SOUTH-EAST FINLAND - RUSSIA ENPI CBC PROGRAMME 2007-2013

Efficient use of natural stone in the Leningrad region and South-East Finland

Document of best practices on natural stone evaluation and research

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This project is co-funded by the European Union, the Russian Federation and the Republic of Finland

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1. Introduction

Stone is a durable and ecological building material which can be fully recycled. In particular granitic dimension stone, with its high-silica composition, effectively resists climatic stresses and the attacks of air impurities, so common in many of our industrial cities today. Furthermore, granite extraction (excluding blasting) and processing are purely mechanical processes with no chemicals or other polluting substances involved. Consequently, the use of granitic stone fits in well with the idea of sustainable development. The quality of the stone must thus meet very high standards, which means that marked variations in colour, structure, and technical properties cannot be tolerated. In the market for dimension stone there is a constant need for new products with enough reserves and quarrying potential to satisfy the demand of the market for a long time. Potential sites for good stone, meeting all the quality standards, are difficult to locate and require increasing activity from the industry. In order to cope with this situation, a better focused exploration for dimension stone is needed.

2. The process of natural stone exploration

Natural stone exploration is closely linked to geological mapping and its methods. It can be said that natural stone exploration is an application of geological bedrock mapping. The same systematic and geological observation procedures are used in both. Natural stone deposit exploration differs from conventional bedrock mapping by concentrating on some aspects that are seldom observed in bedrock mapping, such as the amount of fractures and joints, fracture systems as well as homogeneity and colour of the rock.

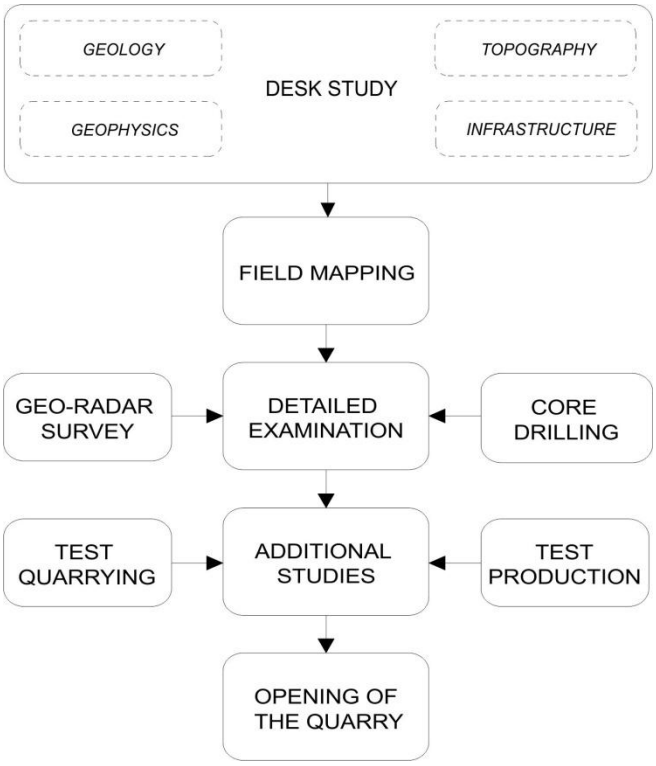

Fig. 1 The process of geology based natural stone exploration as a flowchart according to Selonen et al. (2000).

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2.1. Desk study

A starting point of the natural stone exploration is usually a region where it is known to have bedrock that is interesting to a company or companies. The idea of natural stone exploration can arise also from the regional interest to strengthen the local natural stone companies' operating environment. In both cases the desk study starts with getting acquainted with the existing material of the study area.

2.1.1.Geology

The modern geological mapping data allows getting quite accurate view of the geology of a certain region, which helps in choosing the most interesting areas where to focus the field work.

- Bedrock maps and explanations to the maps
- Geological articles from the rock type or region
- Geological reports
- Scientific publications
- Articles in magazine
- Example of the reference list
- Geological maps (map database of Finland)

Geology and commercial names of the stone types

The commercial naming systematic of natural stones differs from the geological naming. In general the commercial naming system is simpler and many of the geological rock names have been collected under a single term. As an example the hard silicate rocks are categorized under the commercial name granite containing syenite, granite, granodiorite, diorite, gabro, anorthosite and diabase. Sandstone marble and limestone are categorized under soft stones. In addition there are schist and soapstone. The term granite consists also of metamorphic rocks like migmatites and multicolour stones. Stones are divided into groups according to their colour and structure. The colours can be red, brown, green, black grey etc. The colour can be uniform or diverse. The structure of the stones can be massive or oriented such as in migmatites and gneisses.

In natural stone evaluation are used mainly geological terms and classifications. The commercial definition will be given to the rock if it comes into the market. The geological name is also important for evaluating the mineralogical and chemical suitability of the stone to production. The geological name is given according to IUGS and BGS classifications.

Typical stones for natural stone production

- Granites
- Rapakivi granite
- Black stones
- Schist
- Soapstone

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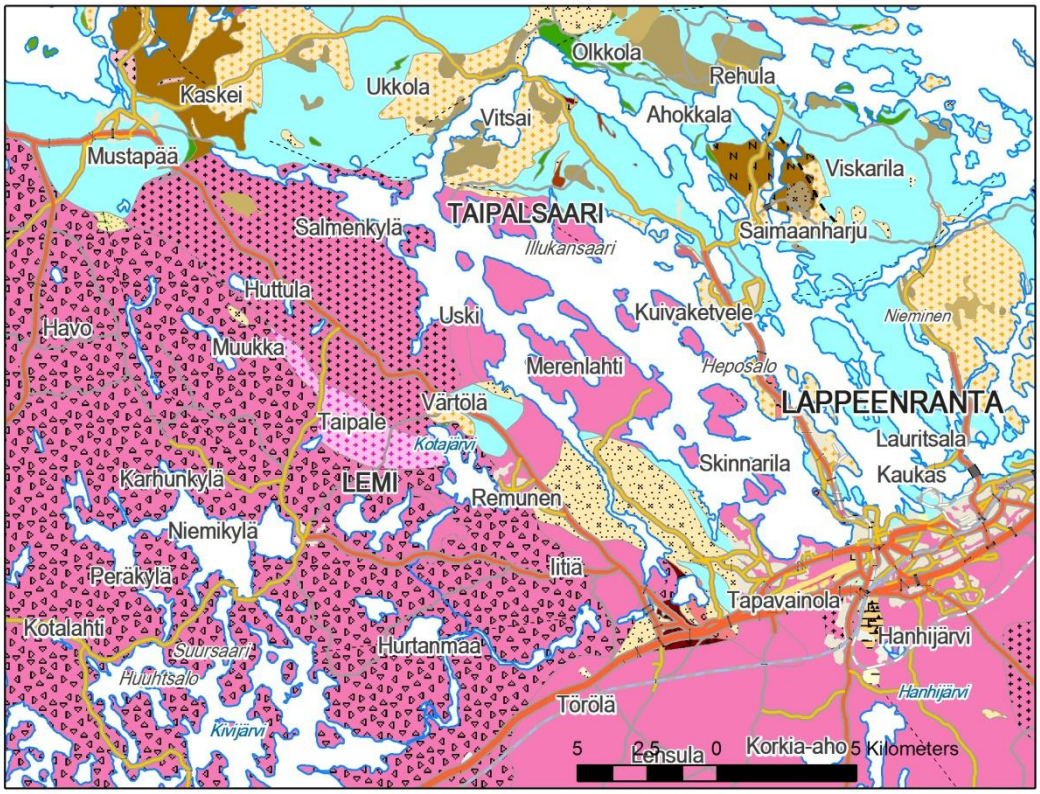
Geological maps and explanations to the maps:

- Simonen, Ahti 1987. Kaakkois-Suomen rapakivimassiivin kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the map-sheet areas of the rapakivi massif in SE Finland. Suomen geologinen kartta 1:100 000 : kallioperäkarttojen selitykset lehdet 3023+3014, 3024, 3041, 3042, 3044, 3113, 3131, 3133. Espoo: Geologian tutkimuskeskus. 49 p.

Geological map of digital bedrock data.



