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Bedrock geology of the Kvarken area

Pekka Sipilä, Leif Björk, Leif Kero, Hannu Kujala, Antero Lindberg, Petri Virransalo

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Abstract

The bedrock mapping of the Kvarken area (Merenkurkku in Finnish) in 2003–2005 was part of the Finnish-Swedish Geonat partnership project. The purpose of the project was to provide information about the geology and nature values of Kvarken to ensure sustainable development of the region. The results of the project were decisive when the UNESCO World Heritage Committee placed Kvarken archipelago and the High Coast of Sweden on the World Heritage List.

The bedrock of the Kvarken area consists mainly of Paleoproterozoic supracrustal and plutonic rocks belonging to the Svekofennian province of the Fennoscandian Shield. On the Finnish side the bedrock is part of the Pohjanmaa schist belt and in Sweden it belongs to the Härnö group. Metasedimentary mica gneiss and various migmatites prevail. Due to the partial melting and simultaneous deformation of the metasedimentary rocks a heterogenic rock, typical of the Kvarken area, was formed. Traditionally, it is called Vaasa granite in Finland and mobilatetes in Sweden. On the Swedish side, synkinematic granites and graniodorites are the most common intrusive rock types. However, Paleoproterozoic diorites, gabbros and ultramafic intrusive rocks are rare in the entire Kvarken area, as well as volcanic rocks. Punakari granite and feldspar porphyry dikes at Vaasa archipelago and Korsnäs carbonatite are late- and postkinematic rocks in Finnish side. In Sweden, this group includes the Härnö granite. Mesoproterozoic rocks in the area include the Bonde rapakivi granite in Sweden and the Gulf of Bothnia's sedimentary rocks and Postjotnian olivine diabase veins. Paleozoic Cambrian sandstones and siltstones in the Söderfjäden meteorite crater are the youngest rocks in the area.

Keywords
Vaasa granite, granodiorite, diatexite, mobilate, granite, rapakivi granite, mica gneiss,veined gneiss, olivine diabase (dolerite), meteorite crater, Paleoproterozoic, Mesoproterozoic, Paleozoic.

Geographical area
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Tiivistelmä Raportti liittyy vuosina 2003-2005 tehtyyn Merenkurkun alueen kallioperän kartoitukseen. Kartoitus käsitti kapeat rantakaistat Suomen ja Ruotsin puolelta sekä niiden väliin jäävän saariston kokonaisuudessaan. 1:200 000 kallioperäkartta on tämän raportin liitteenä.Työ oli osa suomalais-ruotsalaista Geonat yhteistyöprojektia, jonka tulokset olivat ratkaisevia, kun UNESCO:n maailmanperintökomitea päätti heinäkuussa 2006 hyväksyä Merenkurkun saariston maailman perintöluetteloon yhdessä Ruotsin Korkean Rannikon kanssa. Merenkurkun alueen kallioperä koostuu pääosin Paleoproterotsooisista suprakrustisista ja plutonisista kivistä ollen osa Fennoskandian kilven Sveofennidien provinssia. Suomen puolella se kuuluu Pohjanmaan liuskevyöhykeeseen, joka jatkuu Ruotsin puolelle Härnö ryhmänä. Vallitsevina kivilajeina ovat paleoproterosooiset kiillegneissit ja erilaiset migmatiitit. Näiden metasedimenttien osittaisen sulamisen ja samanaikaisten liikuntojen seurauksena syntyi Merenkurkun alueelle tyypillinen heterogeeninen kivi, jota Suomen puolella on perinteisesti kutsuttu Vaasan graniitiksi, Ruotsissa mobilaatiksi. Ruotsin puolella synkinemaattiset graniitit ja granodioriitit ovat yleisimmät intrusiivikivet. Vöyri tyypin graniitit Suomessa kuuluvat samaan ikäryhmään. Paleoproterotsooiset dioriitit, gabrot ja peridotiitit ovat harvinaisia kaikkialla Merenkurkun alueella, kuten myös vulkaaniset kivet. Punakarin graniitti ja maasälpäporfyyrijuonet Vaasan saaristossa sekä Korsnäsin karbonaatti ovat myöhäis- ja postkinemaattisia kiviä Suomessa, kuten myös Ruotsin puolelta Härnö tyypin graniitit. Mesoproterotsooisia kivilajeja ovat Pohjanlahden sedimenttikivet, Bonden rapakivi Ruotsissa ja postjotuniset oliviinidiabaasit. Alueen nuorimpia kiviä ovat Söderfjärdenin meteoriittikraatterin paleotsooiset kambrikauden hiekka- ja silttikivet.	
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Sammandrag (Leif Björk 2006)

Berggrunden i Kvarkenområdet utgörs till största delen av de urgamla rötterna till en prekambrisk bergskedja. För ca 1880 miljoner år sedan, under den svekokarelska orogenesen, omvandlades de sedimentära och vulkaniska bergarterna djupt nere i jordskorpan och fick därvid sitt nuvarande utseende. Samtidigt intruderades de av magmor som bildade djupbergarter. I samband med bergskedjeveckningen bildades en hög bergskedja som under knappt två tusen miljoner år har eroderats till nuvarande nivå.

Områdets geologiska utveckling började med att leriga och sandiga sediment avsattes på obekant äldre havsbotten. I den syrefria miljön bildades också sulfid- och kolvätehaltiga sediment. Vulkaniskt material, lavor och askor, avsattes också i mindre omfattning.

Djupt nere i jordskorpan omvandlades dessa avlagringar till metagråvackor, ställvis med grafit- och/eller sulfidförande horisonter. Det vulkaniska materialet omvandlades till amfiboliter och andra metavulkaniter. I samband med den partiella uppsmältningen av de sedimentära bergarterna och rörelser i jordskorpan bildades på den finländska sidan en typiskt heterogen bergart, den s.k. Vasagraniten. Lokalt ser den ut som en djupbergart med stora fältspatströkorn men kan även på samma lokal övergå i ett gnejsaktigt utseende. De största homogena djupbergartslika områdena finns öster om Vasa, men även vid kusten och i den finländska skärgården finns stora områden med liknande bergarter i områden med gnejsiga bergarter. På den svenska sidan motsvaras Vasagraniten av schollenmigmatit och mobilisat.

För 1880 – 1800 miljoner år sedan intruderades de sedimentära bergarterna av magmor som huvudsakligen bildat granitiska djupbergarter. Efter en lugn period på drygt 200 miljoner år trängde granitiska magmor för ca 1570 miljoner år sedan in i de övre delarna av jordskorpan där de bildade batoliter av rapakivi. Inom Geonat-området har rapakivi påträffats endast på ön Bonden utanför den svenska kusten. Den sista hittills kända magmatiska händelsen i området inträffade för ca 1270 miljoner år sedan, då de magmor som gav upphov till de postjotniska diabaserna intruderade. Dessa diabasgångar finns både på den finska och svenska sidan av Kvarken.

