actual need for construction minerals has to be reckoned, both in the short run and in a more general perspective until 2050. Proposals for further geological exploration in this study highlight the most essential regions for securing the supply of construction minerals in the Harju County.

The study was made with the assistance of the Ministry of the Environment, Teede Tehnokeskus AS, local municipalities of the Harju County, Graniidikeskus OÜ, the Road Administration, the Environmental Board, the Land Board, Eesti Raudtee AS and many experts and entrepreneurs in the field of construction minerals.

Electronic version of the investigation (in Estonian): https://www.egt.ee/et/eesmargid-tegevused/maapoueressursside-otsingud-ja-uuringud/projektid/harju-ehitusmaavarad
Tamm, J., Liivamägi, S., Bauert, H., Hade, S., Kaasik, T., Kattai, V. 2018. Ehitusmaavarade levik, kaevandamine ja kasutamine Harju maakonnas [The distribution, mining and use of construction minerals in the Harju County]. Unpublished report of the Geological Survey of Estonia, Rakvere, 187 pp. [In Estonian].

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Estonian black shale as a potential resource of "battery metals"

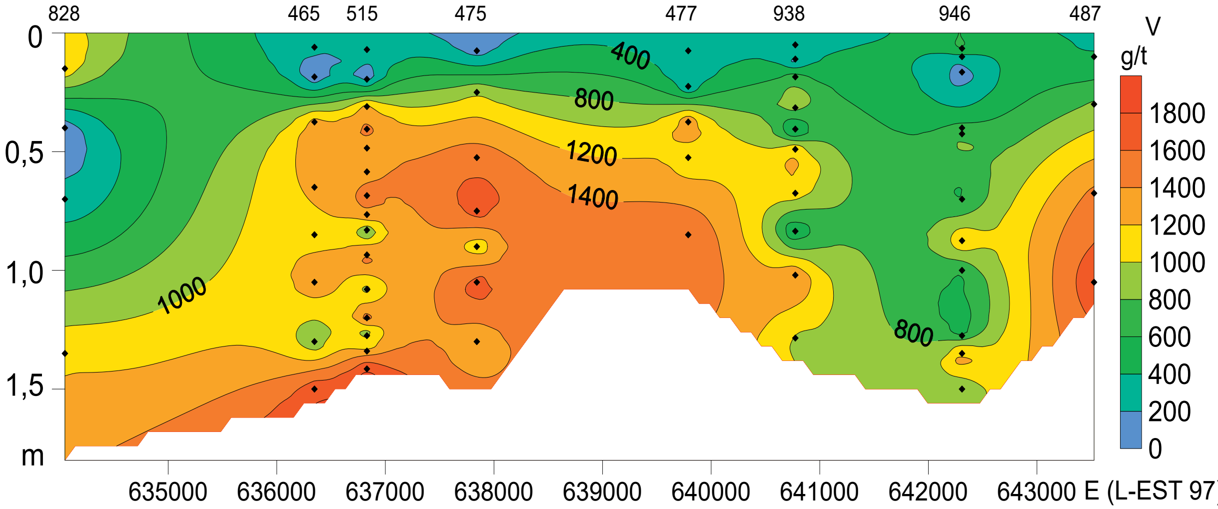
The Geological Survey of Estonia compiled a review of the Estonian black shale (graptolite argillite) deposit. Its emphasis was on the question: what is the metal exploration potential of graptolite argillite found in the Estonian territory, or the potential of the graptolite argillite deposit hosting occurrences of ore-grade mineralisation?

RESEARCH IN SEARCH FOR NEW KNOWLEDGE

It should be mentioned as a brief explanation that metalliferous black shale occurring in Estonia has been locally termed as graptolite argillite due to the existence of specific fossils in it and because of the fine-grained nature of the rock.

The review was initiated from the fact that the world metal market is constantly changing. Therefore, there was a need to put the Estonian black shale in the context of current trends. For many years, black shales have been primarily considered as low-grade uranium ores or as a source of shale gas, with some examples also showing successful exploitation of copper. At present, we are witnessing a growing demand for so-called "battery and electric car" metals. From this perspective, black shales are considered and explored primarily for their vanadium (V) content but also for e.g. cobalt, nickel, or rare earth elements.

Existing research reports and academic articles were reviewed for this study. However, the majority of information exists now only in the form of hard copies produced during the Soviet era. A selection of the



A vertical west-easterly cross-section depicting the distribution of V (grams per tonne) in eastern Estonia; vertical (exaggerated) and horizontal axes in meters.

most significant information was scanned and digitalised using optical character recognition. The work resulted in a database containing geochemical and geological data on some 4000 samples. However, the number of variables is not large, usually the concentrations of V, U, Mo and Pb, as well as calorific value being available. Data have been made available with this effort, allowing the application of modern statistical methods as well as geospatial analyses (see an example in the figure).

The new report indicates that V might comprise more than 80% of the value of the metals found in the black shale. Although historical data have some serious quality problems, it can be deduced that V should be the most valuable component of the Estonian black shale. Such a view obviously implies a high recovery of V from the resource, highlighting a shortcoming of the prospects of black shale exploitation — there is currently no process available for enriching metals from the shale.

Nevertheless, the exploration potential of Estonian black shale can be significant, especially when considering its large territorial coverage (12,210 km^2, partly exposed) and the immense "order of magnitude" reserve of about 88 megatons of vanadium pentoxide.

In comparison with recent exploration subjects in the world, Estonian black shale might still remain as a low-grade ore. Highest average concentrations of vanadium pentoxide per drill core exceed 0.2%, while vanadium pentoxide concentrations of nearly 5% have been reported at some sites elsewhere in the world. Successful exploitation would require development of a technology capable of recovering a high amount of shale constituents.

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Metallogenesis of crystalline basement rocks

Crystalline basement of Estonia is located in the north-western part of the Russian Platform at the southern slope of the Fennoscandian shield. A. Öpik suggested already in 1935 that Estonian crystalline rocks could be a continuation of geological structures in central Sweden and Finland. A. Luha came to the same conclusion in 1946, and the fact was confirmed by later datings. Thus, it is possible that mineralization of Fennoscandian crystalline rocks could occur also in Estonia.

RESEARCH IN SEARCH FOR NEW KNOWLEDGE

Mapping of crystalline basement was initiated in 1960s, when the Soviet Union started searching for ore deposits that could have economic value. During the period 1969–1990 more than 300 deep drill holes intersecting the crystalline basement were drilled in northern Estonia with a density of approximately one hole per 60–100 km^2. Up to 23,000 samples were analysed, resulting in the discovery of over 30 polymetallic occurrences besides the already known Jõhvi magnetite quartzite deposit. Anomalous concentrations of elements such as Cu, Pb, Zn, Au, Ag and Ni were found.

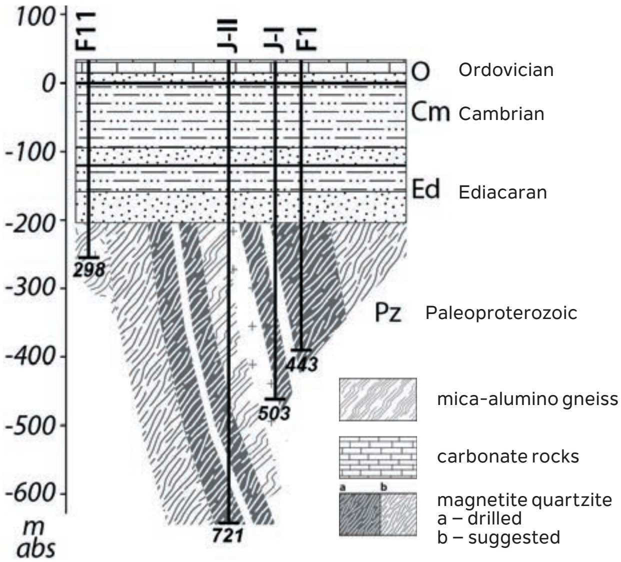
The Estonian basement is divided into zones based on gravitational and magnetometric anomalies, mineral assemblages and metamorphic conditions. The Tallinn and Alutaguse zones stand out from a rather heterogeneous basement by their mineralization occurrences of pyrite- and pyrrhotite-bearing graphite gneisses, carbonate rocks, quartzites and metavolcanites. Several types of intrusive rocks are common, such as tholeiites, shoshonites, komatiites and lamproites reportedly rich in Ti, Fe, P, K and Mg. These rocks could possibly originate from the mantle, suggesting the existence of deep faults and therefore, possible higher concentration of rare earth elements.