Legend

Lithological units at 1:200 000 scale (1:500 000 - 1:50 000)

- 21111134 Porfyyrinen graniitti
- 211111351 Rapakivigraniitti
- 211111352 Viborgiitti
- 211111353 Pyterliitti
- 211111354 Porfyyrinen rapakivigraniitti
- 211111355 Kvartsiporfyyrinen rapakivi
- 21111136 Mikrokliinigraniitti
- 2111114 Granodioriitti
- 21111142 Porfyyrinen granodioriitti
- 2111133 Kvartsidioriitti
- 2111134 Dioriitti
- 2111144 Gabro
- 21111441 Noriitti
- 21111442 Gabronoriitti
- 21111445 Sarvivälkegabro
- 211121 Peridotiitti
- 21123 Mafinen vulkaniitti
- 211321 Diabaasi
- 2113221 Plagioklaasiporfyriitti
- 212211 Kalkkikivi
- 21345 Kalkkisilikaattikivi
- 213491 Biotiittiparagneissi
- 2135124 Pyrokseenigneissi
- 213521 Amfiboliitti

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Bedrock of Finland 1:200 000 is a unified whole of Finland geological database, which has been compiled by generalising the not to scale data. The data consists of a lithological / single polygon layer and linear layers, in which faults, form lines and dykes are represented. The data are at 1:200 000 scale, which indicates that the main part of the not to scale data have been generalised to correspond to a product at a scale of 1:200 000. Those not to scale areas where the source data scale is greater than 1:200 000 have not been generalised. The data have been produced during 2009 from not to scale version 1.0. The lithological / rock unit polygon layer includes unit codes, age information and lithological codes as attributes in accordance with the Finnish Register of Geological Bedrock Units (Finstrati). The line layer has its own hierarchical classification. The layer files of Finnish and English language are included in the product. The bedrock database is updated as new data is available. The developing of the map database is carried out continuously.

Detailed geological maps

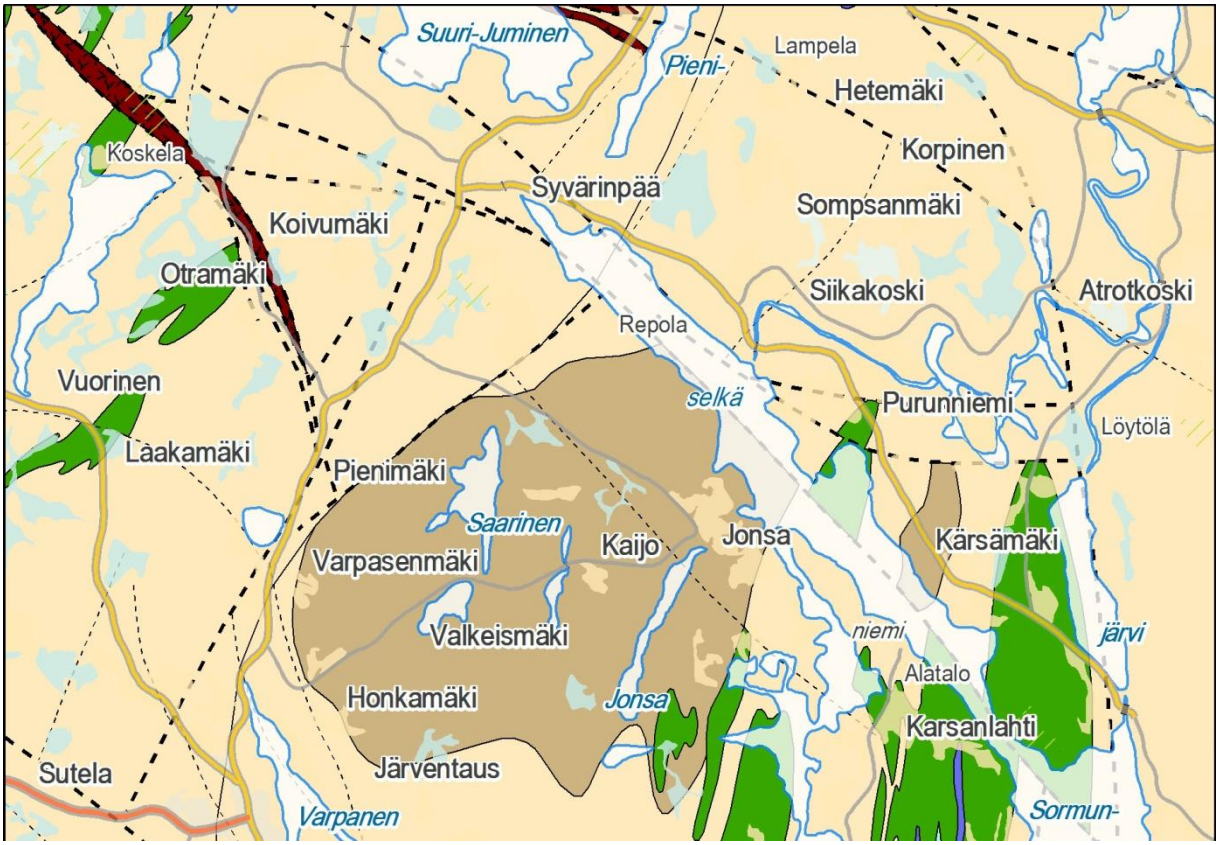

Fig. 2. Detailed geological maps can be produced from the digital database in the appropriate scale. This data can be also used in portable computers that are used in the geological mapping and prospecting. Detailed geological maps together with geophysical and other information can help in interpretation and planning of the sites to be checked in the field.

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Reports:

Reports can be internal or public information that is available to everybody. As an example the following reports of GTK. Typically the reports can concern regional mapping and resource evaluations.

- Koho, Seppo 1994. Maaperäkartoituksiin liittyvät refraktioluotaukset v. 1993. 7 s., 1 l., 1 levyke Geological Survey of Finland, Archive report, Q18/23.0/93/2.
- HÄRMÄ, Paavo 2001. Etelä-Karjalan rakennuskivivarojen etsintäkartoitus 1998-2001.

Scientific articles:

Articles are usually published in scientific publications or conferences. Often the articles can be peer reviewed before accepted for publishing.

- Dempster, T. J.; Jenkin, G. R. T.; Rogers, G. 1994. The origin of rapakivi texture. Journal of Petrology 35 (4), 963-981.
- Rämö, O. Tapani; Nironen, Mikko; Kosunen, Paula; Elliott, Brent A. 1999. Proterozoic granites of South-Central Finland - traverse across a Paleoproterozoic terrane boundary : field trip to southern and central Finland, September 13-18, 1999. Helsinki: Helsinki University Press. 106 p.
- GALLO, Alexander 2004. Comparazione di metodi di valutazione di rocce ornamentali tra Italia e Finlandia.
- Selonen, O., Luodes, H. & Ehlers, C. 2000. Exploration for dimensional stone – implications and examples from the Precambrian of southern Finland. Engineering Geology 56, 275–291.

Articles in magazines:
Some articles can be more popular and published in various magazines.

- Luodes, Hannu 1999. Prospecting for dimension stone in Finland. Roc Maquina, 32, s. 131-132, ISSN 1130-8362.

2.1.2.Geophysics

General geophysical data can be used in evaluating the bedrock and interesting units within them. Different geophysical data can reflect different properties of the bedrock and help to detect geological units in covered areas.

- General geophysical maps
    - Magnetic maps

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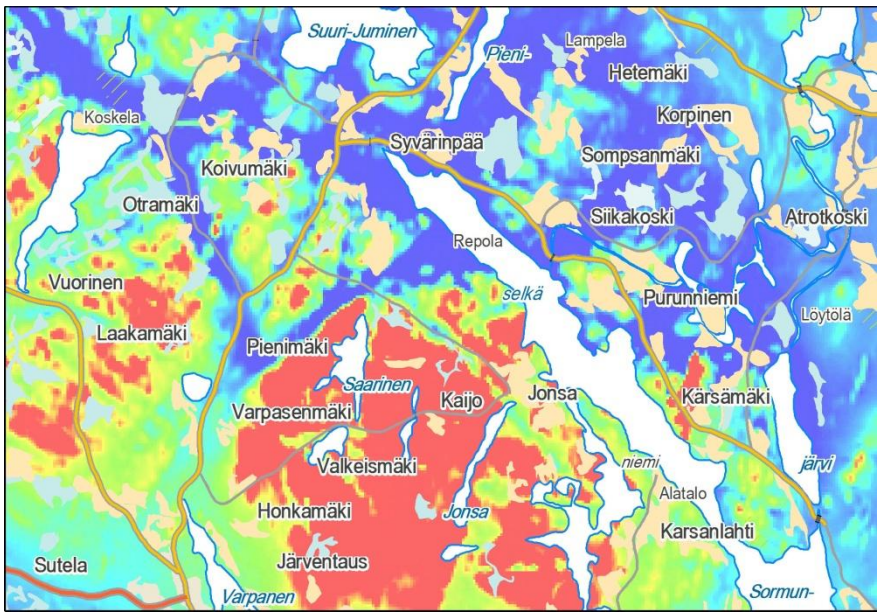

Fig. 3.Magnetic value of the bedrock

Blue areas have low magnetic value, red areas have high magnetic value. The magnetic properties of the map reflect the properties and mineralogy of the bedrock.