De 1400 –1200 miljoner år gamla, mäktiga förekomsterna av sedimentära bergarter i såväl Finland som i Sverige visar att bergskedjan Svekofenniderna redan vid den tiden var kraftigt eroderad. Dessa sedimentära bergarter finns som mäktiga avlagringar också under Östersjön, bl.a. på båda sidorna om Kvarken. Seismiska undersökningar har visat att bergarterna även finns som mindre förekomster i bottensänkor vid den finländska kusten. Stabila tektoniska förhållanden med ständig erosion och sedimentation har rått fram till nutid. Ett exempel på detta är de kambriska sedimentbergarterna i den 520 miljoner år gamla meteoritkratern vid Söderfjärden.

Referensord
Vasa granite, granodiorite, diatexite, mobilisat, granite, rapakivi granite, glimmergnejs,veined gnejs, olivin diabas, meteorit krater, Paleoproterozoic, Mesoproterozoic, Paleozoic.

Geografisk område
Finland, Österbotten, Korsnäs, Molpe, Vasa,Korsholm, Vörå, Nykarleby
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1 INTRODUCTION/JOHDANTO

The bedrock mapping of the Kvarken area (Merenkurkku in Finnish) in 2003–2005 was part of the Finnish-Swedish Geonat partnership project. The purpose of the project was to provide information about the geology and natural values of Kvarken to ensure sustainable development of the region. The results of the project were decisive when the UNESCO World Heritage Committee placed Kvarken archipelago and the High Coast of Sweden on the World Heritage List. Kvarken is the first natural heritage site in Finland. On the Finnish side, the Geonat project area covered a strip of shore about 3 km wide from Korsnäs to Oravainen. On the Swedish side, the corresponding strip of shore was in the municipalities of Umeå and Nordmaling (Fig.1). At population centres, the width of the strip was 10 km. The archipelago between Finland and Sweden was an essential element of the area. All the islands and islets in the archipelago were mapped. In places the rocky terrain crops out from beneath the unconsolidated deposits as smaller and larger outcrops. The present sedimentary cover (mostly till) ranges in thickness from few of tens of centimeters to over 10 meters. The bedrock outcrops in the Kvarken area are often glacially eroded and polished and whale back rock outcrops with glacial striation and erosion marks are rather common.
In addition, all of the region's previous bedrock observations in Finland and Sweden were digitalised for the project. The material was used for creating a 1:200,000 bedrock map (Appendix 1). The surface area on the Swedish side was 3,400 km^2, and 6,250 km^2 on the Finnish side, including the archipelago. The bedrock was mapped by the geological surveys of Finland and Sweden. The purpose of the present publication is to report the bedrock material compiled in the project at that time. Geophysical parameters are given only from the Swedish side of Kvarken because in Finland the mapping team did not have a geophysicist on the field.

Merenkurkun alueen kallioperäkartoitus vuosina 2003-2005 oli osa suomalais-ruotsalaista Geonat yhteistyöprojektia. Projektin tarkoituksena oli tuottaa informaatiota Merenkurkun geologiasta ja luontoarvoista alueen kestävän kehityksen turvaamiseksi. Projektin tulokset olivat ratkaisevia, kun UNESCO:n maailmanperintökomitea päätti heinäkuussa 2006 hyväksyä Merenkurkun saariston maailman perintöluetteloon yhdessä Ruotsin Korkean Rannikon kanssa. Merenkurkku on Suomen ensimmäinen luonnonperintökohde. Geonat -projektin alue käsitti Suomen puolella noin 3 km leveän rantakaistan Korsnäsistä Oravaisiin. Ruotsin puolella vastaava rantakaista sijoittui Uumajan ja Nordmalingin kuntiin (Kuva 1). Asutuskeskusten kodalla kaistan leveys oli 10 km. Oleellinen osa aluetta oli Suomen ja Ruotsin välinen saaristo, mistä kartoitettiin kaikki saaret ja luodot. Lisäksi projektia varten digitoitiin kaikki alueen vanhat kallioperähavainnot sekä Suomesta että Ruotsista. Kerätyn aineiston perusteella alueelta tehtiin 1:200 000 kallioperäkartta (Appendix 1). Ruotsin puolella alueen pinta-ala oli 3400 km^2 ja Suomen puolella 6250 km^2 mukaan lukien saaristo. Kallioperäkartoituksesta vastasivat Suomen ja Ruotsin Geologiset tutkimuskeskukset. Tämän julkaisun tarkoituksena on raportoida projektissa tuolloin kertynyt kallioperäaineisto. Tekstissä on geofysiikan parametreja vain Ruotsin puolelta, koska siellä vallitsevan käytännön mukaan maastotöissä on aina mukana geofyysikko, Suomessa samaa käytäntöä ei ole.

Figure 1. *Location of the Kvarken area*

2 GEOLOGIC HISTORY OF THE KVARKEN AREA

The bedrock of the Kvarken area belongs to the Precambrian Svekofennian province (Nironen 2015, pers.comm) of the Fennoscandian Shield and is composed of hard crystalline rocks. They have developed during 700 million years (Ma) time period ranging from Paleoproterozoic, ca. 2000 Ma, to Mesoproterozoic, ca. 1300 Ma ago. 520 Ma ago Paleozoic sediments were deposited on the eroded peneplane surface of the Precambrian crystalline rocks. Most of the Paleozoic sediments have been eroded during the last 500 million years. Evidence of the sedimentary cover can still be found in the Söderfjärden meteorite impact basin, where tens of meters of thick pile of Paleozoic sediments (Cambrian) have been preserved.