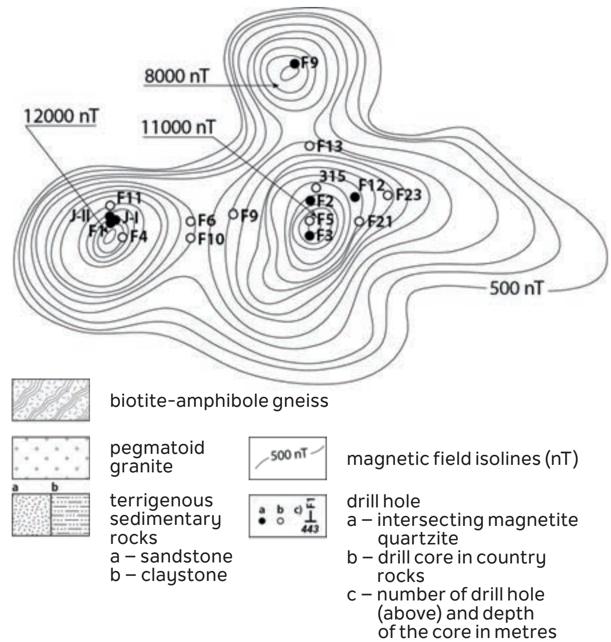
A major portion of crystalline basement consists of metamorphic rocks that are generally cut by microcline granite veins that may have intruded into the country rock during a tectonically active period 1850–1750 million years ago. Relatively high concentrations of Th and U have been analysed in these granites (Petersell *et al.* 1991).

Current knowledge indicates that the most potential ore occurrences are related to metal-bearing graphite gneisses, Mn-rich iron quartzites, Ti-Fe-rich or Fe-P-rich alkaline intrusive rocks, and high P-REE concentration shoshonites in an anorthosite rapakivi formation. Most prospective areas are located in north-eastern Estonia, where enrichment of elements like Zn, Cu, Pb, As, Co, Ni, Ag and Au have been noted for instance in Sonda and Uljaste sulphide-bearing graphite gneisses.

Mn-rich iron quartzites are likewise enriched with sulphide minerals. Several different sulphide minerals, such as pyrite, pyrrhotite, chalcopyrite and sphalerite can be found together with magnetite. Most prospective occurrences are located near Jõhvi and Sakusaare.

After a nearly 30 years long hiatus in research, the Geological Survey of Estonia





Schematic geological cross-section of the sedimentary and crystalline rocks of the Jõhvi magnetic anomaly after Petersell *et al.* (1985).

has now taken the responsibility for continuing the studies of the crystalline basement. The demand for resources has changed in the meantime, due to advances in technology. In the old-time laboratories it was not possible to determine such elements that are today demanded in an increasing amount. The understanding of geology has also changed. Instead of the Soviet-time isolation, restricted to a certain school of thought, we now can compare our geological findings with well-studied regions of the world.

The first step of crystalline basement studies involves collecting, digitizing and interpreting all the important results of previous research. Also, drill cores of most potential ore sections are already being studied and analysed with state-of-the-art methods.

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Related work

A review of the Jöhvi Magnetite deposit, Estonia. 2016. Prepared for Estonian Ministry of Environment. SRK Consulting (Sweden) AB, SE687, 12 pp.

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Petersell, V., Talpas, A., Põldvere, A. 1985. Aruanne rauamaakide formatsioonide uurimisest Eesti eel-Kambriumis [Report on investigation of iron ore formations in Precambrian, Estonia]. Unpublished report of Geological Survey of Estonia, 129 pp. [In Russian].

Petersell, V., Kivisilla, J., Pukkonen, E., Põldvere, A., Täht, K. 1991. Maagiilmingute ja mineralisatsioonipunktide hindamine Eesti aluspõhjas ja aluskorras [Assessment of ore manifestations and locations of mineralization in the basement of Estonia]. Unpublished report of Geological Survey of Estonia, 284 pp. [In Russian].

Öpik, A., 1935. Eine mögliche geologische Deutung der magnetischen Anomalien Estlands. Comptes rendus de la Commission geodesique Baltique reunie a Tallinn et Tartu du 20 au 30 aout 1935, 287–288.

Investigating the possibilities for valorising phosphorite

The Geological Survey of Estonia has started together with universities to develop a technology for valorising Estonian phosphorite. Mining of a mineral resource and selection of a technology for enriching raw material depends on the results of feasibility studies and environmental impact assessment.

RESEARCH IN SEARCH FOR NEW KNOWLEDGE

This study has been financed by the Estonian Research Council
PUTJD705

Phosphorite was mined in Estonia during 1920–1991. Initially, dry separation was used for processing the raw material, later on froth flotation was taken into use. Mining of phosphorite was ceased after the Soviet Union collapsed. A hiatus started in systematic studies of phosphorus resources and valorising technologies, lasting for more than 25 years. The Department of Geological Resources at the Geological Survey of Estonia has set the goal to undertake comprehensive investigation, which covers both the utilisation of raw material and the phosphorus circulation.

Phosphorus is an indispensable natural element, which is globally essential for growing plant products. Already by now, agriculture suffers from the lack of phosphorus. More and more methods are developed for making it possible to keep phosphorus compounds in circulation, but they are not efficient enough. On the other hand, resources of phosphate rocks are dwindling in the world – for every ten years, the average concentration of phosphorus in mined raw material decreases approximately one percent and at the same time, the concentration of heavy metals and radioactive substances increases.

Estonian phosphorite is a sandstone, which contains an abundant amount of obolus (brachiopod) shell fragments. These shells consist mainly of fluor-carbonate apatite or francolite, the P_2O_5 concentration of which is up to 35%. Quartz, dolomite, calcite, pyrite and clay are found as mineral impurities in phosphorite. Estonian phosphate stands out with its low concentration of heavy metals. In comparison with phosphate mineral resources in the world, it has an exceptionally low content of cadmium (1–5 ppm), as well as of uranium. Estonian phosphorite is particularly valuable in regard with the limit values set for phosphate fertilisers in the European Union. However, occasional high concentration of MgO and iron compounds makes its valorising more complicated.

Which technologies make it possible to produce quality phosphates, providing value for most of the raw material constituents, irrespective of the complexity of their mineralogical composition? Are the currently known technologies for valorising phosphorus raw material useful for processing Estonian phosphate, as well?

In most cases, more than one method is used together in enriching phosphate raw material. Three technologies are most widespread: a) wet separation with a sulfuric acid solution or froth floatation or phosphorite flotation; b) hydrochloric acid processing or the Ecophos method; c) heat treatment.

Wet separation is the most known technology for extracting phosphate, during which phosphoric acid is produced from phosphorus-rich raw material. Flotation as a separation process takes place in three phases. Selective flotation of dolomite from francolite is possible in mildly acidic conditions. A process of several steps is used in enriching silica-rich phosphate raw materials.