- Electromagnetic maps

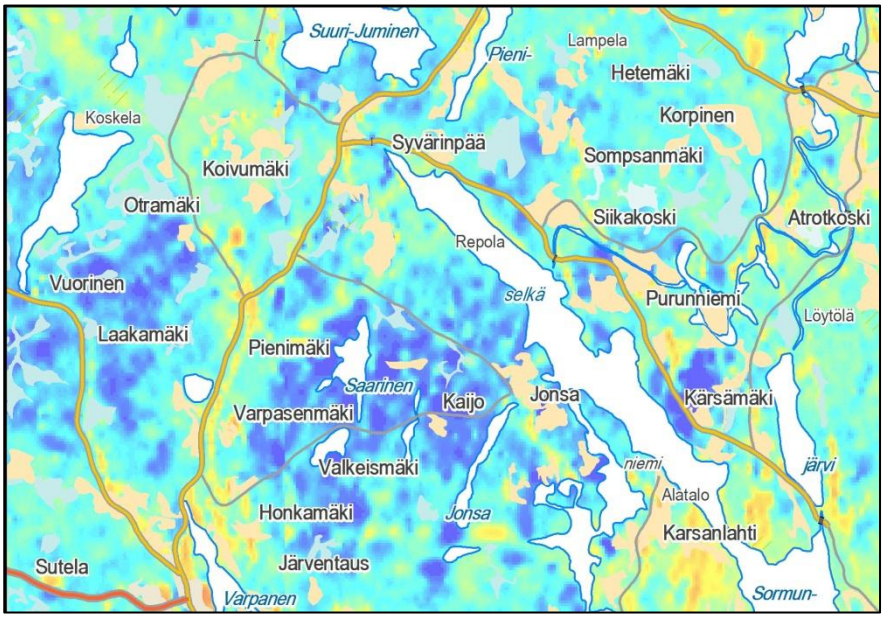

Fig. 4. Real component of electromagnetic properties

The electromagnetic maps show e.g. the conductivity of bedrock. With high conductivity can be detected the rock types with higher amount of conductive minerals causing defects on the natural stones. Such minerals may be pyrite or pyrrhotite that form iron hydroxides and visual defects on the rock surface.

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- Detailed geophysical maps

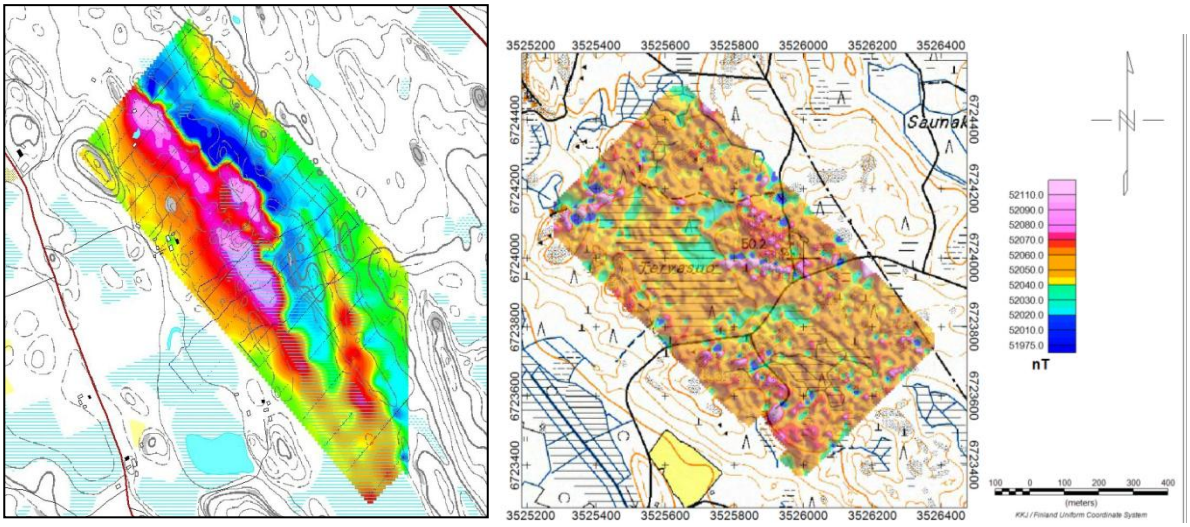

Fig. 5. Detailed magnetic maps. The measurement area on the left side picture is about 800 metres.

Detailed geophysical maps are often based on ground measurements and can give more accurate information about the geophysical properties of the bedrock. The values are measured manually from the investigation area and recorded with the measurement devices and GPS positioning. Detailed maps are used in defining the contacts between rock types and location of certain bedrock units.

- Gravimetric maps

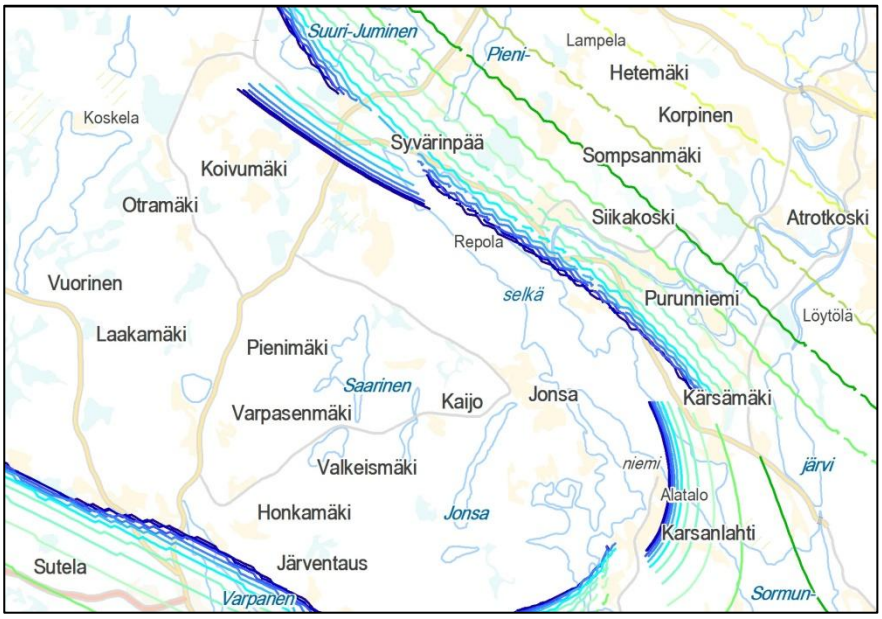

Fig. 6.Interpretation of gravimetry

The gravimetric maps show the density and gravity of the rock types helping to detect different bedrock units and their contacts. This is helpful e.g. in exploration of mafic and ultramafic rocks that are usually denser than the surrounding rock types.