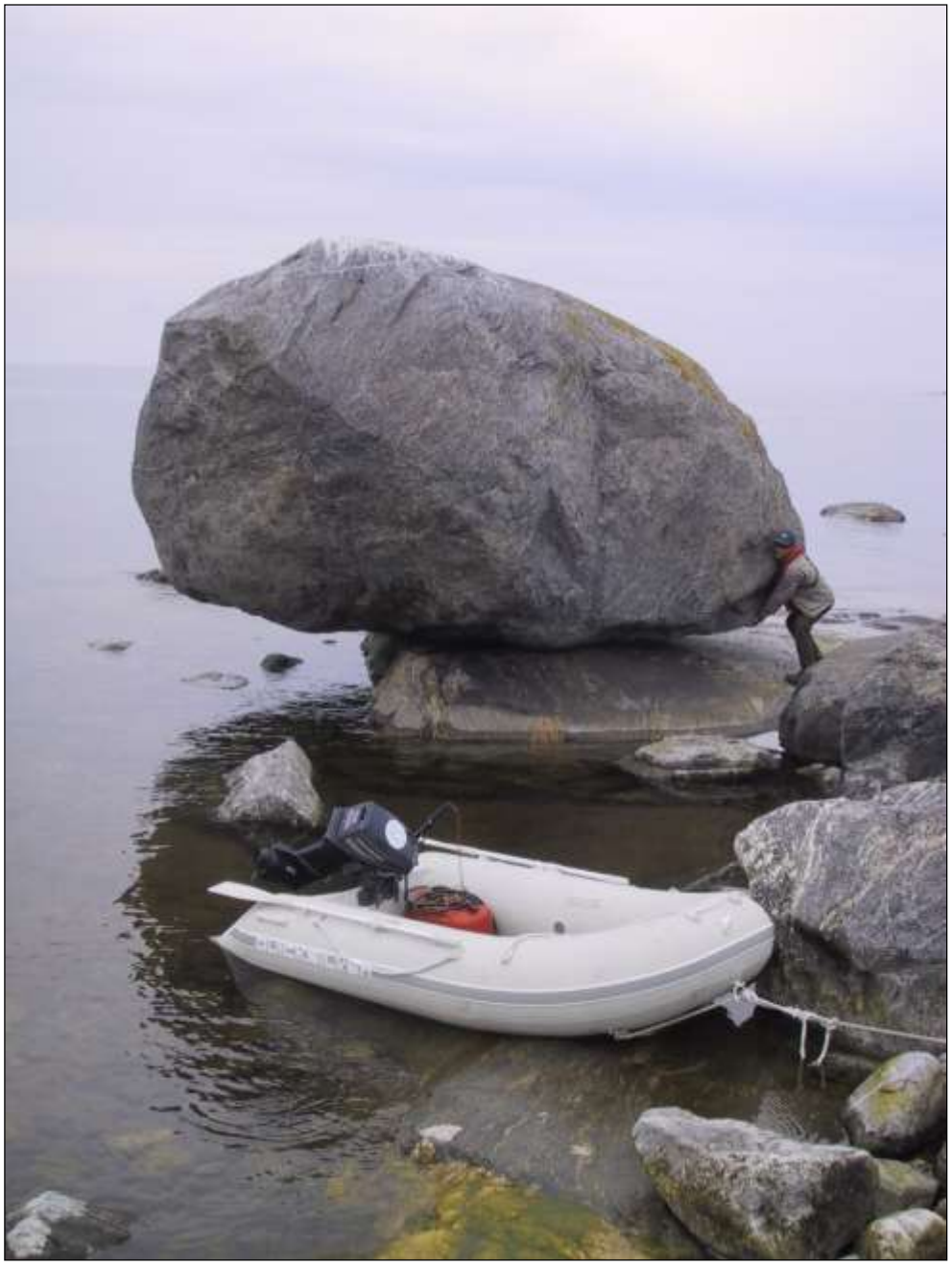

Figure 2. *"Sampling", Norra Djupörbådan, Finland* (Photo: Hannu Kujala)

The geological history of the crystalline rocks in the Kvarken area starts with turbiditic sedimentation of sand and mud beds on the unknown ancient ocean floor. Volcanic material, lavas and pyroclastites, deposited as intercalated beds and minor constituents within the turbidites. Subsequently, during the orogenic movements 1880 Ma ago (Svecofennian orogeny), this sedimentary pile sank down to about 15 kilometers deep into earth's crust, recrystallised as mica gneisses and veined gneisses, different types of migmatites and finally also partly fused into granodioritic melt. Intercalated mafic volcanic rocks recrystallised as metavolcanites and amphibolites. Due to the partial melting and recrystallisation of the sediments the current, rather heterogeneous rock association in the Kvarken area, called the Vaasa granite (in Finland) and schollen (raft) migmatite or mobilizate (in Sweden), was formed. Abound 1800 Ma ago small late to post-orogenic granitic plutons as well as felsic dikes and pegmatites were intruded. After a inactive period of 200 Ma, about 1570 Ma ago, rapakivi magmas intruded the upper parts of the crust and crystallised as batholites. The felsic rapakivi magmatism was accompanied by mafic magmatism, expressed as diabase (dolerite in Sweden) dykes (Sub-Jotnian) and gabbros intruding the bedrock. Quartz-feldspar porphyries found only as boulders around the coastal area of Vaasa are considered as near surface equivalents to the rapakivi magmatism. The last magmatic event in the Kvarken area was the intrusion of olivine diabases (dolerites) (Post-Jotnian) at1270 Ma.

The Svecofennian orogenic belt had lost much of its mountainous grandeur before the early Mesoproterozoic time and thick sediments, 1400-1200 Ma old, consisting of red Jotnian sandstone deposits covered large areas in Satakunta and Muhos in Finland, and in Nordingrå, Gävle, Dalarn and Småland in Sweden. Extensive Jotnian sandstone deposits have also interpreted to be at the bottom of the Bothnian Sea and the Bothnian Bay, north and south of Kvarken. Small boulders of red sandstone are common in the Finnish coastal area near Vaasa as well as further inland. During stable tectonic conditions successional erosion and sedimentation (e.g. the 600 Ma old, grayish Lauhanvuori sandstone, Finland) continued and the Svecofennian surface flattened to peneplain.

In Cambrian, 520 million years ago, a meteorite hit the Earth’s surface and created impact basin in the SE-corner of the Kvarken area (Lehtovaara 1992). The impact crater provided a shelter to the Cambrian sediments against erosion and abrasion until present time, and thus we have an unique Paleozoic sedimentary record preserved within the Svecofennian schist belt.

Lower Cambrian siltstone in the Bothnian Sea with comparable seismic velocities to the Bothnian Bay sedimentary rocks, north of the Kvarken area, give evidence for the Söderfjärden belonging to the once widespread Cambrian sedimentary strata (Axberg 1980, Winterhalter 2000). Also erratics of sandstone found in many places in western Finland show similarities to the sandstones of Söderfjärden (Laurén et al.1978).

During the orogenic period the sedimentary rocks were ductile deformed and typical gneissic structures, such as polyphase were formed. Later the bedrock has been rigidly deformed seen as jointing and faulting. A major shear zone (The Merenkurkku shear) runs from south of the Söderfjärden impact basin to northwest towards Kvarken. According to seismic reflection data the thickness of the Earth’s crust in the Kvarken area is estimated to be over 50 kilometers (Korja et al. 2001).

3 PALEOPROTEROZOIC ROCKS

3.1 Paleoproterozoic supracrustal rocks

3.1.1 Mica gneisses and veined gneisses

The metasedimentary rocks of the Kvarken area are grey, fine-grained and more or less tectonically foliated and banded rocks of greywacke and argillitic origin (Figs. 3 and 4). In Sweden they belong to the Härnö group, which forms a continuation of the Pohjanmaa or Bothnian shist belt in Finland (Lundqvist 2000). In the Swedish part of the Geonat area, these rocks have been metamorphosed to sedimentary gneisses grading to veined gneisses (Fig. 4), and in areas of stronger partial melting they occur as veined gneisses grading to schollen migmatites (Fig. 5) and mobilizates (Fig. 6 and 7). Locally the veined gneisses are rich in garnet, and feldspar porphyroblasts occur in the mobilizates. The meta-arenitic parts of the sedimentary gneisses have densities between 2601 and 2803 kg/m^3. The magnetic susceptibility is generally low, between 5 and 200 x10^{-5} SI-units in the meta-arenites and between 5 and 630 x10^{-5} SI-units in the meta-argillites, where the highest values are found in graphite- and pyrrhotite-bearing horizons. Spectrometer measurements show potassium contents between 1.9 and 3.6 %, uranium between 1.8 and 8.9 ppm and thorium between 11.0 and 54.0 ppm. The gamma index, $m_{\gamma,}$ is 0.5 – 1.8.