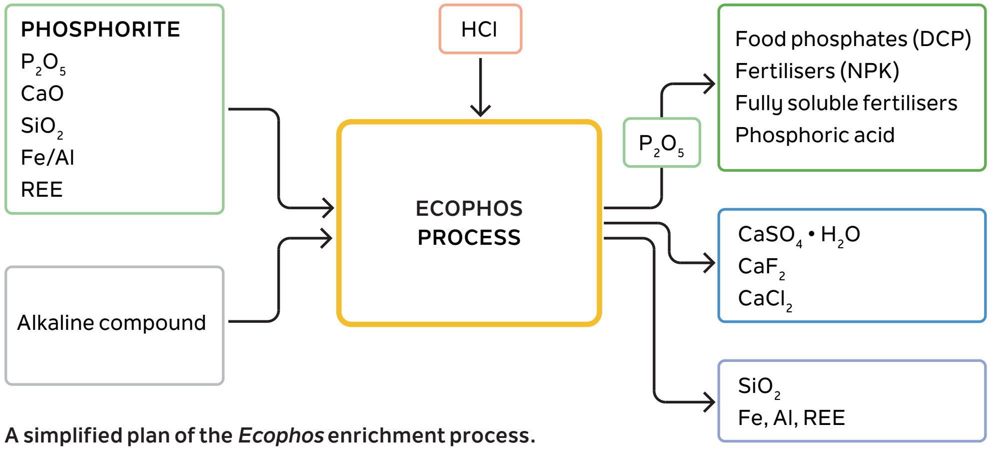
Such a process where coarse and superfine sand are initially separated from the raw material, followed by dolomite and quartz sand together with pyrite, is suitable for enriching Estonian phosphorite. The P_2O_5 rich concentrate is decomposed with sulfuric acid.

The wet separation process has been applied for tens of years, with the same principles. However, the method is very sensitive in regard with impurities, as accessory components existing in the raw material are passed on in the produced phosphoric acid. Moreover, in average five tons of phosphogypsum for one ton of P_2O_5 is formed in wet separation. However, the possibilities for using phosphogypsum are limited, as it contains environmentally harmful elements.

Froth flotation of phosphorite (GTK Mintec, 2018).

Hydrochloric acid processing or the Ecophos method is a multistage technology developed in Belgium. The method makes it possible to produce high-quality phosphates, and in tandem valorise most of the constituents of phosphate raw material. The product of the process is a clean and stable phosphate salt, dicalcium phosphate ($CaHPO_4$; DCP in short), which contains 41% of P_2O_5. It is possible to produce dicalcium phosphate more inexpensively than phosphoric acid and transport it packaged or as pulp. Gypsum ($CaSO_4 \cdot 2H_2O$) and calcium chloride ($CaCl_2$) are useful by-products of this technology. Regeneration of hydrochloric acid (HCl) makes the technology more economic. Taking into account that the Ecophos method makes it possible to valorise also lower quality phosphate raw material and keep phosphorus better in circulation, this technology is applicable also for processing Estonian phosphorite.

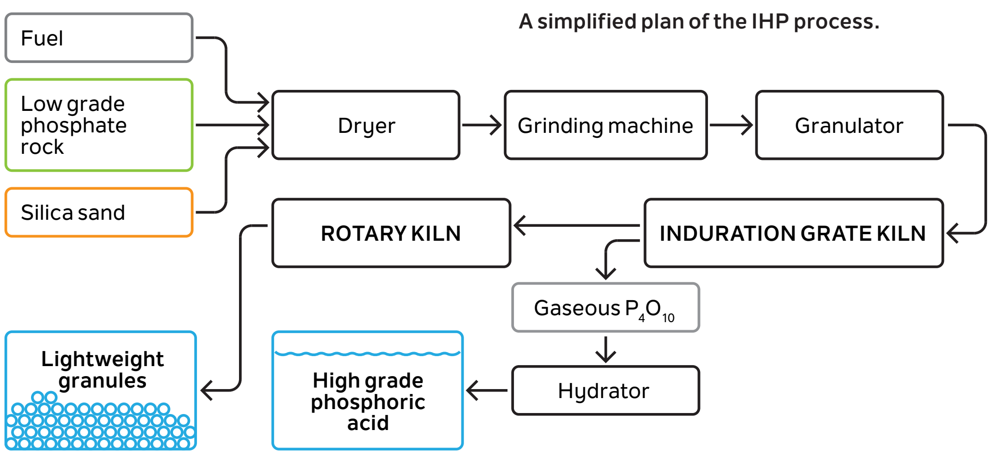
Heat treatment includes three principal phases of manufacturing phosphate products: preparation



A simplified plan of the *Ecophos* enrichment process.

of material, heat treating and hydration reaction. Considerable technological development has taken place in heat treatment during recent years. The process developed for producing phosphoric acid with a higher degree of purity is called as Improved Hard Process (IHP), during which no phosphogypsum is formed. This process suits for valorising phosphate raw material of lower quality. Silicon used in the IHP process makes it possible to lower the costs of the treatment, while it is rather undesirable in wet separation. Advantages of the IHP process are smaller energy consumption and production of phosphoric acid (H_3PO_4) with a high degree of purity. Calcium silicate granules that form during heating can be used for producing construction materials. Taking into account the composition of the Estonian phosphate raw material, IHP heat treatment is suitable for valorising our phosphorite.

A simplified plan of the IHP process.



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The Arbavere Georesource Research Centre

In February 2018, the Geological Survey of Estonia started establishing a modern research centre on geological resources in the Arbavere village of the Kadrina municipality, Lääne-Viru County. All the state-owned drill cores, with the total length of 120,000 m, placed in 25,500 storage boxes will be assembled in the central complex. The deposited drill cores will be used for doing applied research and for training the next generations of experts.

Renovation of the old Arbavere field station to a Geological Survey of Estonia research centre on geological resources was initiated with the decree "General principles of Earth's crust policy until 2050", approved by the parliament of Estonia on 6 June 2017. Its second part, „Principles for developing the field and priority development directions" states in paragraph 4.1.2: to ensure the purposeful use of existing and additional geological material (including drill cores), the state will guarantee a long-term and proper storage of geological materials, free access to them for research, and the possibility of storing the additional geological rock materials. As a result of forthcoming construction and rebuilding, modern circumstances will be formed in the new research centre for studying state-owned drill cores.

The longest drill core of Estonia is from the 815.2 m deep Soovälja borehole K–1, which was drilled in the middle of the Kärdla meteorite crater on the Hiiumaa island in 1990. The next longest drill core is from the 787.4 m deep Ruhnu borehole 500, drilled in 1972 for exploration of petroleum and gas manifestations in the middle part of the Ruhnu island.

WHY ARE THE DRILL CORES PRESERVED?

A drill core is an important source of geological information, as data on subterranean structures are collected by describing and sampling the cores. These data are used for compiling geological maps, in studying geological resources, including groundwater and assessing environmental geological conditions and in compiling scientific work.

Because drilling is expensive and technically complicated, it is purposeful to store quality drill cores for further research. The use of deposited drill cores for fulfilling new geological tasks decreases the expenses of planned geological work (geological mapping, hydrogeology, exploration of mineral resources) and enhances the trustworthiness of research of the geological structure of the Estonian subsurface.

Databases do not substitute drill cores, as data of earlier studies reflect the level of knowledge at that time, and is related to the goals of a particular investigation. When knowledge and objectives change, supplementary description and/or sampling of cross-sections of drill-cores has to be done.

Drill cores are stored with labels from the time of boring, in special 1-metre-long boxes. A drill core placed in boxes has been marked (information on depth and stratigraphy), documented, sampled and photographed.