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- Combination maps

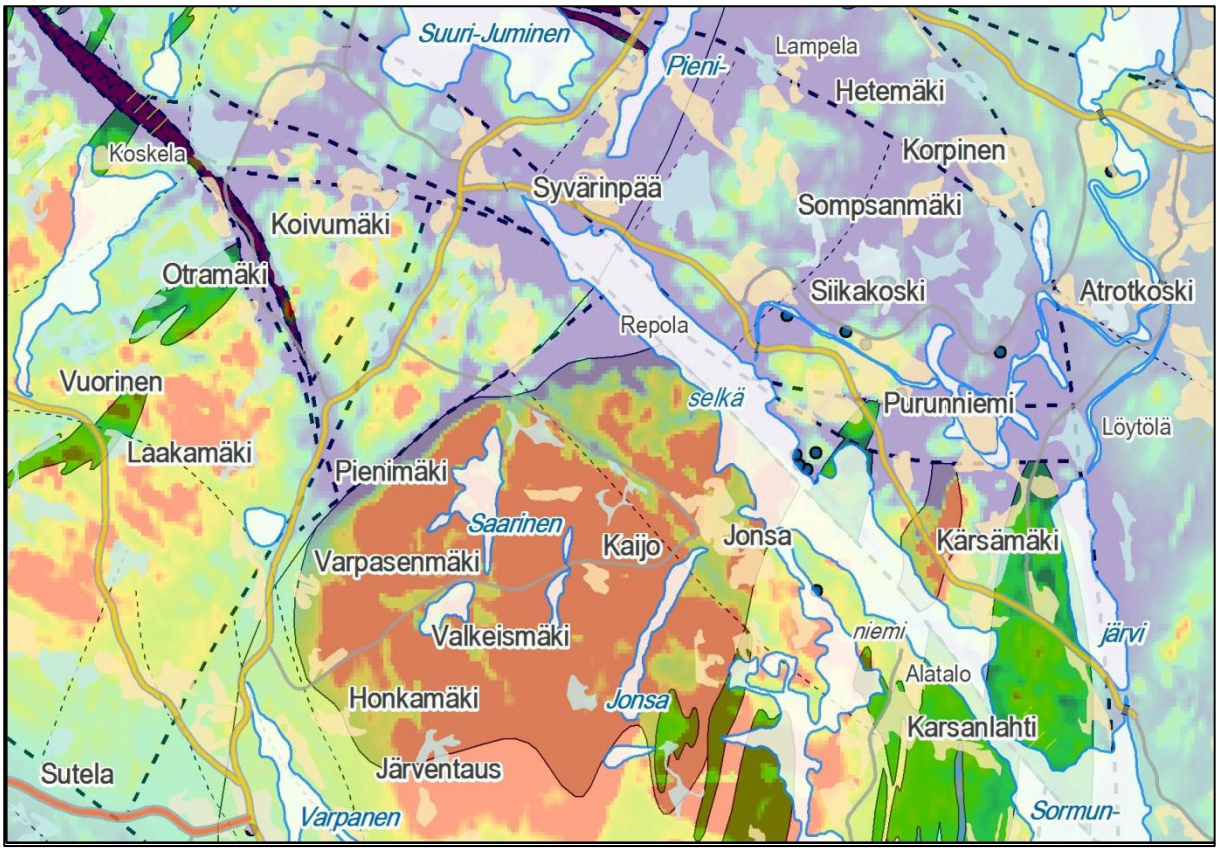


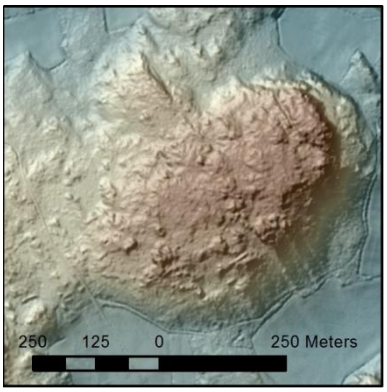
Fig. 7. Combined geological and magnetic maps.

In the combination maps it can be seen which rock types and geophysical phenomena are related to each other and also to evaluate differences within the bedrock units. In the map above the bedrock units are drawn as coloured polygons and the magnetic properties are show with colour spectrum.

2.1.3.Topography

The topographic data can reveal geological orientations and large structures in areas where the soil cover is not too thick and some parts of the bedrock are exposed. This is typical for the areas where the higher hills have been washed during and after the last ice age.

Fig. 8. Structures in rapakivi granite, Taivassalo, SW Finland. The area has been covered by sea just after the Ice Age and the higher hill areas have been washed. The surroundings of the hill are covered by clay and silt material as typical sea bottom.



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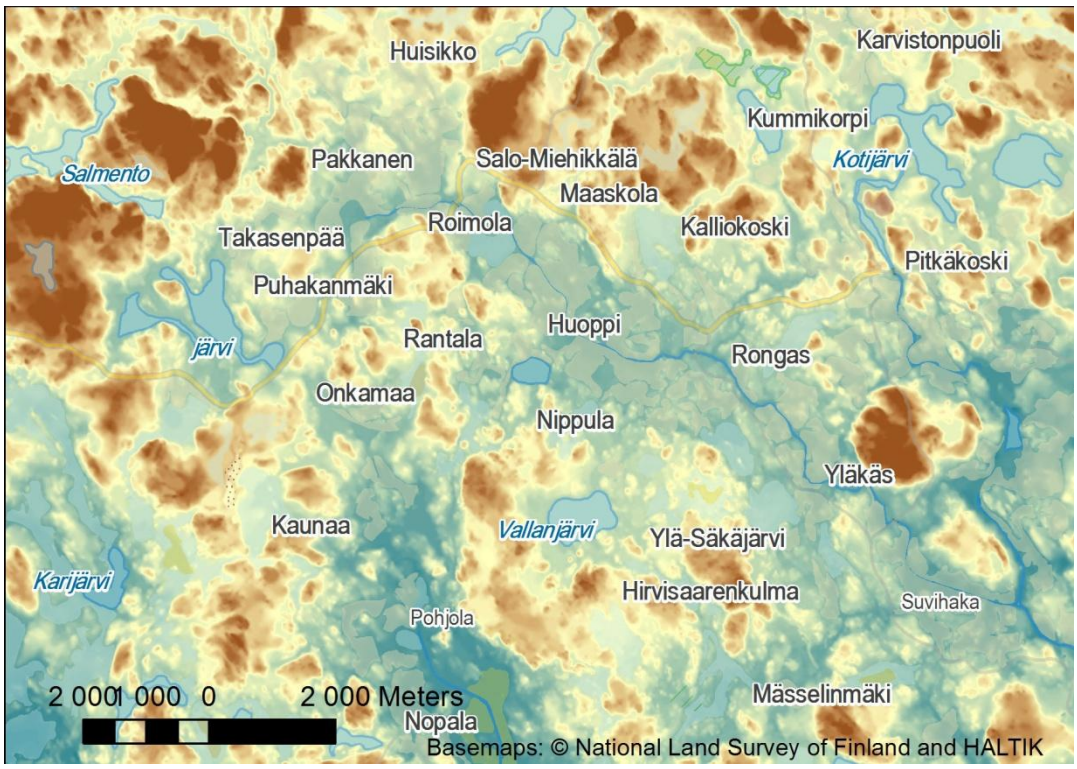

Fig.9. An elevation map processed from the elevation data with 10 meter point interval.

Fig. 10. An elevation map produced from airborne laser scanning elevation data.

- Can be used for geological interpretation
- Can be used in environmental evaluations

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2.1.4.Infrastructure

Road availability and conditions

- Map presentation with main roads and road classification
- Description of the road conditions