Figure 3. *Thin veining and pegmatite dyke in mica gneiss, Korsnäs, Finland. Length of the scale bar is 16 cm. (Photo: Pekka Sipilä).*

Figure 4. *Sedimentary gneiss with thin veining, Bjännön, Sweden. (Photo: Oskar Sigurdsson).*

Figure 5. *Veined gneiss to schollen migmatite, Kont, Sweden. (Photo: Leif Björk).*

Figure 6. *Strongly migmatized metasedimentary rock/mobilizate with restite of meta-arenite and micaschlieren and cut by a narrow pegmatite dyke, Kronören, Sweden. (Photo: Leif Björk).*

Figure 7. *Concentric skarn restites in schollen migmatite to mobilizate, north of Norrbyn, Sweden. Length of the hammer is 60 cm. (Photo: Oskar Sigurdsson).*

Also in Finland varying metamorphic conditions caused recrystallisation and formation of veined gneisses, ductile deformation (Fig 8), partial melting and, in an ultimate case formation of crystalline plutonic rocks. Schollen migmatites and mobilization are common in Finland. Graphite- and pyrrhotite-bearing schists as well as mafic metavolcanic rocks occur as intercalated layers within the mica and veined gneisses. Graphite- and pyrrhotite-bearing rocks are eroded deeper than the surrounding gneisses and, hence, are rarely seen in outcrops, but on geophysical maps they can be traced as long and narrow anomalies displaying the general structures of the gneiss complex. In the more migmatized rocks restites of meta-arenite, mafic metavolcanic rock and skarn reveal the sedimentary origin. Calc-silicate concretions, round nodules, generated at the time of consolidation of the sediments, are common.
Mineralogically these metasedimentary rocks of the area are mainly composed of quartz, plagioclase and biotite. Alkali feldspar, muscovite, chlorite and opaques occur to a lesser extent. Garnet, cordierite and sillimanite porphyroblasts are present in varying amounts. Accessory minerals are apatite, epidote, and zircon.

Figure 8. *Ductile deformation in veined mica gneiss. Restites of skarn- and pyrrhotite- bearing gneiss. Storsanden, Finland. Length of the scale bar is 16 cm. (Photo: Antero Lindberg).*

3.1.2 Mafic and intermediate metavolcanic rocks

Volcanic rocks are rare in the Geonat-area around Kvarken. On the Finnish side mafic metavolcanics have been found south of Rönnskär (Fig. 9), from drill holes in Korsnäs and Raippaluoto, in the western side of the island of Molpe and in the eastern part of Halsö (Nykänen 1960a). These basaltic and andesitic volcanogenic rocks occur as narrow tongue-shaped intercalated beds within the mica and veined gneisses. These greenish, hornblende- and cummingtonite-bearing schists have a striped and foliated appearance due to metamorphism, but in some places pyroclastic and pillow lava structures are still recognizable (Breilin et. al 2005).

In Sweden mafic metavolcanic rocks have their largest occurrence on the peninsula of Järnäs but occur also as thinner intercalations and fragments in the metasedimentary rocks, pre-dominantly in the area between Umeå and Nordmaling. These mafic metavolcanic rocks are grey to dark grey, mostly fine-grained and tectonically foliated and banded (Fig. 10). Hornblende and plagioclase constitute between 60 and 80 % of the rock and biotite and quartz between almost 40 and 20%. Accessory minerals are muscovite, zircon and alkali feldspar. The magnetic susceptibility is commonly 50 – 250 x 10^{-5} SI-units but measured values range from 40 – 1000 x10^{-5} SI-units. The potassium content is about 1.7%, uranium 2.0 ppm and thorium about 5.5 ppm according to spectrometer measurements. The gamma index, $m_{\gamma,}$ is 0.37.

Figure 9. *Mafic metavolcanic rock at Rönnskär, Finland. Length of the label is11 cm. (Photo: Petri Virransalo).*

Figure 10. *Banded mafic metavolcanic rock/amphibolite, Bådahällsviken, Sweden. (Photo: Oskar Sigurdsson).*

3.2 Paleoproterozoic plutonic rocks

3.2.1 Synkinematic plutonic rocks

Granites, granodiorites, tonalites.

On the Finnish side of the Kvarken area are also heterogeneous, coarse-grained rocks, which can be divided into porphyritic and even-grained types These rocks are known as Vaasa granite, but have also been called as diatexites (Lehtonen et al. 2005, Breilin et al. 2004, Mäkitie 2000). On the Swedish side these heterogeneous rocks correspond approximately to so called mobilizates. According to Mäkitie (2000) two types of diatexites can be found in Ostrobothnia, i.e. biotite and pyroxene diatexites. In the Finnish Geonat area no pyroxene has been found in these rocks. The rocks called the Vaasa granite are generated from partial melting and recrystallization of the Evijärvi metasedimentary rocks (Mäkitie 2000; Sipilä et al. 2008; Suikkanen et al. 2014). The mineralogical and chemical composition of the Vaasa granite is

generally granodioritic, but there are also granitic and tonalitic variations These rocks are most homogenous and plutonic in appearance at Alahärmä and Lapua to the east of the Geonat area, but there are extensive homogenous parts also within the Geonat area. Between the texturally plutonic units the rock can

Figure 11. *Coarse-grained porphyritic granodiorite, so-called Vaasa granite, Östra Norrskär, Finland.* (Photo Pekka Sipilä).

be very heterogeneous even in the scale of outcrops (Sipilä et al. 2008). In the Geonat bedrock map (Appendix 1) the homogenous units are shown as granodiorite and the heterogeneous parts as granodiorite with mica gneiss symbols. The porphyritic type is quite extensive, homogeneous, non-foliated and extremely sound rock with a typical plutonic appearance. It contains large, several centimeters long feldspar megacrysts (Fig. 11). In places intrusive contacts between porphyritic rock and mica gneiss are seen (Fig. 12). The equigranular type is more heterogeneous (Fig. 13). In some areas relics of partly melted mica gneisses, fragments of psammitic, calc-silicate beds and calcareous concretions indicate the source rock. Garnet and biotite are common, and occasionally sillimanite and cordierite as well as small dark garnet-biotite restite 'drops' are present. The heterogeneous, equigranular rock grades commonly to a porphyritic type. In the heterogenous rock type partly crystalline crystal mush has surrounded conformly the roundish gneiss inclusions. The sulphide-bearing mica gneiss layers have best been preserved from the partial melting. Mäkitie (2000) has established a U-Pb monazite age of 1872±5 Ma for the porphyritic granodiorite. According to Suikkanen et.al. (2014) the U-Pb age from four magmatic zircon crystals separated from Vaasa granite is 1.88−1.89 Ma.