The establishment of a research centre of geological resources in Arbavere makes it possible for the Geological Survey of Estonia to:

- organize research of state-owned drill cores for domestic and international purposes;
- create optimal circumstances for safe storage of state-owned drill cores;
- create conditions for ensuring occupational health and safety of study groups while examining stocked rocks and sedimentary sections;
- develop domestic cooperation in applied research with Estonian research institutions and train next generations of experts;
- develop international cooperation for carrying out research on mineral resources and environmental geology, financed by the European Union and European Commission in the framework of international cooperation programmes (including e.g. European Innovation Partnership on Raw Materials, EIT Raw Materials, GeoERA);
- use stored rocks, sediments and equipment of the research centre in organizing seminars, arranging workshops and popularizing geosciences to different target groups.

According to the 2017 data, there are now 4700 drill core storage boxes in three storerooms of the former Arbavere field station and another 1600 stored outdoors, or altogether 33,000 m of drill cores. The buildings at the premises comprise together with the depositories a main building from the 1970s with accommodations and workrooms, an accommodation container, and work- and washrooms at the end of one of the storerooms. Another eight new storages will be added, as well as workrooms and accommodations. While planning the complex, an emphasis has been put in ensuring optimal work management, making it both cost and time effective, and simplifying hosting cooperation partners.

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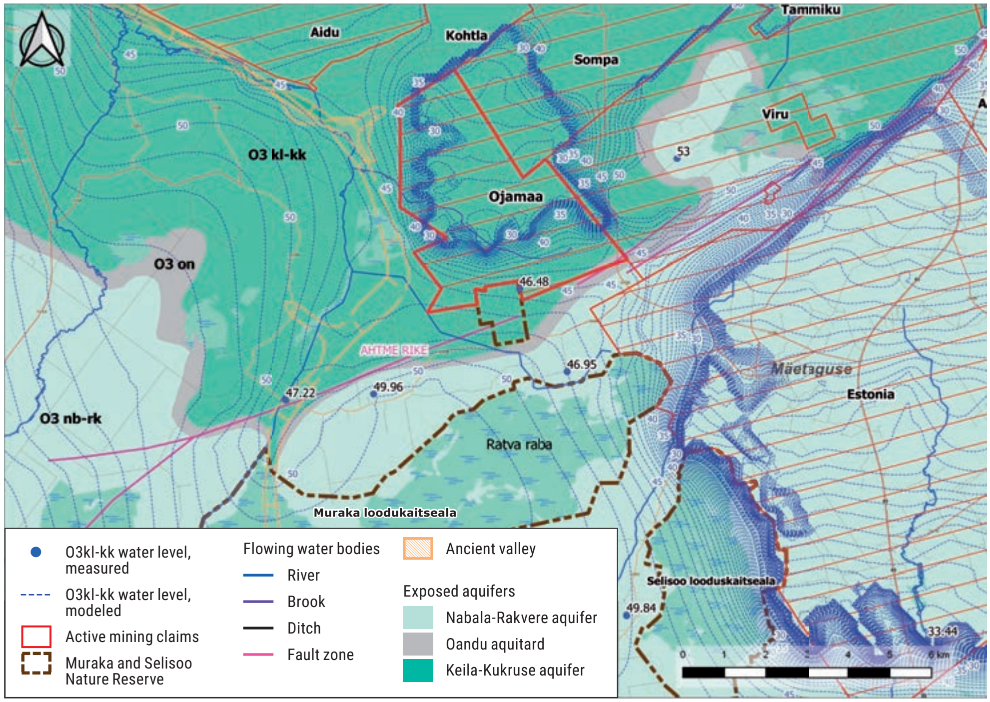
Studying the water regime of the Baltic Oil Shale Basin with the new Virumaa groundwater flow model

The ground- and surface water of the Ida-Viru County oil shale basin is above all endangered by lowering of the groundwater level and the related change in water quality, taking place as a consequence of oil shale mining. During the monitoring, groundwater level was measured and its chemistry was analysed in observation wells adjacent to the Ojamaa mine and at observation points of groundwater and vegetation of the Ratva bog.

Applying a new regional groundwater flow model of the Lääne-Viru and Ida-Viru Counties or the Virumaa model in the analysis and interpretation of monitoring results was an essential innovation in comparison with monitoring during previous years. The Virumaa model has been designed by scientists of the University of Tartu, and it is further developed by the Geological Survey of Estonia. The area covered by the Virumaa model is 160 × 200 km, which is approximately a quarter of the territory of Estonia. The model has been

Monitoring of ground- and surface water was carried out at the Ojamaa oil shale mine of VKG Kaevandused OÜ, a subsidiary of Viru Keemia Grupp (VKG), and in the Ratva bog belonging to the Muraka bog system. The task was to assess the possible influence of the Ojamaa mine on the groundwater regime and terrestrial ecosystems dependent on groundwater.

Befitting the requirements of the European Union Water Framework Directive (2000/60/EÜ) and the National Development Plan for the Use of Oil Shale 2016–2030, human impact (including oil shale mining) on ground- and surface water and on groundwater dependent terrestrial ecosystems has to be assessed more in detail.



Water levels at the Keila-Kukruse aquifer modelled with the Virumaa model adjusted for studying the groundwater regime of the Ojamaa mine.

discretised into cells of 200 × 200 m in size. In the vertical direction, the model considers altogether 20 aquifers and aquitards. The model makes it possible to assess the impact of both currently working and future mines on groundwater flow in eastern Estonia, and is also applicable for studying other groundwater-related issues.

Analysis of the groundwater regime in the region of the Ojamaa mine is the first example of applying the Virumaa model in actual groundwater research. The model was further discretised in the study area to reduce the cell size. It is possible to state on the basis of groundwater level measurements, analysed chemical composition and water flow modelled with the adapted model that oil shale mining has had an influence on the groundwater regime in the study area. The groundwater regime has not been changing only because of activity of one particular mining company, but it has been influenced by several mines operating in the region, also by those that are closed by today.

It is possible to use the results of monitoring and modelling of the collected data for planning more sustainable and environmental-friendly mining of oil shale.

Pärn, J., Tarros, S., Polikarpus, M., Osjamets, M., Raidla, V. 2019. Ojamaa kaevevälja põhjaveeseire ja Muraka soostiku ökosüsteemi seire 2018. aastal [Groundwater monitoring of the Ojamaa mining field and monitoring of the ecosystem in the Muraka bogland in 2018]. Unpublished report of the Geological Survey of Estonia, Rakvere, 50 pp.