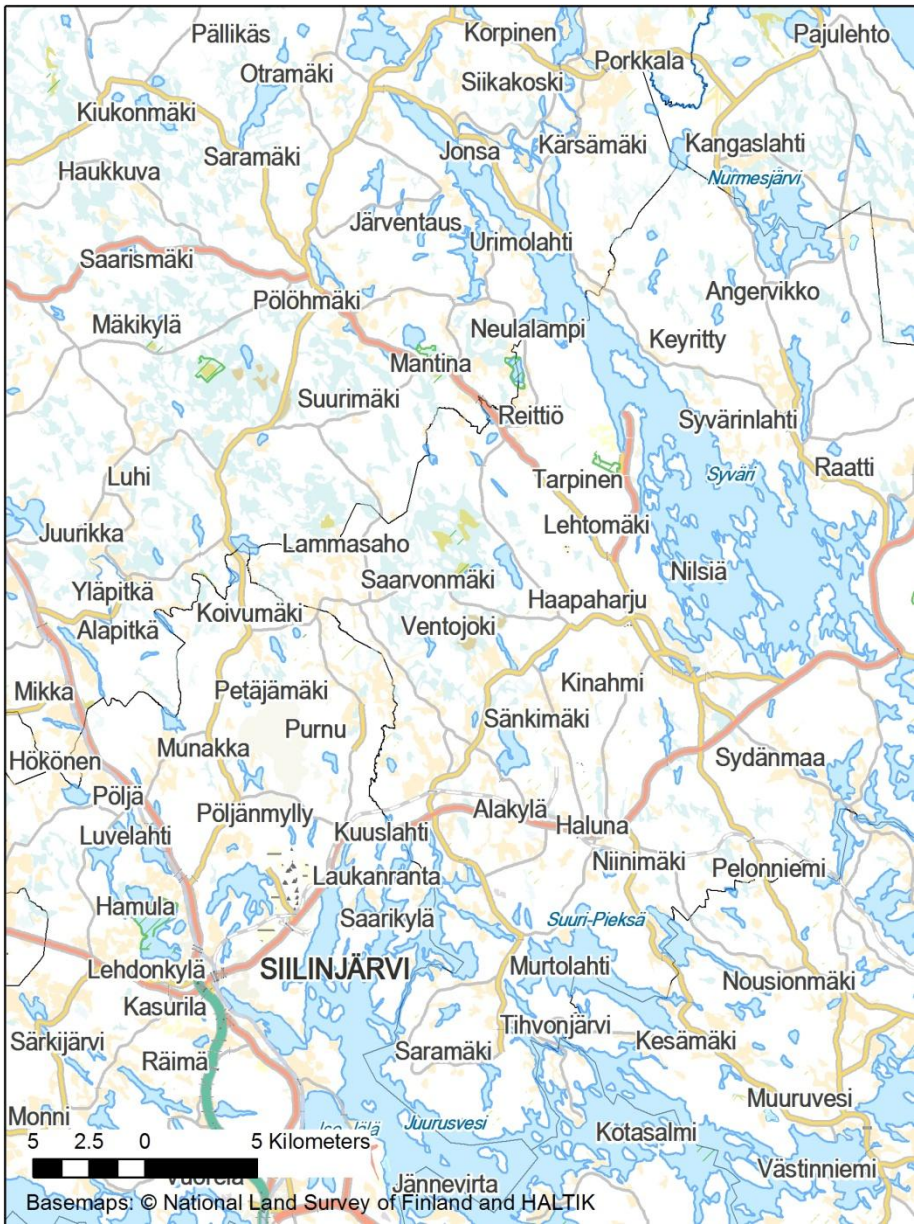

Fig. 11. The road infrastructure.

Logistic possibilities

- Roads
- Railroads
- Water ways

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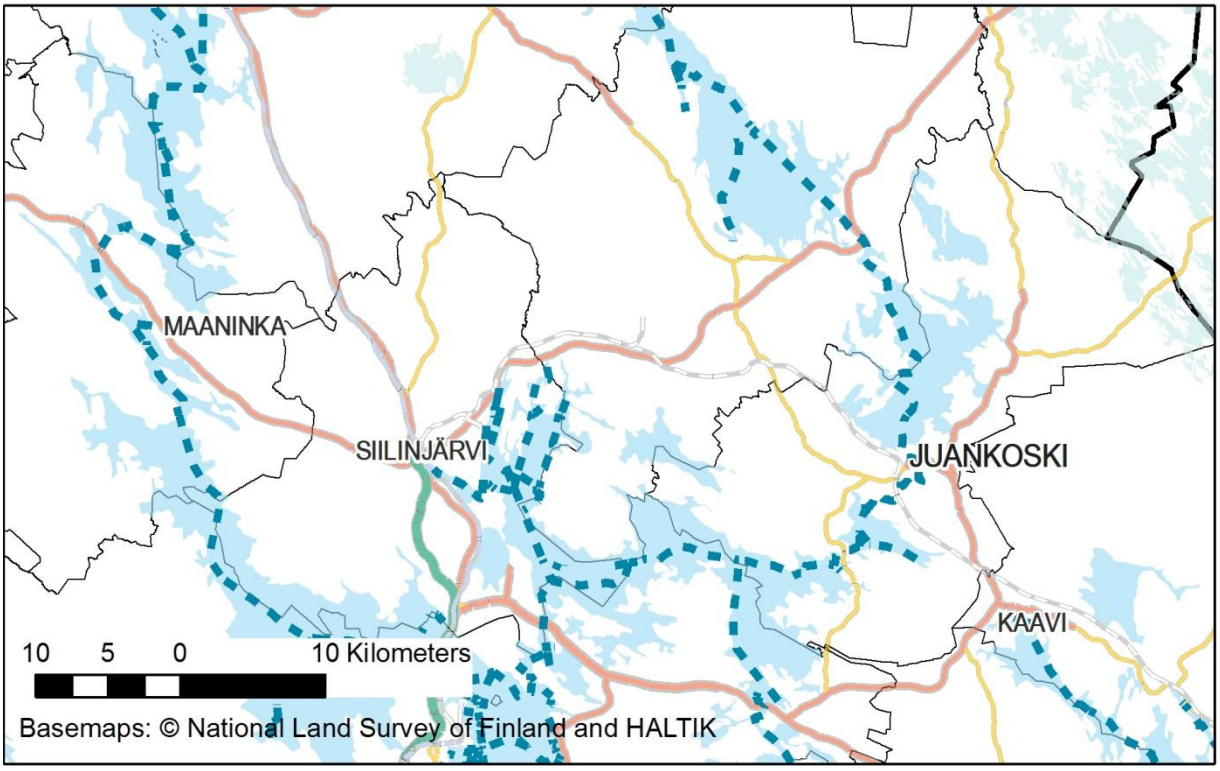

Fig. 12. Inland water ways indicated by blue dotted line.

Protected areas

- Environmental protection
- Landscape protection (National Board of Antiquity)
- Historical sites
- Map example of the environmental protection

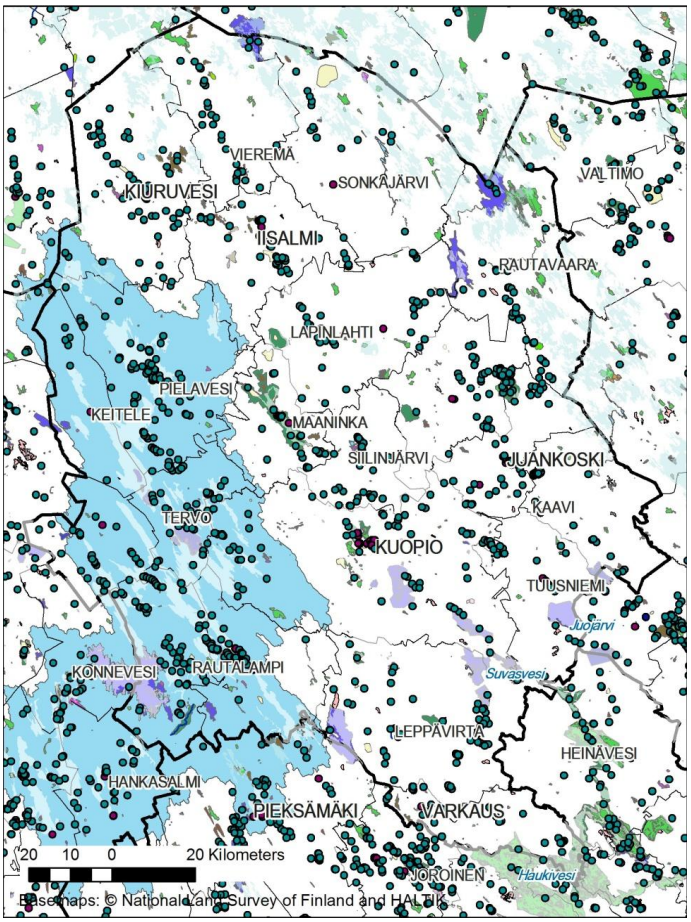

Fig. 13. Protected areas and sites in North Savo region. Environmental protection areas marked with different colours. Protected museum sites as green points and larger areas with coloured polygons.

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3. Field mapping

Bedrock mapping for prospecting

Fig. 14. Bedrock mapping.Photo © Jari Väätäinen, Geologian tutkimuskeskus, 2000.

Normal bedrock observations are carried out in the prospecting of new natural stone occurrences and deposits. The work is mainly mapping and evaluation of the bedrock outcrops and producing a total picture of the geological environment to point out the most homogeneous and un-fractured areas. Conventional elements of the mapping including bedrock data, texture and structure data and the tectonic evaluation of the area are used for making the total evaluation. When the promising areas and occurrences have been found the bedrock surface is usually exposed either by hand work or by a machine, such as an excavator.

Fig. 15.

The outcrop surface is often exposed by an excavator.

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The exposed outcrops are mapped in detail for the joints and fractures of different dimension. The observations of the fractures can be mapped with a paper map and compass or by measuring the fracture orientation by GPS equipment (starting point, middle points, ending point). In the latter case the data is already in digital format and can be use for visualizing the fracture patterns more easily.

Number	X coord	Y coord	z coord	Type	Measurement
5026	6724245,064	3525539,379	42,632	J1	055-88
5027	6724247,048	3525538,319	42,618	J1	055-88
5028	6724248,349	3525537,67	42,615	J1	055-88
5029	6724243,828	3525538,32	42,604	J3	
5030	6724244,716	3525537,772	42,542	J3	055-88

Fig. 16. Detailed mapping with GPS positioning. Measured fracture end points of in a table. The plunge of the fracture indicated in the measurement column.