Figure 12 . *Intrusive contact between coarse-grained porphyritic granodiorite and veined mica gneiss,Raippaluoto, Finland. Vertical part of the granodiorite is about 50 cm in thickness. (Photo: Pekka Sipilä).*

Figure 13. *Mica gneiss inclusions in heterogenous, even grained granodiorite, Klubbskatan, Finland. Length of the scale bar is 16 cm. (Photo: Pekka Sipilä).*

On the Swedish part of the Geonat area synkinematic granite to granodiorite is the most frequent plutonic rock. Around Nordmalingsfjärden it is mostly greyish, fine- to medium-grained, and porphyritic (Fig. 14). To the east and south of Umeå, some granitic to granodioritic rocks are augen-bearing and xenoliths of sedimentary gneiss and mafic to ultramafic rocks occur. Other occurences are rather homogeneous (Fig. 15) and grade partly into tonalitic varieties. Some quarries for dimensional stone (now abandoned) and aggregate production, have been established in these granodiorites to tonalites. Quartz, plagioclase and alkali feldspar dominate the rocks, biotite, muscovite, amphibole and pyroxene are subordinate phases, and sphene, calcite, opaques, epidote, zircon and apatite commonly occur in minor amounts.
In areas where the surrounding metasedimentary rocks show sign of strong metamorphic alteration, the synkinematic granitoids locally are recrystallized. The augen-bearing to porphyritic granite to granodiorite generally has low magnetic susceptibility, 18 – 50 x 10^{-5} SI-units, and its magnetic remanence is also low. The density varies between 2639 and 2820 kg/m^3. Spectrometer measurements show a content of potassium of 1.7 to 3.6%, uranium 0.8 – 6.2 ppm and thorium 7.3 – 32.7 ppm. The gamma index, $m_{\gamma,}$ is 0.87 – 1.37. Corresponding values for the homogeneous granite to granodiorite are potassium 1.9 – 3.6%, uranium 1.3 – 4.9 ppm, and thorium 7.1 – 9.7 ppm, and for more tonalitic varieties potassium 1.3 – 3.0%, uranium 1.3 – 4.9 ppm, thorium 6.4 – 11.5 ppm. The gamma index, $m_{\gamma,}$ is 0.38 – 0.69 for the granite to granodiorite and 0.32 – 0.75 for the granodiorite to tonalite.

Figure 14. *Medium-grained augen-bearing to porphyritic synkinematic granite to granodiorite, Lill-Simpan, Sweden. (Photo: Leif Björk).*

Figur15. *Fine-to medium-grained synkinematic granodiorite with a quartz-feldspar xenolith,* Norrbyskär, Sweden. (Photo: Leif Björk).

3.2.2 Ultramafites, gabbros, diorites, quartz monzodiorites.

During ore exploration diamond drilling in Korsnäs in Finland has relieved tens of meters of thick, conformable horizons of ultramafics in the mica gneisses (Nykänen 1960 a, b). The ultramafics are medium-grained hornblendites, pyroxenites and serpentinites. A nickel deposit in a metadunite has been found in Oravainen in Finland, situated just off the coast line (Isohanni 1985). Ultramafic rocks are found as boudinaged fragments in mica and veined gneisses, as well as in the Vaasa granite. These fragments are considered to originate from an ultramafic magma intruding the sedimentary rocks before the main deformation phase in that area. The Tistronskär gabbro, south of Raippaluoto, is exposed only at a few small islands (Lehtonen et al. 2005). On the geological map this gabbro is delineated from the magnetic anomaly pattern on the geophysical map. The anomaly is approx. 1 x 13 kilometers in size. Geochemically, the Tistronskär gabbro is a quartz-monzogabbro and has a slightly alkaline chemical characteristic. The exact age of the gabbro is unknown, however, it is considered to be older than the main deformation phase, and in places near the Tistronskär gabbro inclusions are found in the granodiorite indicating the Tistronskär gabbro being older than the granodiorite. Some of the inclusions are roundish whereas some are angular (Fig. 16). A few gabbroic outcrops have also been found near the village of Molpe in Korsnäs, Finland.

Figure16. *Gabbro enclave in mobilized and ductically deformed host rock, in which only relicts of mica gneiss are left, Storsanden, Finland. Length of the scale bar is15 cm. (Photo: Antero Lindberg).*

In Sweden a number of minor mafic bodies ranging in composition from ultramafite to diorite (Fig. 17) occur among the metasedimentary rocks and synkinematic granitoids. Most of them are small, only the grey to dark grey, medium-grained, massive to weakly foliated quartz monzodiorites to diorites (Fig. 18) associated with the synkinematic granitoids east of Umeå reach an extension which may be represented at the actual map scale. The mafic rocks have high densities, between 2919 and 3045 kg/m^3, the magnetic susceptibility is 35 – 5500 x10^{-5} SI-units and the remanent magnetization, the Königsberg ratio, is 0.50 – 1.75. The natural gamma radiation is low; the potassium content is 0.3%, uranium 0.2 ppm and thorium1.0 ppm. The gamma index, $m_{\gamma,}$ is 0.06.

Figure 17. *Diorite or amphibolite of uncertain origin, Ansmark, Sweden. (Photo: Leif Björk).*

Figure 18. *Medium-grained quartz monzodiorite, Stöningsberget, Sweden. (Photo: Leif Kero).*

3.2.3 Late and postkinematic rocks

Granites, pegmatites, aplites

Some latekinematic granites are situated on the Finnish side, north of Kvarken. In the area of Punakarit islands, northeast of Raippaluoto, there is a red, porphyritic, coarse-grained granite with a magmatic flow structure (Fig. 19). The zircon U-Pb age of the granite is 1866 ±7 Ma (Huhma pers.comm). This granite has been quarried for dimension stone use in the 19th century and has been used in many buildings in the Vaasa area. Coarse-grained, reddish or white pegmatites as well as light-colored, fine-grained aplite granites are common in the areas occupied by mica gneisses, veined gneisses and synkinematic plutonic rocks. Pegmatites usually form conformable bodies, but occasionally they crosscut the gneisses. Aplites often occur as narrow dikes.

***Figure 19**. Magmatic flow structure in coarse grained, porphyritic granite, Punakarit, Finland. (Photo: Pekka Sipilä).*

In Sweden latekinematic granite occurs among the metasedimentary rocks, especially in the area east of Nordmaling. It is mostly red to reddish light grey and fine-grained (Fig.20) with transitions into coarser grained pegmatitic granite. The mix of fine-grained granite and pegmatite is typical for Härnögranite. It has fragments of sedimentary gneisses and mafic rocks, and dykes of pegmatite and aplite are frequent. These dykes are also common in the metasedimentary rocks and the synkinematic granitoids. They are not shown on the present 1: 200 000 scale Geonat bedrock map but on the 1: 50 000 scale bedrock maps (Nilsson & Kero 1989, Björk & Kero 1992). Härnögranite is mainly composed of quartz (ca. 30%), alkali feldspar (ca. 40%), plagioclase (ca. 15%) and biotite and muscovite (a little more than 10%). Both magnetic susceptibility and density of the granite are low, 0 – 10 $x10^{-5}$ SI-units and 2595 – 2652 kg/m^3. The potassium content is between 4.5 and 6.4%, uranium 3.2 – 9.7 ppm and thorium 20.1 – 78.1 ppm. The gamma index, $m_{\gamma,}$ is 1.01 – 2.65.

Figure 20. *Fine-grained, latekinematic granite, Härnö granite, Strömsör, Sweden. Length of the GPS gadget is14.5 cm. (Photo: Leif Björk).*

Feldspar porphyry dykes

At the Vaskiluoto beach and on the islands outside Vaasa, light-red feldspar porphyry dykes intrude the mica gneiss. The dykes range from a few centimeters to five meters in thickness. Feldspar phenocrysts occur even in the thinnest of the dykes. There appear to be no prevalent direction of the dykes, which crosscut the mica gneiss and the porphyritic granodiorite, at the same time brecciating it (Fig. 21). Radiometric dating on zircon gives the dyke an age of ca. 1.8 Ga (Lehtonen et.al., 2005).