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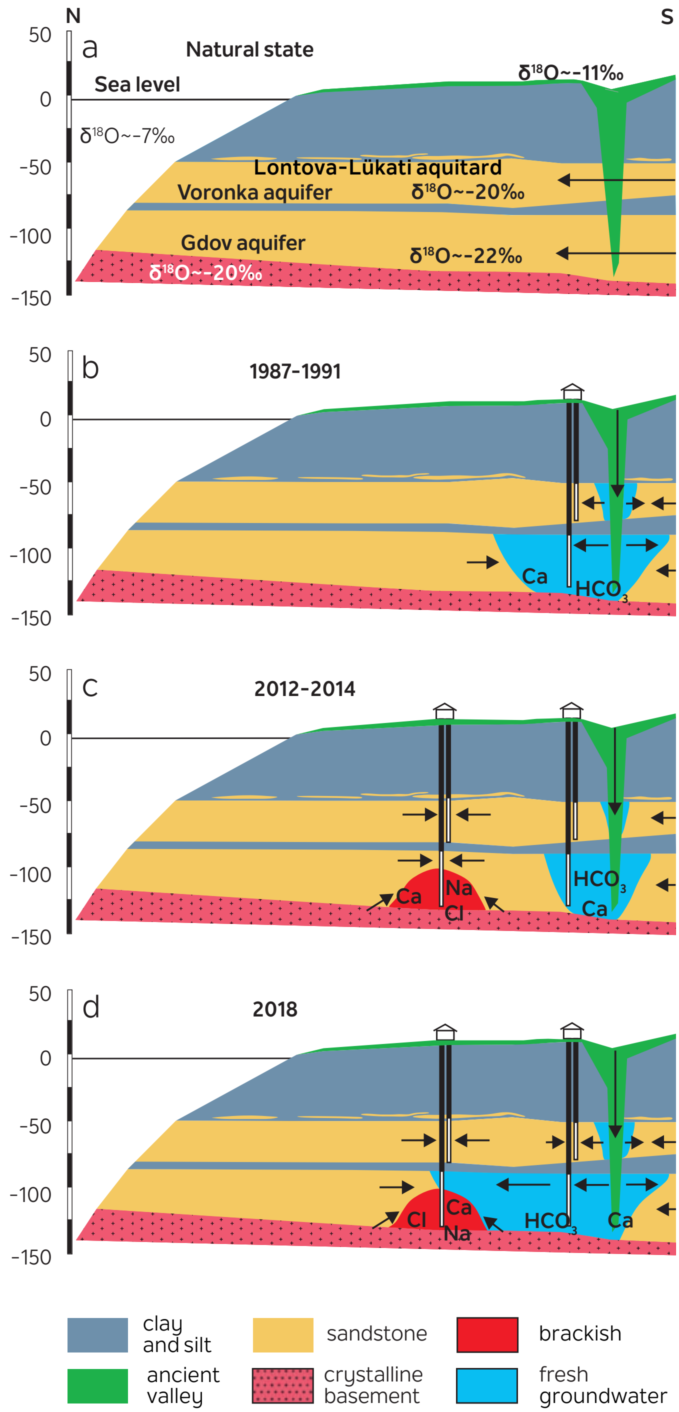
Groundwater problems of the Viimsi Peninsula and their causes

The Cambrian-Vendian aquifer is almost the sole source of drinking water on the Viimsi peninsula. The recent rapid increase in population on the peninsula has raised groundwater consumption. Fall in hydraulic heads has led to an increase in Cl^- in the aquifer. Our main aim is to elucidate whether the increase in Cl^- concentration is related to seawater intrusion or rather to the intrusion of saline water from the underlying crystalline basement.

The salinisation and desalinisation zones in the study area are spatially clearly detectable and uncharacteristic to seawater intrusion. Our results refer to the infiltration of saline groundwater from the underlying crystalline basement as the main source of salinity in the study area. However, the risk of seawater intrusion in the future cannot be ruled out.

We expect that the three-component mixing in the aquifer has occurred in two stages. Groundwater abstraction that started in the 1960s lowered the hydraulic head by several meters, the strongest impact occurring first close to a buried valley, where infiltration of modern water became the main compensation mechanism. In 2012, the new



central groundwater intake started to operate in the central part of the peninsula and the main groundwater abstraction shifted to this area. Here, upwelling of saline groundwater from the underlying crystalline basement became the dominant process causing changes in groundwater quality. The ensuing deterioration of groundwater quality led to re-opening of wells in the southern part of the peninsula, decreasing the compensation from the underlying crystalline basement and supporting the movement of modern groundwater from the buried valley to the central parts of the peninsula. Chemical and isotopic composition of groundwater suggests that at present the front of modern groundwater has almost reached the new groundwater intake and the wells receive groundwater from both the basement and the buried valley.

It has also been observed that changes in salinity are related to changes in the activity of radium isotopes. The higher Ra activities have been attributed to the prolonged contact with rocks of the crystalline basement. However, ^{226}Ra values in modern groundwater in the peninsula are moderately high and $^{226}Ra/^{228}Ra$ increases towards the buried valley which may indicate heterogeneous presence of uranium in surfaces of sedimentary rocks. We hypothesise that O_2-rich meltwater infiltration would have supported U transport into the aquifer and ^{226}Ra may also partly originate from secondary U deposits within the sedimentary complex.

Link to the full version of the article: https://www.mdpi.com/2076-3263/9/1/47

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The project GroundEco "Joint management of groundwater dependet ecosystems in transboundary Gauja-Koiva river basin"

The project "Joint management of groundwater dependent ecosystems in transboundary Gauja-Koiva river basin" (Ground - Eco) is being implemented within the Interreg V-A Estonia-Latvia cross-border cooperation programme 2014–2020 (www.estlat.eu).

This project is launched in cooperation between partners from Estonia and Latvia. It aims at enhancing sustainable management of common groundwater resources and associated terrestrial ecosystems in the transboundary Gauja (Koiva in Estonian) river basin. The plan is that Latvian partners will adapt the existing methodology developed by Estonian partners, for identifying groundwater dependent ecosystems. Later on, it will be tested in cooperation in the pilot areas – Kazu leja in Priekuli district, Latvia and Matsi spring mire complex in the Rõuge municipality, Võru County, Estonia.

The location of Estonian and Latvian pilot study areas and rivers Mustjõgi and Gauja on the digital ground elevation map (Estonian Land Board 2019).

GroundEco project

PARTNERS

Latvian Environment, Geology and Meteorology Centre

Ministry of the Environment of Estonia

Geological Survey of Estonia

Tallinn University Institute of Ecology

University of Latvia

Latvian Nature Conservation Agency

Vidzeme Planning Region

The Estonian pilot study site Matsi spring mire and the groundwater monitoring network on an orthophoto image (Estonian Land Board 2019).

The Gauja-Koiva river basin is administratively divided by the state border between Estonia and Latvia. However, it is characterized by a single life cycle of waters, including groundwater.

The GroundEco project pilot area in Estonia, Matsi, consists of three spring-fed mire polygons in the lower part of the slope in Mustjõgi river valley, a tributary of the Koiva (Gauja) river. In total, the spring mire covers 4.6 hectares, the largest patch being 3.4 ha. Deposits (layers) of tufa and iron (III) oxide were found during the most recent investigation. The substrate conditions in the spring mire are alkaline, with plant species composition indicating carbonate-rich conditions (pH varies from 6.9 to 8). The spring mire is in rather good, near-natural condition. However, it is evidently affected by drainage ditches at its margins and by beaver activity. Most of the spring mire is open and treeless, but areas around ditches are overgrown with forest (predominantly birches with a mixture of spruces). Conditions are typically drier in drained parts, and some ecosystem components (species, mire structures) found in open, wettest parts are absent. Dominating vascular plant species are sedges, but many other species are present.

Estonian partners from the Geological Survey of Estonia and Tallinn University perform now research in the territory of the Matsi spring mire. The study is focused on the surface water network, seasonal water level changes, and on identifying potential loads affecting the terrestrial ecosystem. Boring was carried out at the spring mire groundwater monitoring stations for determining the composition of sediments before installing piezometers. Automatic loggers measured the water level, temperature and electric conductivity. Water level changes are also monitored in local dug wells and deeper bored wells in the neighbouring spring mire area. Georadar investigation will be conducted for a better understanding of peat and calcareous deposits of the spring mire. This method shows the depths of different geological layers underneath the spring mire, including bedrock sediments (mainly sandstone, and also silt) of the Middle-Devonian Gauja stage.