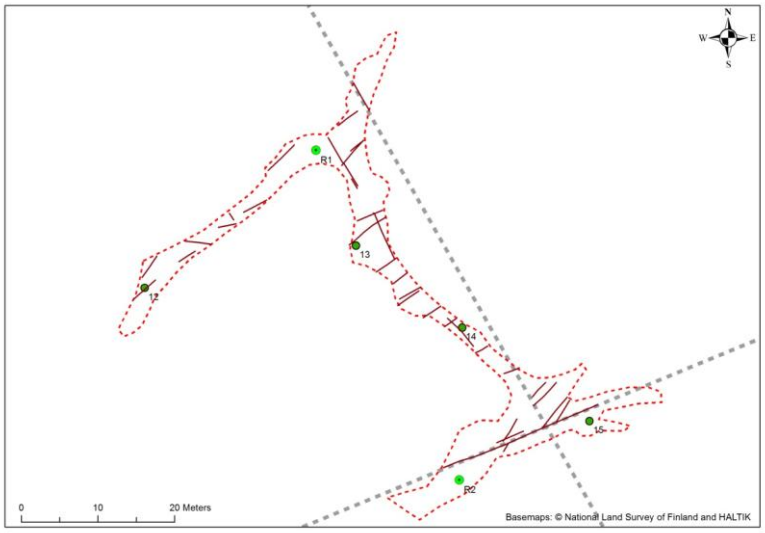

Fig. 17. Fracture observations plotted on a map. Locations of samples presented as points.

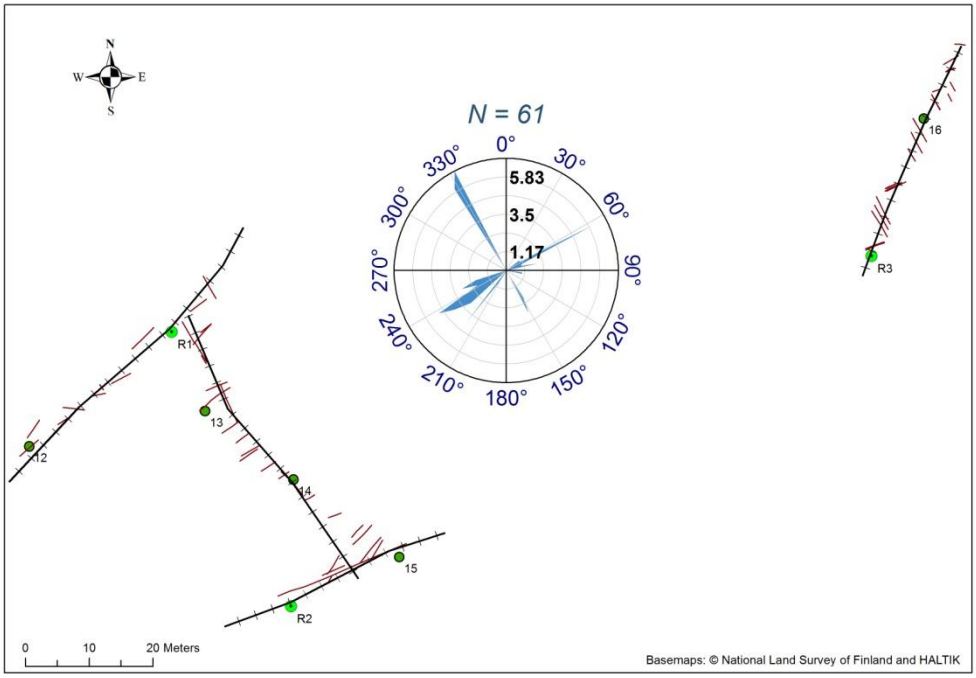

Fig. 18.Fracture observed plotted in a map with a rose diagram to visualize the proportion of different fracture directions.

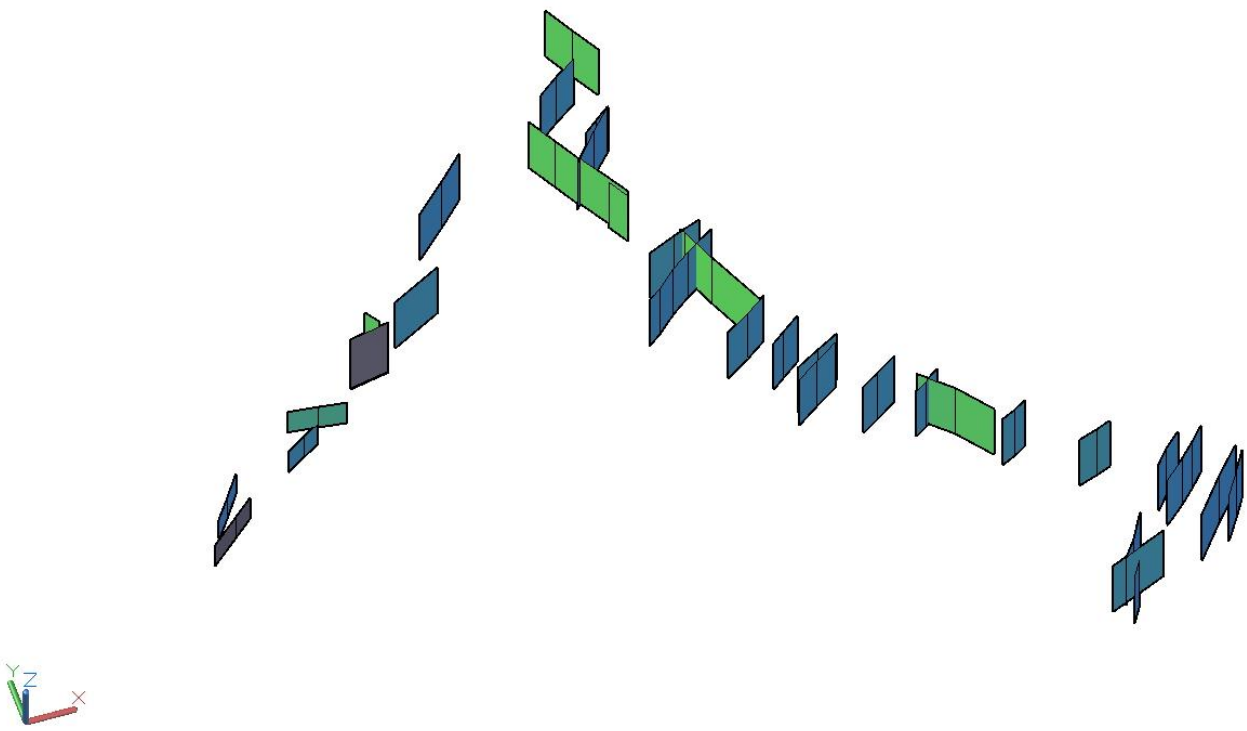

Fig. 19. The observed fractures can be presented in a 3D view. Different fracture directions presented in different colours.

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Observation of the stone colour and texture.

The colour, homogeneity and texture are first observed from the exposed outcrops. The evaluation of the potentiality is usually made from the first visual observations of the rock surface. The defects are often easier to see from weathered surface than from the fresh stone.

Fig. 20. A typical homogeneous rapakivi granite texture and colour observed from an outcrop. The stone texture is uniform and looks homogeneous.

Fig. 21. Observation of the inconsistencies and defects on rapakivi granite. In this case there can be found a cross-cutting granitic vein and an inclusion of another rock type in the rapakivi granite.

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4. Deposit scale examination

4.1. Ground penetrating radar survey

The ground penetrating radar (GPR) equipment is used systematically in the natural stone quality evaluation. The aim of the GPR study is to assess especially the horizontal and sub-horizontal fracture patterns and frequency. The GPR consists of transmitter and receiver that are usually located in the GPR antenna. The transmitter sends a radar pulse to the rock. A part of the pulse energy is reflected back from fractures to the receiver and from the time the pulse has travelled in the rock it can be calculated the depth of the reflecting surface. The radar pulse is reflected back from the surfaces if the difference in dielectric properties of the rock and the surface (e.g. open fracture) is large enough.

Fig. 22. Ground penetrating radar equipment used in exploration. The control unit (receiver) SIR-3000 and the antennae between 40 and 400 MHz.