Figure 21. *Inclusions of porphyritic granodiorite (Vaasa granite) in the feldspar porphyre dyke at Domarskäret island outside Vaasa, Finland. Length of the drawing pen is 12 cm. (Photo: Pekka Sipilä).*

Carbonatites

The host rock for the Pb-mineralisation in Korsnäs in Finland, mined between 1961-1972, is carbonate rock, which on the basis of its trace elements is considered to be magmatic (Papunen 1986). The carbonatite is heterogeneous and fragmented by pegmatites. It has been interpreted to represent a dyke emplaced in a fracture zone. The most common skarn mineral is diopside and many kind of mineral accretions occur. During drilling montmorillonite-filled cavities with crystalline mineral aggregates were found. The most typical well developed crystals filling the cavities are calcite, but also apophyllite, harmotome, barite, celestine and pyrite were present. The apatite of the ore had exceptionally high REE-concentrations. A titanium age of ca1825 Ma from the ore is considered to represent the age of the ore deposit.

4 MESOPROTEROZOIC ROCKS

4.1 Subjotnian diabases

On the Geonat-area no Subjotnian diabase dykes have been found in outcrops. In Raippaluoto, in Finland, east-west situated magnetic anomalies, which are narrow, parallel and rectilinear, may indicate the presence of a Subjotnian dyke swarm.

4.2 Sedimentary rocks of the Gulf of Bothnia

The present knowledge of the distribution of sedimentary rocks at the bottom of the Gulf of Bothnia is based on boulders found in the Finnish coastal area, a few drill holes and on interpretation of geophysical data (Winterhalter 2000, Koistinen et al. 2001). Extensive deposits of Mesoproterozoic Jotnian sandstone lie at the bottom of the Bothnian Sea and in the Bothnian Bay area. The Jotnian sandstone has been covered by later Neoproterozoic (Riphean and Vendian) siltstones and sandstones, and then by Paleozoic (Cambrian) sandstones and siltstones. The deep-seismic studies indicate the presence of a sandstone basin several kilometers of thick in the Gulf of Bothnia (BABEL Working Group 1993).

4.3 Rapakivi granites

Within the Kvarken area rapakivi granites outcrop only on a small skerry called Bonden in Sweden. The rock is red, medium-grained, massive, quartz-porphyritic rapakivi granite (Fig. 22), which is cut by thin, irregularly shaped dykes of fine-grained, massive, quartz-porphyritic, ”aplitic” rapakivi granite (Fig. 23) . Both granites are penetrated by thin, fine-grained quartz rich veins and fine-grained granite porphyry veins. The rapakivi granite has a syenogranitic composition with alkali feldspar (ca. 50%) and quartz (ca. 35%) dominating and a combined plagioclase and sericite content of 10%. Opaques, biotite, chlorite, epidote, hornblende, zircon and fluorite occur in minor amounts. U-Pb-dating of zircon from the Bonden Rapakivi granite gave an age of 1574+15/-9 Ma. This dating, ordered by the Geonat project, was carried out by the Laboratory for Isotope Geology, Swedish Museum of National History, Stockholm. Palaeomagnetic studies have been performed on the granite. The fine-grained dyke has a high coercivity and a stable remanence. The correspondence with the Nordingrå granite, which has been dated to 1580 Ma, is good. The magnetic susceptibility of the rapakivi granite is rather high, 965 – 1340 $x10^{-5}$ SI-units, with some high values from the ”aplitic” granite, which also has a stable magnetic remanence in highly demagnetized fields. Spectrometer measurements indicate a potassium content between 5.2 and 5.9%, and an uranium content between 4.3 and 10.4 ppm, with higher values in the ”aplitic” granite. A thorium content between 34.1 and 34.9 ppm is measured in the quartz-porphyritic Rapakivi granite and 48.0 – 52.7 ppm in the ”aplitic” granite. The gamma index, m_{γ}, is 1.41 – 1.75 in the quartz porphyritic Rapakivi granite and 1.69 –2.11 in the”aplitic” granite.

Figure 22. *Medium-grained, quartz-porphyritic Rapakivi granite, Bonden, Sweden. Photo: Leif Kero).*

Figure 23. *Medium-grained, quartz-porphyritic Rapakivi granite with a dyke of fine-grained,"aplitic" Rapakivi granite, Bonden, Sweden. (Photo: Leif Kero).*

4.4 Post-Jotnian diabases (dolerites)

The Post-Jotnian, dark diabases (also known as dolerites) in the Finnish Kvarken area (Figs. 24 and 25) form voluminous sills and dykes, which in the Vaasa archipelago run mostly in NNW-direction, and are interpreted to be nearly horizontal. The diabases are unmetamorphosed and have an ophitic texture typical to even the fine-grained diabases. Contacts are crosscutting and sharp, but no contact metamorphism is observed. The thicker diabases have ca one meter thick, fine-grained, chilled margins showing that the emplacement took place in hybabyssal conditions near the surface. Some of the diabases in the Rönnskär area, in Finland, contain narrow feldspar, carbonate, amphibole and scapolite veins. Curved fractures are common. Radiometric age determination of the olivine diabase from Molpe, Korsnäs, gives an age of 1268±13 Ma (Suominen 1991).

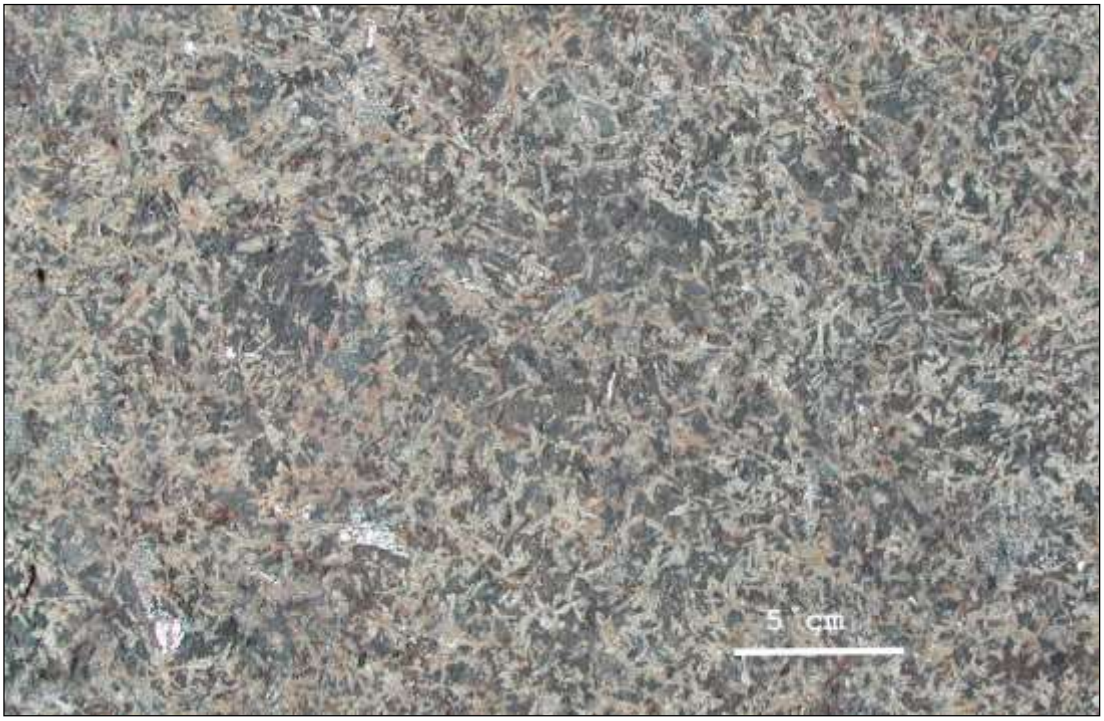

Figure 24. *Ophitic texture in olivine diabase, Rönnskär, Finland. (Photo: Antero Lindberg).*