The GroundEco project pilot area in Latvia, Kazu leja (ca 100 hectares in area), is a subglacial valley that adjoins the Gauja river main valley. The slopes of the valley are overgrown with mixed forest, whereas the valley bottom is covered by fen and grassland vegetation. Tufa deposits are found at the north-western end of Kazu leja. Once it had one of the largest tufa reserves in Latvia. Tufa extraction took place during the first half of the 20th century, probably even earlier. Tufa deposits filled a side ravine of Kazu leja as well as formed an outwash cone at the base of the main valley. Most of the tufa has been extracted by today, leaving largely disturbed overgrown landscape of pits, ponds and channels. In particular, an outcrop of solid tufa and a cascading waterfall on top of it are artefacts of mining. Carbonate-rich petrifying springs are discharging both at the bottom and upper part of the southern slope of Kazu leja. However, the frequently visited largest waterfall is heavily trampled, putting a load on the vegetation. In addition, a melioration system of adjacent fields discharges in the same water course, raising concerns about excess nutrient input.

The wetland at the base of the main valley is obviously fed by calcareous springs emerging from the slopes of the Kazu leja, as well as by precipitation. Another water source might be groundwater discharging at the base of the valley, masked by vegetation and peat deposits. The proportional contribution of these water sources both in terms of water quantity and of minerals is not known and

The Latvian pilot study site Kazu leja, marked with a red polygon on an orthophoto image (Latvian Geospatial Information Agency 2019).

From the left to the right: hydrogeologist Siim Tarros with the peat profile of the Matsi spring mire, a tufa deposit at the Kazu leja pilot area and ecologist Agnese Priede from the Latvian Nature Conservation Agency.

will be investigated during the pilot study. Springs with highest hypsometrical level of discharge could also be affected by diffuse agricultural pollution. A detailed investigation of vegetation is necessary for exploring the current condition. The abiotic site conditions and biotic components (vegetation, invertebrates) will be investigated in detail during the summer 2019.

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Studies on radon risk

Radon (Rn) studies at the newly created Geological Survey of Estonia followed two objectives during the year 2018. The first topic is derived from the transposition of the EU Council Directive 2013/59 EURATOM by the Ministry of the Environment. The second topic is environmental and geological research motivated by issues that arose during the process of compiling the Atlas of Radon Risk and Natural Radiation in Estonian Soil in 2017 (Petersell *et al.* 2017). The Radon Risk Atlas summarizes soil and indoor air radon surveys carried out over the last few decades.

Transposition – radon research methodology for municipalities. Years long labour by Estonian radon investigators found further use from August 2018 on, when a regulation by the Ministry of the Environment entered into force, introducing a reference level of 300 Bq/m^3 as the highest permitted activity concentration of Rn.

A forthcoming indoor climate regulation will set special limits for vulnerable categories in the society, mainly affecting childcare facilities, where the reference level for Rn will be set at 200 Bq/m^3. Health authorities have thus shown sense of responsibility for future generations.

The regulation also imposes an obligation on employers to ensure that soil radon does not enter working places, schools, kindergartens, old people's homes or other facilities. The wish of European radon researchers is that local communities will be advised on measures to keep Rn within limits. State authorities, including those in Estonia, intend to give support in this endeavour.

Reference levels for indoor radon concentration in workrooms, the procedure for radon measurements and the obligations of employers at workplaces with an increased radon risk is formulated in the regulations by the Estonian Ministry of the Environment (in Estonian: RT I, 03.08.2018, 4,).

On the basis of previous radon studies accomplished with the publication of the Radon Atlas, the Ministry of the Environment together with the authors of the atlas compiled a radon risk territory classification for municipalities:

I Municipalities with high to very high radon risk

II Municipalities where too little radon research has been done for assessing the risk

III Municipalities where it can be assumed that the potential radon risk is low, on the basis of research and geological conditions

During 2018, the first year of executing national implementation of the radon risk regulation, the Geological Survey of Estonia had to develop a methodology for radon surveys targeting such municipalities where the potential Rn risk is ambiguous.

Rn studies in problem areas. Rn studies with geological motivation focused so far on unanswered issues regarding Rn anomalies. This action was started practically at the doorstep of the headquarters of the Geological Survey of Estonia. A monitoring point is located in the Rakvere town, exactly on the Rakvere esker, one of the largest of its kind in Estonia. This object has been a planned target of geological radiation research already for quite a while. Soil radon levels in Fennoscandian eskers fluctuate seasonally. The question is, whether the Rakvere esker follows a similar pattern.

Siim Nirgi and Siim Tarros setting up a radon monitoring point at the slope of the Rakvere Esker. The ruins of the Rakvere Order Castle, also located on the esker, stand out in the background.

A second Rn monitoring site was set up between the Uku and Loobu fault zones in between the Tapa and Läpi villages. The aim was to observe whether the rock in the fault zones is cracked, which would enable gases from the depths to move easily, or whether they rather are clay-filled blocked scars of the bedrock impeding the radon flow.

A third Rn monitoring location was established in the Põlva-Melliste region. Monitoring there should provide an explanation for the prevalence of high Rn anomalies in a Devonian sandstone area where, however, rocks with a high uranium content have yet not been found in Estonia. In comparison, such rocks are known to occur along the south-eastern border of Estonia.

As yet, it is too early to draw conclusions about the three monitoring locations, because the results of radon measurements during the summer 2018 were extraordinary. That particular summer was exceptionally dry, while the purpose of the monitoring is to investigate the movement of soil radon under normal weather conditions.

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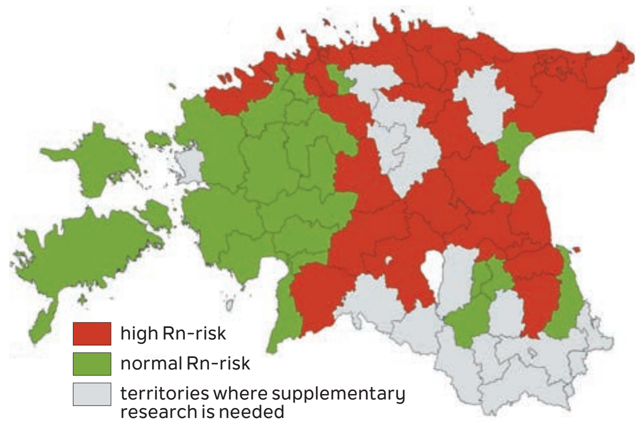
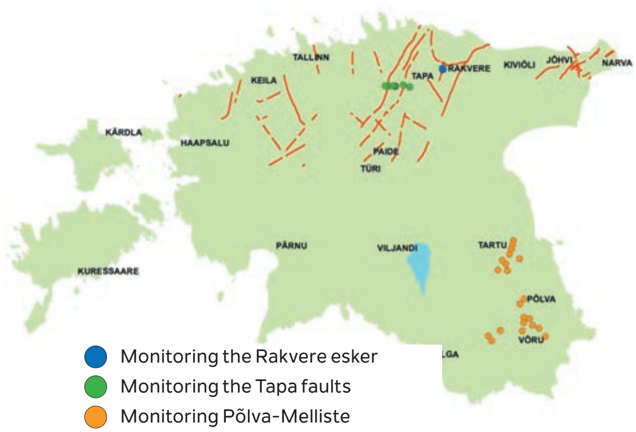