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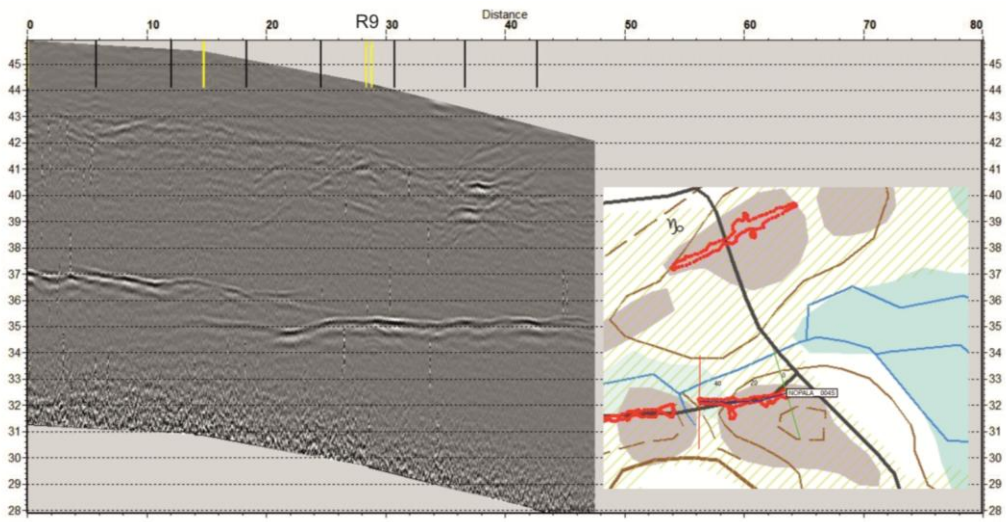

Fig. 23. Ground penetrating radar profile (left) and the topographic map (right) indicating the radar profile location in the field.

4.2. Geophysical investigations

Detailed geophysical measurements are carried out by manual measurements in the field. The data is recorded with the measuring instruments and the point of measurement is taken from a GPS device. The data is processed with specific software to produce interpretation maps. The geophysical interpretations are combined with the available geological knowledge to make a comprehensive model of the deposit.

Among the methods used are e.g. electrical resistivity tomography (ERT), induced polarization (IP) as well as ground magnetic measurements. Also petrophysical measurements can be done in the laboratory conditions using samples taken from the investigation area.

The aim of the ERT and IP measurements is to detect features on different depth scales. The depth penetration of the measurements can be adjusted by changing the distance between electrodes. If the spacing between the electrodes is small, the depth penetration is low and the penetration increases by lengthening the electrode spacing.

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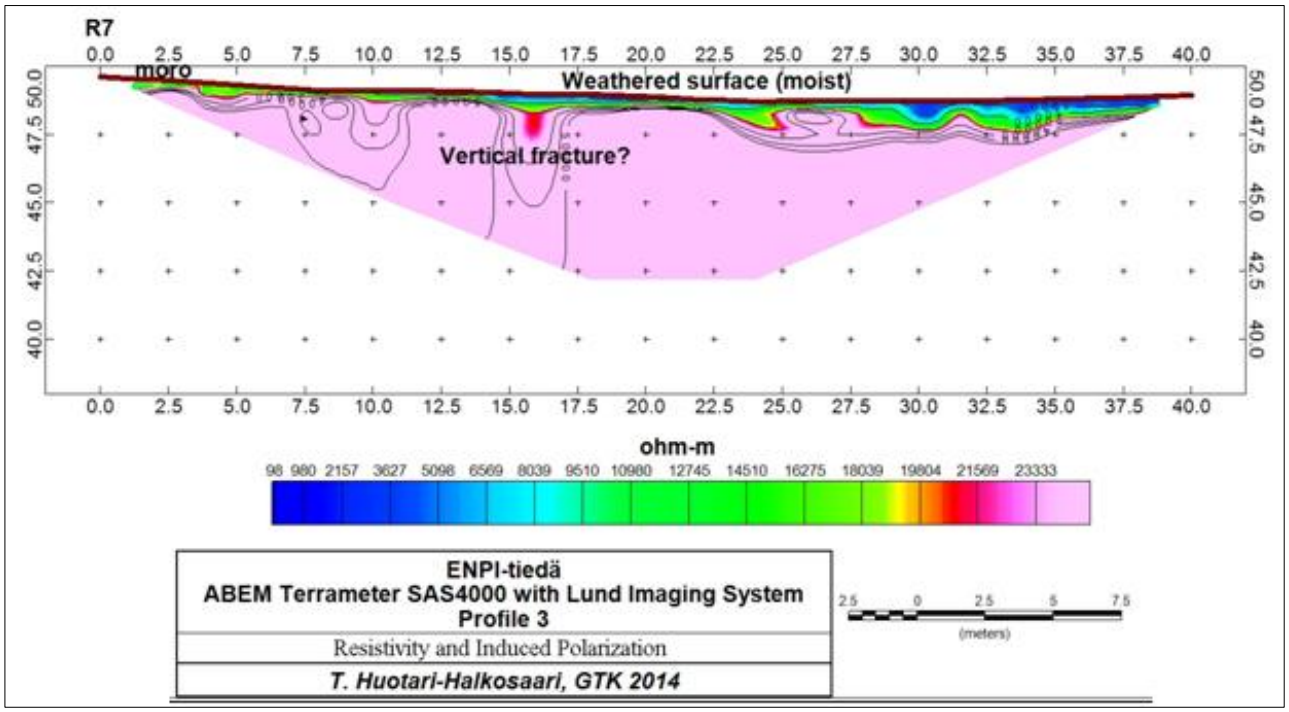

Fig. 24. An example of the ERT and IP measurements. Interpreted section in a rapakivi granite deposit.

The structural properties of the bedrock can be investigated with magnetic measurements. Airo et al. (2008) conducted that bed rock structure and lithology, crustal weakness zones and lineaments can be detected from the airborne magnetic data with dense line spacing (75-100 m). Even denser line spacing can be used when the measurements are carried out on the ground and done manually along the measurement lines. The line spacing can be e.g. 20 metres depending the topography conditions and variation of rock types in the bedrock. The soil cover on the bedrock can affect the measurements and the interpretation of the results. Therefore areas with thin soil cover are preferred.

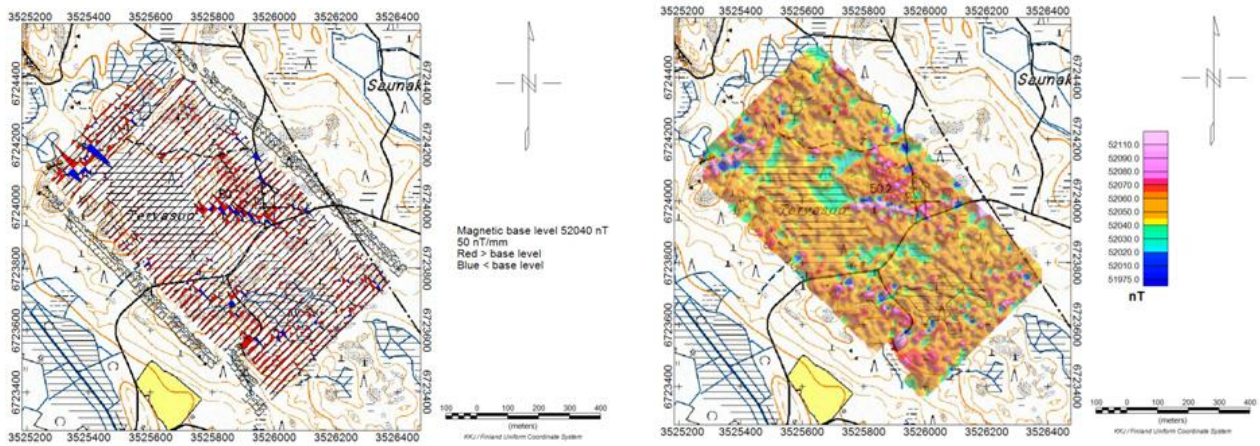

Fig. 25. Magnetic profile map from Nopala area (left) and total field magnetic intensity (TMI) map (right). Basemaps: © National Land Survey of Finland

The LiDAR data of National Land Survey of the Finland is available from most areas of Finland. It is made by laser scanning equipment in airborne measurements. The elevation accuracy of the Lidar data is about 0.5

metres and the data can be used for detecting structural features of the bedrock. Lidar data can be also combined with other data such as magnetic measurements and GPR measurements.