Figure 25. *Curved fractures in olivine diabase, Strömningsbådan, Finland. (Photo: Pekka Sipilä).*

In the southern parts of the Swedish Geonat area the dolerite occurs as gently dipping sills covering relatively large areas and as narrow, steeply dipping dykes, which strike in a WNW direction. Locally, thicker sills have clearly visible layered structures (Fig. 26) and thin dykes have chilled margins (Fig. 27, 28). The dolerite of the area is a dark grey, locally greenish black, fine- to coarse-grained rock with doleritic texture. Large number of N-S-striking dykes are mainly located east of Nordmaling and south and east of Umeå. The N-S dolerites east of Nordmaling have influenced the orientation of drumlines, which seem to occur in areas between the scars left by eroded parts of dolerite dykes. The dolerite consists of ca. 65% plagioclase, ca 20% olivine, ca 10% clinopyroxene and the remaining minerals are among others magnetite, biotite and apatite. The density of the diabases is between 2968 and 3058 kg/m^{3}and the magnetic susceptibility is mostly between 870 and 6980 x10^{-5} SI-units. These values are almost similar to those reported from Ulvödolerite at Nordingrå (Larsson & Magnusson 1976, Magnusson 1976, Mattson & Elming 2003, Elming et al 2004). The Königsberg ratio is 0.34 – 1.92. The potassium content is between 0.8 and 1.0%, uranium 0.1 – 0.4 ppm and thorium 2.0 – 2.6 ppm. The gamma index, $m_{\gamma,}$ is 0.13 – 0.17.

Figure 26. *Dolerite showing layering, the layers are 0.1 – ca1 m thick and gently dipping to the east. Blågrundet, Sweden. (Photo: Leif Björk).*

Figure 27. *Dolerite dykes in mobilizate of sedimentary origin. A thin dolerite dyke cuts a broader one, the pencil is 15 cm long, Kronören, Sweden. (Photo: Leif Björk).*

Figure 28. *Close-up of the dolerite dyke in dolerite of fig. 27. Chilled margin clearly visible to the left, pencil is in the same place as in fig. 27, Kronören, Sweden.(Photo: Leif Björk).*

5 PALEOZOIC ROCKS

5.1 Söderfjärden meteorite crater and Cambrian sandstones and Siltstones

The Söderfjärden meteorite crater, situated 10 kilometers south of Vaasa, forms a nearly circular depression. It has a diameter of 6 kilometers and shows a discontinuous rim of 30-40 m in height (Laurén et al. 1978). Based on gravimetric studies and on drilling data, the crater has an uplifted central part in its basal topography. The age of the impact has been set to ca. 520 Ma ago, a time shortly before the sediment deposition (Anneli Uutela pers. com.). Sandstone and siltstone make up a 250 m thick sedimentary strata in the lower part of the depression basin, and are overlain by glacial overburden of 80 m in thickness. The sedimentary rocks have been dated micropaleontologically to Lower Cambrian (Tynni 1978).

6 ECONOMIC GEOLOGY

6.1 Ore deposits

In 1961-1972 a Pb-ore mine was active in Korsnäs in Finland. Altogether ca. 860 000 tons of ore was quarried with the enriched ore being 45 000 tons. The ore body was approx. 400 meters long and 3-20 meters thick with a Pb-concentration between 3.5-5 %. The occurrence of the Pb-ore is controlled by the carbonatite hosting it in a fracture zone situated in a pegmatite-rich mica gneiss (Papunen 1986).

In the Oravainen bay in Finland a Ni-mineralisation has been localised in the sea bottom at a depth of 8 m and about 1 km from the shore (Isohanni 1985). The mineralisation is situated in an ultramafic pipe-like intrusion with a diameter of 2000 m^2. An inventory of the deposit down to 250 meters depth gives 1.3 million tons of ore with approx. 0.95 % Ni and 0.16 % Cu. Around the airport of Vaasa peridotite boulders with elevated concentrations of Ni and Cu have been reported (first layman sample: Ni 0.7 % and Cu 0.2 %, Paraisten Kalkki Oy 1977). However, although local drilling has taken place the origin of the boulders is unknown.

6.2 Dimension stone deposits

In the area of Punakari islands, northeast from Raippaluoto, in Finland is a red, porphyritic, coarse-grained granite showing magmatic flow structures (Figure 11). This granite was quarried for dimension stones in the 19th century, and has been used in many buildings in the Vaasa area.

6.3 Aggregate quarries

Gravel occurs sparsely in the area and bedrock aggregates have been used to substitute gravel.
In the Kvarken area in Finland is several aggregate quarries, both active (Fig 29) and abandoned. Nearly all of them are in synkinematic granitoids. During 2005 twelve (18) quarries were active on the on the Finnish Geonat area. The number of the abandoned quarries is estimated to be about 20.
To estimate the qualities and quantities of the bedrock aggregates a local investigations was made in Pohjanmaa at the end of the 20th century (Britschgi et al 1999). The bedrock aggregates for each commune were specified. Table 1 shows the results of the investigation for the Finnish Geonat area. Rocks with technical properties suitable for very high quality demands have not been found in the region. This has led to exploitation of rock material of slightly inferior quality.

Figure 29. *Aggregate quarry at Mustasaari, Finland. (Photo: Pekka Sipilä).*

In the year 2006 there was about nine aggregate quarries operating on the Swedish site of Kvarken and its closest vicinity (Fig. 30). Most of them are located in synkinematic granitoids and quartz monzodiorite to diorite (Fig. 31) and some in sedimentary gneiss. Table 2 shows results from Swedish analyses done within the frames of this project. The laboratory of Mark Radon Miljö (MRM) at Luleå carried out the analyses. When evaluating the results it is important to consider that contractors by sophisticated crushing techniques to some extent are able to improve the technical properties of some rock materials.

Figure 30. *Aggregate quarries in the map area and its nearest surroundings in Sweden in 2006.*

Figure 31. *Aggregate quarry in synkinematic tonalite to quartz monzodiorite, south of Bergsboda,* Sweden. (Photo: Leif Björk).

Table 1. Estimated number of aggregate formations for each commune, partly outside the Geonat area. The limit value between the hard rock (LA-value <30) and the bulk rock (LA-value >30) is set for the Los Angeles value of 30. (Source: GTK register of hard rock aggregates in Finland).