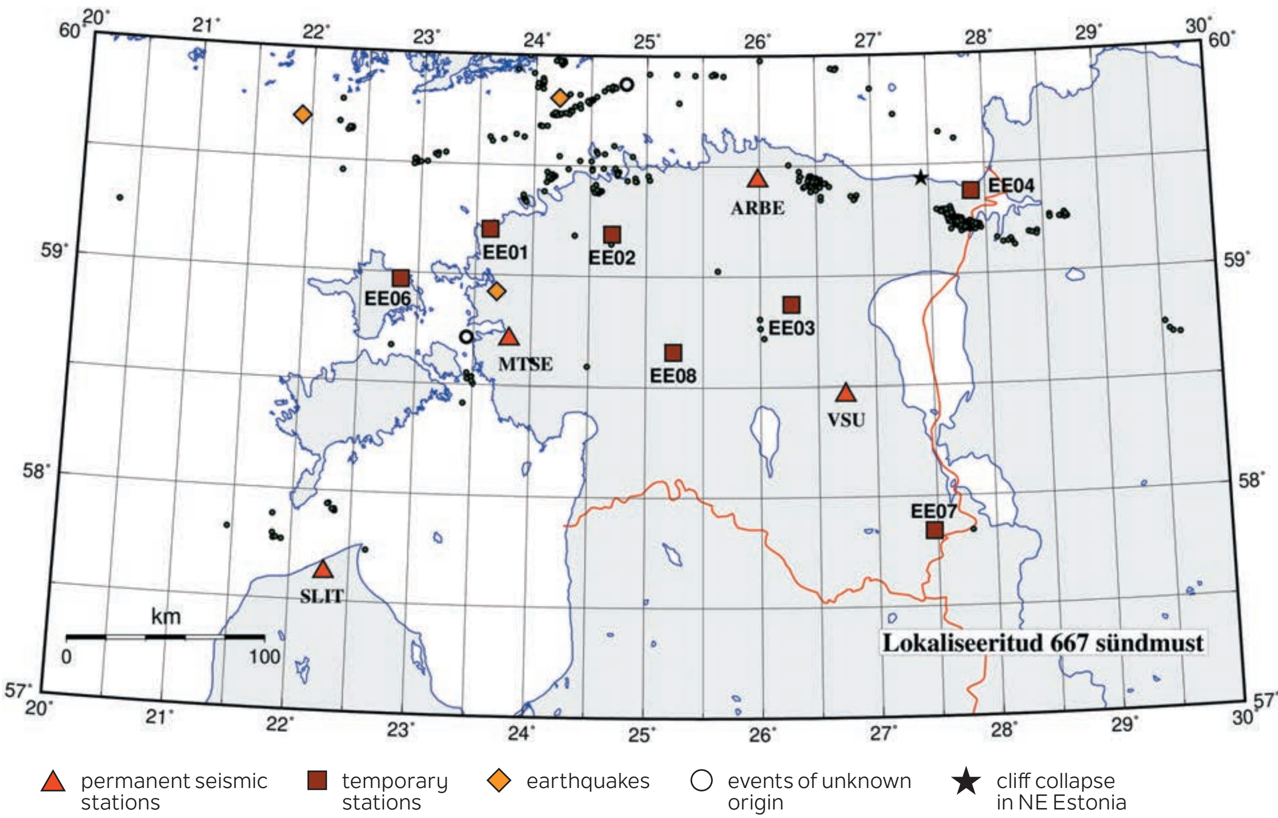
Schematic map of municipalities regarding Rn risk.



Locations of Rn monitoring points. Red lines indicate fault zones.

Related work

Petersell, V., Karimov, M., Täht-Kok, K., Shtokalenko, M., Nirgi, S., Saarik, K., Milvek, H. 2017. Eesti pinnase radooniriski ja looduskiirguse atlas. The Atlas of Radon Risk and Natural Radiation in Estonian Soil. Koch. R. (ed.). Eesti Geoloogiakeskus, Tallinn, 89 pp. [In Estonian and in English].



Seismic events located by the Geological Survey of Estonia in 2018 (dark dots).

Seismic traces of human activities and Earth tremors in 2018

Thanks to seismology, we know the layered inner structure of the Earth down to its core. Thanks to seismology, we are well aware of ground movements, even the tiniest ones that otherwise would pass unnoticed in everyday life.

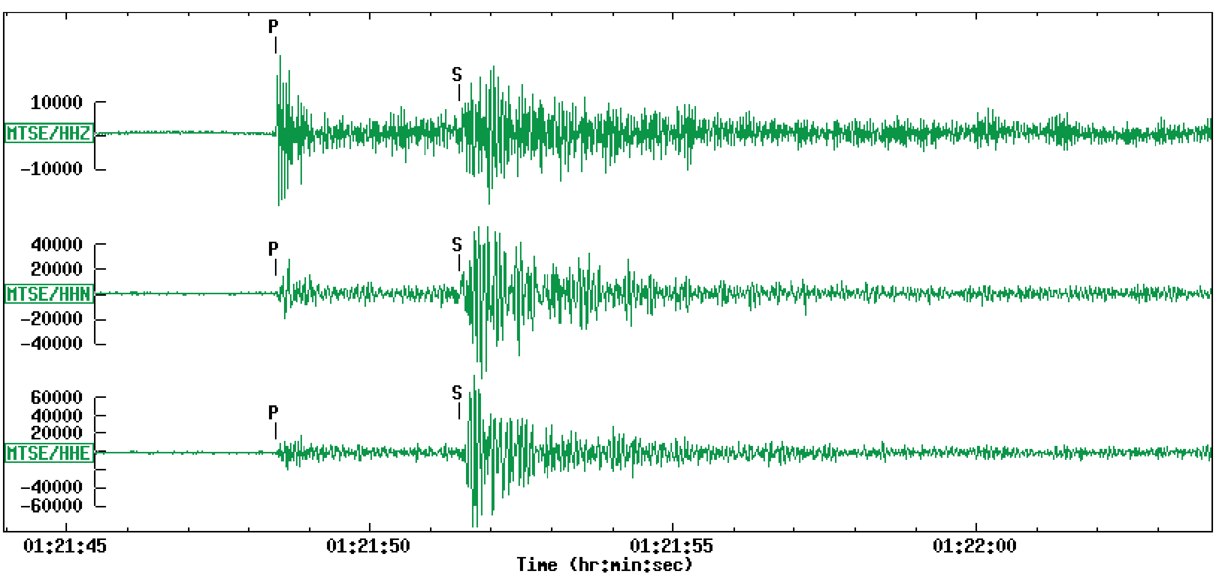
From the beginning of the 21st century, three permanent seismic stations have been operated in Estonia. They provide fairly accurate information on seismic events taking place in our country, e.g. whether an earthquake occurred in west Estonia, or instead, another blast in the Narva open cast oil shale mine was recorded.

As seismic waves do not come to a stop at state borders, it is advantageous for monitoring agencies to join the forces with neighbouring countries by exchanging data and know-how. This is the case also with Estonia, where the geological survey co-operates for common goals primarily with our neighbour in the north, the Helsinki University Institute of Seismology. Finnish seismologists have provided us a loan of their equipment thus that instead of three, our network consists now of no less than ten seismic stations measuring ground motion. With the current Estonian network configuration, seismically defined locations of blasts in quarries focus from diffuse clouds to compact clusters. On the basis of the locations and depths of ground tremors, it is possible to detect whether the event took place in a quarry or in a fracture deep in the crystalline basement.

The joint Estonian-Finnish monitoring system produced 667 locations of seismic events in 2018. Of these, 661 were identified as signals of routine blasting operations. On land, these were explosions in open cast oil shale mines, particularly in the Narva mine, or limestone quarry blasts. Sea mine eliminations were carried out in Estonian coastal waters, most intensively in May during the Baltic Sea naval exercise Open Spirit. Seismic events in the Gulf of Finland outside the Estonian territorial waters at 59.5–60° N and 23–28° E can be associated with the construction of the Nord Stream 2 gas pipeline. According to Gazprom, mine eliminations along the route of the pipeline were started in May. However, seismic locations reveal that the first explosions took place in the eastern end of the route already in early February.