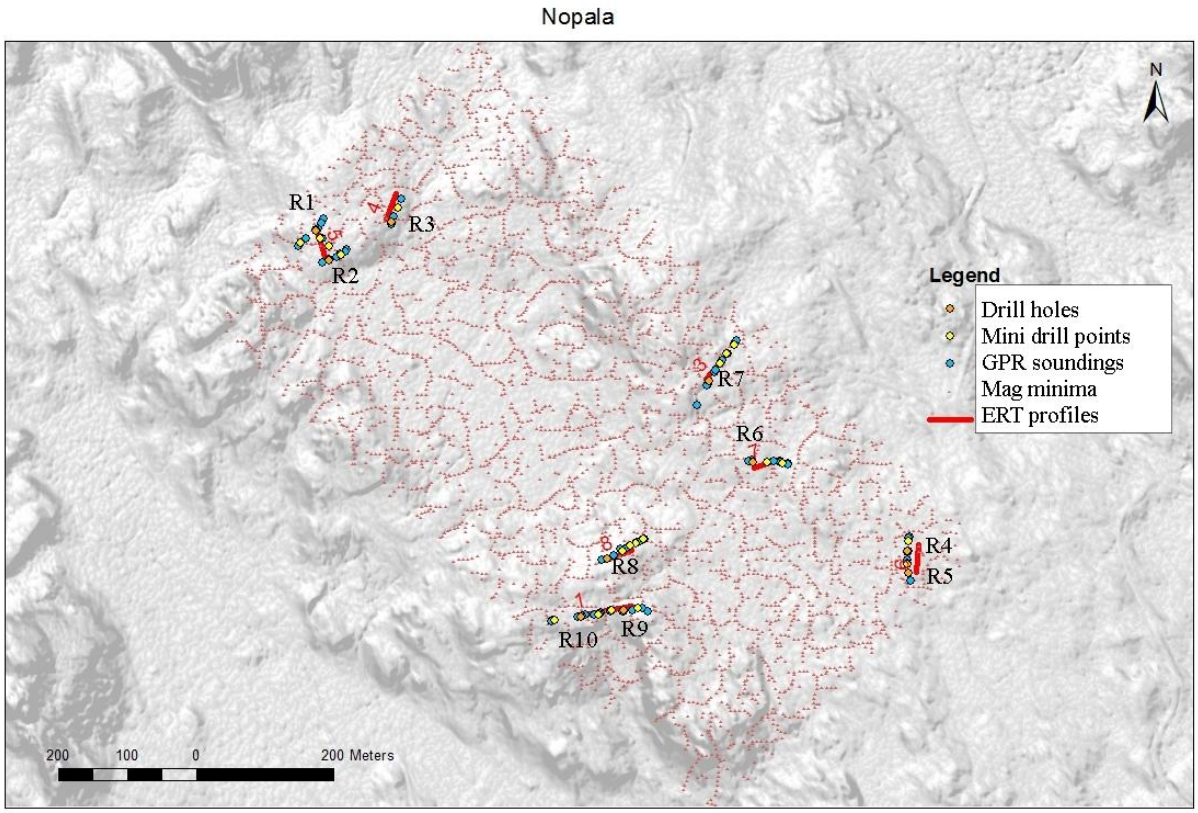

Fig. 26. The LiDAR data with magnetic minima, ERT lines, GPR profiles as well as mini drill and drill hole locations. Data from the Topographic Database of the National Land Survey of Finland © NLS and HALTIK.

If there are diamond core drill holes in the area, they can be utilized for making drill hole in situ measurements and to investigate the petrophysical properties of the rock. The measurements can be done with 4 probes that measure in situ magnetic susceptibility, resistivity, density and natural gamma radiation along the drill hole. Usually the calibration of the drill hole data needs also petrophysical measurements from the drill core samples. The need is evident for susceptibility and density data.

According to Airo & Säävuori (2013) the most important parameters, density and magnetic properties in the rock can be used to characterize different rock types. These parameters also reflect the mineralogical changes caused by geological processes. Airo & Säävuori (2013) also mention that porosity may have a role for example for weathered surface rocks, but it is not a main "standards" petrophysical property like density magnetic susceptibility and remanent magnetization. Rock density describes the bulk mineral composition in rock. Magnetic suscetibility reflects the iron and magnetite content and the remanent magnetization the magnitude of ancient magnetization in rock.

Porosity, susceptibility and density can be measured with the petrophysical investigation of the samples taken from the bedrock surface. If the rock is highly weathered the samples shoul be taken also from deeper levels, preferably from drill cores of diamond core drilling. The petrophysical properties are

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connected also to the porosity and weathering degree of the rock. The resistivities of the rock samples near the surface can be lower than in deeper parts of the rock, which refers to higher porosity in the weathered rock (pores are water saturated).

4.3. Diamond core drilling

The drill cores from diamond core drilling give a continuous rock sample that can be used in evaluation of the colour and texture of the rock as well as the weathering of the rock surface and the fracture patterns. The diamond core drilling is the most expensive research method and therefore it is essential to find the representative places where to drill the holes. It is also the only method that can give reliable information about the rock colour and variations.

Fig. 27. Diamond core drilling with light equipment reaching down to 100 m depth. The drill holes in natural stone research are typically less than 30 m deep.

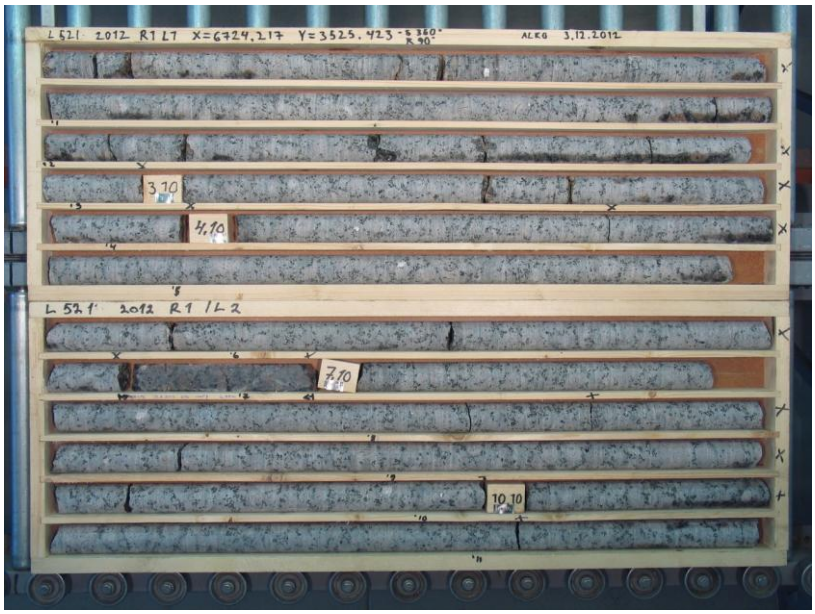

Fig. 28. Diamond drilling cores to observe the structure, texture and colour as well as the fractures, their orientations and frequency. The width of the drill core box is 1 metre. The diameter of the drill core is typically 46 mm.

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Fig. 29. Assessment of the stone texture, fractures and colour from the diamond drilling cores. In the middle, a drilling core has been split in two halves and the other side has been polished to observe better the colour and the texture.

5. Additional studies

5.1. Test quarrying

Fig. 30. The test quarrying tells the extraction properties of the rock. It also gives an estimation of the block size and yield of the deposit.

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The test quarrying is carried out when the other quality parameters of the rock are found to be favourable. It tells about the real quarrying properties and challenges that may come when extracting the material. It can also give an estimation of the block yield and profitability of the natural stone production. The fracture patterns can be in unfavourable inclination for quarrying or there may come exceptional amount of waste rock that can cause more expenses in starting of the quarry.

5.2. Test production

Test production is carried out with the material from the test quarrying. It consists of making actual products in the factory and observing the quality of the products from technical and aesthetical aspects. In the test production can be tried different kinds of surface finishing, such as polished, matte, sandblasted, bush-hammered and burned. They all give different appearance and can change the colour and look of the stone. It is also important to find out how the stone resists the surface treatment mechanically. The material from the test production can be used in marketing and acquiring opinions of the market about possible uses and suitability for different purposes.

6. Opening of the quarry

First of all, the quarry must also get land extraction and environmental permits to start the quarrying. This process can take time more than half a year, usually longer than that because the local inhabitants and neighbours usually want to have their opinions taken into account in the licensing process. The land extraction permit is given by the municipality in which the quarry exists and the environmental permit is usually given by local municipality or the local Regional State Administrative Agencies (AVI).

The quarry is opened if the stone is suitable according to mechanical and physical properties as well as mineralogical composition and it has good evaluation from the market. The general economical situation affects the market demand and thus the opening of the quarry. The demand of different kinds of colours and textures of the rock vary from time to time and the biggest stone importers, such as China, are essential in determining the production.

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