Commune *Kunta* *Kommun*	*Number of Formations* *Muodostumien määrä* *Antal förekomster*	*Area of formations (ha)* *Muodostumien pinta-ala (ha)* *Förekomsternas yta (ha)*	*Quantity (mill m³)* *Määrä (milj. m³)* *Kvantitet (milj. m³)*		*Total (mill.m³)* *Kokonaismäärä (milj. m³)* *Totalt (milj. m³)*
			Hard rock *Kova kivi* *Bättre berg-material*	*Bulk rock* *Massakivi* *Sämre berg-material*	
Korsnäs	8	68	1.5	7.9	9.4
Maalahti Malax	46	489	4.6	46.1	50.7
Maksamaa Maxmo	38	144	0.02	19.7	19.72
Mustasaari Korsholm	89	364	0.5	52	52.5
Oravainen Oravais	23	76	6.8	3.9	10.7
Uusikaarlepyy Nykarleby	107	1047	1.1	138.2	139.3
Vaasa Vasa	15	26	0.1	2.7	2.8

Table 2. Technical properties for selected rocks of the Swedish map area.

Type of rock *Kivilaji* *Bergart*	*Density* *Tiheys* *Densitet*	*Studded tyre test value* *Kuulamyllyarvo* *Kulkvarnsvärde*	Los Ange-les value LA-luku *LA-tal*	*micro-Deval value* *micro-Deval arvo* *micro-Devalvärde*	*Quality class* *Laatuluokka* Kvalitetsklass		*Locality* *Näytteenotto-paikka* *Provtagnings-lo-kal*
Granite - granodiorite, augen-b.	2.68	12.6	26.2	7.9	2		Rundvik
Sedimentary gneiss	2.71	13.1	15.9	9.7	2		Järnäs
Sedimentary veined gneiss	2.71	14.8	22.7	10.1	2		N of Drivan
Granite - granodiorite	2.70	14.8	26.5	9.8	2		Korsmyran
Granodiorite	2.79	14.9	17.5	11.3	2		Ersboda
(ca. 1.8 Ga, Lehtonen et al. 2005)Dolerite	2.98	15.0	21.7	11.4	2		Järnäs
Dolerite	3.00	15.0	23.3	11.0	2		Kronören
Granite, latekinematic	2.65	15.0	29.6	9.5	2		Porsmyran
Diorite	2.84	15.8	21.0	12.3	2	Quarry	N of Levar
Granite - granodiorite. augen-b.	2.75	16.7	22.9	12.4	2		Yttertavle
Quartz monzodiorite - to-nalite	2.78	17.6	22.7	12.8	2	Quarry	Bergsboda
Granodiorite - tonalite	**2.73**	**17.6**	**25.9**	**11.8**	2	Quarry	Svartberget
Granite - granodiorite	2.79	19.9	27.0	15.0	3		Sörböle
Sedimentary veined gneiss	2.70	20.2	27.6	16.0	3	Quarry	N of Nordmaling
Amphibolite	2.97	26.6	28.1	21.0	3		Bergöbron
Granite, latekinematic	2.66	14.7	31.0	9.3	3		Strömsör
Sedimentary veined gneiss	2.71	28.5	32.3	22.0	3		Täfteå
Amphibolite	2.84	29.0	34.1	24.0	3		Ansmark
Pegmatite	2.59	13.4	34.7	7.8	3		Bergöbron

7 SUMMARY / YHTEENVETO

The bedrock of the Kvarken area consists mainly of Paleoproterozoic supracrustal and plutonic rocks belonging to the Svekofennian province of the Fennoscandian Shield. Metasedimentary mica gneiss and various migmatites prevail. Due to the partial melting and simultaneous deformation of the metasedimentary rocks a heterogenic rock, typical of the Kvarken area, was formed. Traditionally, it is called Vaasa granite in Finland (1872±5 Ma, Mäkitie 2000; 1.88 Ga, Suikkanen et al. 2014) and mobilatetes in Sweden. The rock contains potash feldspar megacrysts, which are usually large. In places, the rock has a fully intrusive appearance, which is rarer in Sweden than in Finland. In Kvarken area volcanic rocks are rare and occur as interbeds within the mica gneiss. On the Swedish side, synkinematic granites and graniodorites are the most common intrusive rock types. However, Paleoproterozoic diorites, gabbro and ultramafic intrusive rocks are rare in the entire Kvarken area. Punakari granite (1866 ± 7 Ma; Huhma, pers comm.), feldspar porphyry dikes at Vaasa archipelago (ca. 1.8 Ga; Lehtonen et al. 2005) and Korsnäs carbonatite (1825 Ma) are late-and postkinematic rocks in Finnish side. In Sweden, this group also includes the Härnö granite to the east of Nordmaling. Mesoproterozoic rocks in the area include the Bonde rapakivi granite (1574+15/-9 Ma) in Sweden and the Gulf of Bothnia's sedimentary rocks and Postjotnian olivine diabase veins (1268±13 Ma; Suominen 1991). Paleozoic Cambrian sandstones and siltstones in the Söderfjärden meteorite crater are the youngest rocks in the area.

Merenkurkun kallioperä koostuu pääosin paleoproterotsooisista suprakrusisista ja plutonisista kivistä. Ne ovat osa Fennoskadian kilven Svekofennian provinssia. Vallitsevina ovat sedimenttisyntyiset kiillegneissit ja erilaiset migmatiitit. Metasedimenttien osittaisen sulamisen ja samanaikaisten liikuntojen seurauksena syntyi Merenkurkun alueelle tyypillinen heterogeeninen kivi, jota Suomen puolella on perinteisesti kutsuttu Vaasan graniitiksi (1872±5 Ma, Mäkitie 2000; 1.88 Ga, Suikkanen et al. 2014) ja Ruotsin puolella mobilaatiksi. Kivi sisältää yleisesti suuria kalimaasälpähajarakeita, ja paikoin se on asultaan täysin syväkivimäinen. Kuitenkin syväkivimäiset osat ovat Ruotsin puolella harvinaisempia kuin Suomessa. Vöyri tyypin graniitit Suomen puolella ovat anatektisen sulamisen viimeisiä kiteytymiä. Vulkaanisperäisiä kiviä Merenkurkun alueella on vain vähän ja ne ovat välikerroksina kiillegneisseissä. Ruotsin puolella synkinemaattiset graniitit ja granodioriitit ovat yleisimmät syväkivityypit. Paleoproterotsooiset dioriitit, gabrot ja ultramafiset syväkivet ovat sen sijaan harvinaisia koko Merenkurkun alueella. Myöhäiskinemaattiseen ikäryhmään Suomen puolella kuuluvat Vaasan saariston maasälpäporfyyrijuonet (ca. 1.8 Ga; Lehtonen et al. 2005) ja Punakarin graniitti. Korsnäsin karbonatiitista on 1825 Ma:n ikä. Ruotsissa tähän ryhmään kuuluvat Nordmalingin itäpuoliset Härnön graniitit. Mesoproterotsooisia kiviä alueella ovat Bonden rapakivigraniitti (1574+15/-9 Ma) Ruotsissa ja Pohjanlahden sedimenttikivet sekä Postjotuniset (1268±13 Ma; Suominen 1991) oliviinidiabaasijuonet. Paleotsooiset Kambrikauden hiekka- ja silttikivet Söderfjäderin meteoriittikraaterissa ovat alueen nuorimpia kiviä.

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9 APPENDICES

Appendix 1. Electronic map of the Kvarken area.
http://tupa.gtk.fi/kartta/erikoiskartta/ek_101_100dpi.pdf