Three earthquakes were detected in 2018. One of them occurred in the early hours of the 4th of March beneath the Haapsalu town at about 3.5 km depth. Despite the moderate magnitude of 1.7, the ground was shaking to such an extent that several residents were woken up and dogs started barking. The most recent earthquake before this event in Haapsalu took place in 2013 and had the magnitude of 1.0. The other two earthquakes in 2018 occurred under the Gulf of Finland offshore south Finland, where sporadic small fault displacements in the crystalline basement are observed almost yearly.

Seismologists and detectives. The better tools the seismic Sherlocks have, the more far-reaching con-

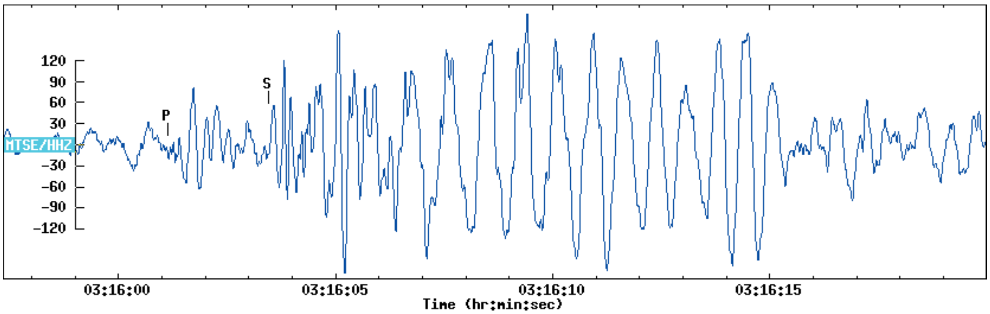


Recording of the Haapsalu earthquake (4 March 2018) at the Matsalu station. P: P-wave onset; S: S-wave onset. Components from above: vertical, horizontal N–S and E–W.

A large-scale collapse of the NE Estonian coastal escarpment that occurred on 15 March, 2018. The height of the cliff is approximately 25 m.

clusions they can make. One particularly intriguing small seismic event, with the magnitude of merely 0.9 took place in NE Estonia immediately after midnight on 15 March. It could not be labelled as an earthquake, nor an explosion in the signal analysis process. Moreover, it did not have the characteristics of mine collapses that occasionally take place in NE Estonia. Thanks to the tight seismic network, the approximate location of this event could be reliably determined. Fieldwork observations confirmed that it is possible to detect seismically a collapse of the cliff escarpment of the north Estonian shoreline. Local residents described their observations of loud thunder audible in the night-time and pointed to the very location of a fresh cliff collapse.

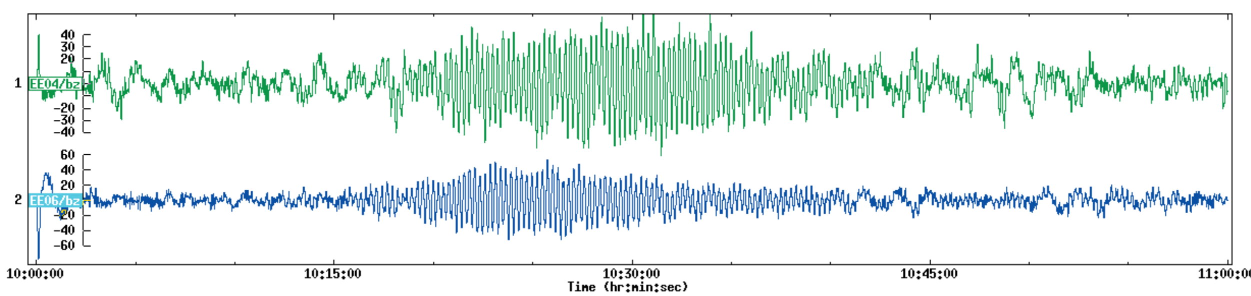
Another curious, magnitude-1.0 event took place at the mouth of the Matsalu Bay on 20 January. The location is accurate enough to confirm that it could not be a quarry blast in the mainland. Moreover, the timing of early Saturday morning is unlikely for blasting operations. Naval exercises and cracking of sea ice are excluded as causes of this event. The Matsalu seismic station recorded a large-amplitude surface wave, which indicates a location close to the ground surface. Could it be an explosion? It is so far obscure whether an old sea mine or some more piquant military object was blown up all of a sudden.



Seismic signal of an unknown origin from the mouth of the Matsalu Bay (20 January 2018), vertical component at the Matsalu station. P: P-wave onset; S: S-wave onset, 1–5 Hz filter.

Earthquakes and deep structures of the Earth. Seismometers used in Estonia are of the broad-band type. They are sensitive for both small local and larger distant events. Large earthquakes of seismically active regions around the globe are routinely recorded. It is important to archive these valuable data as material for research on deep crustal structure of Estonia.

Seismologists and science media around the globe were thrilled of a curious signal on 11 November. It was caused by a yet inexplicable manifestation of volcanic activity under the seafloor of the Indian Ocean, near the Mayotte island north of Madagascar. The mysterious wave train was recorded at seismic stations all over the world. The Estonian stations performed well in this international endeavour. Careful filtering of our data showed that the submarine volcanic greeting from the other side of the world was recognizable also at us, as a spindle-form very low frequency monochromatic surface wave package.



Recording of the submarine volcanic event to the north of Madagascar at Estonian seismic stations. A spindle-like surface wave signal is clearly visible. The duration of the seismogram is one hour (11 November 2018, 10–11 UTC), vertical components of the temporary stations EE04 and EE06, filtered at 0.01–0.1 Hz.

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The laboratory of the Geological Survey of Estonia

The laboratory deals with studying groundwater, surface water and drinking water, as well as with rocks, sediments, soil and mineral resources (including peat). Its function within the state institution is to ensure that samples collected during geological investigations are analysed and measured following technical requirements. The laboratory is ready for developing novel methods when focusing on best solutions for specific problems of its clients and partners.

The laboratory is authorized to use 45 different analysis methods for investigating groundwater, surface water and drinking water. It is accredited to use 30 various analysis methods for studying rocks, sediments, soil, and mineral resources, including peat (Estonian Accreditation Centre, accreditation L093).

The investigation and analysis services of the laboratory are used by both the geological survey and by entrepreneurs and private citizens, who deal with water or mineral resource exploration, mining, energetics, construction and consulting.

The service list of the laboratory of the Geological Survey of Estonia (EGT) is flexible. It follows the needs of Earth's resource research, offering support also for solving non-standard tasks.

Price list of the laboratory (in Estonian):
https://www.egt.ee/sites/default/files/elfinder/article_files/egt_labor_hinnakiri_2018.pdf

11 INTERESTING FACTS

- More than 50 Ltd. companies and firms ordered analyses during one year
- More than 37,000 analyses were performed in the laboratory
- Three chemists and two lab technicians were occupied with the analyses
- Water analyses formed 70% of the volume of the year
- Water analyses formed 60% of job orders by EGT itself
- Water analyses formed 70% of client services
- General analysis of water, peat analysis and granulometric analysis were most desired
- International reference tests of analysing rock, sediment and soil samples were three times partaken in the framework of WEPAL (Wageningen Evaluating Programmes for Analytical Laboratories) ISE (International Soil-analytical Exchange Programme)
- International reference tests of analysing heavy metals and macroelements in groundwater samples were partaken in, within the framework of the Srls programme of the Italian organization Qualitycheck
- Reference tests of analysis of macroelements and heavy metals were partaken in by invitation of the Estonian Environmental Research Centre
- Estonian Accreditation Centre supervision confirmed that the laboratory fulfils the requirements of the accreditation L093 EVS-EN ISO/IEC 17025:2005

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GEOLOGICAL SURVEY OF ESTONIA
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