33 IGC excursion No 16, August 16 – 21, 2008

33 IGC, The Nordic Countries

100 years of migmatite - In Sederholms footsteps

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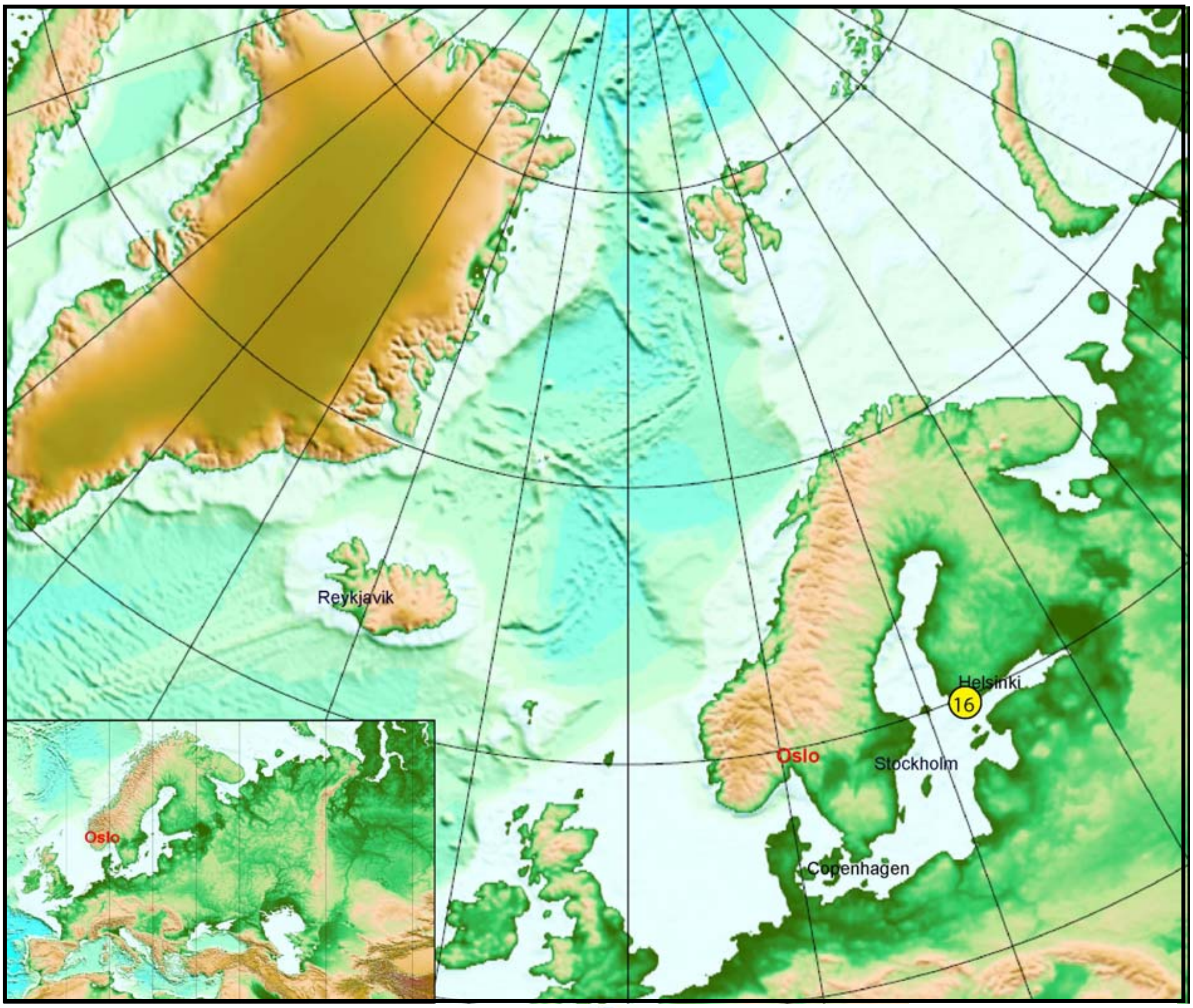

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Abstract

The inspiration for the Sederholm Symposium at the 33rd IGC in Oslo, and this related excursion was to acknowledge the passing, in the year 2007, of one hundred years since J.J. Sederholm (1863 – 1934) published his paper "Om granit och gnejs, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia " (On granite and gneiss, their origin, relations and occurrence in the Pre-Cambrian complex of Fenno-Scandia). This paper can be seen as the catalyst for research in crustal melting processes. Viewed from the perspective of a century ago, and in the light of his other published work, Sederholm's contribution was remarkable because of its wide scope, from analysis of processes in outcrop, to the regional scale, and his determination to apply actualistic principles to ancient and seemingly intractable terrain. This excursion is designed visit some of Sederholm´s key localities, enabling us compare his 100 year old observations with the latest data and interpretations from the same area. The excursion will focus on the regional evolution of the accretionary arc-complex of southern Finland, with particular emphasis on the formation of migmatites during the regional high grade metamorphism between 1840 and 1805 million years ago. The excursion also includest several other areas described by Sederholm, such as the earliest known well preserved volcanic and sedimentary rocks in southern Finland, at Enklinge, and several key localities that illustrate Sederholm's classification of four granite generations in southern Finland.

Logistics

Dates and location

Timing:	**From 16.8 to 21.8 2008**
Start location:	**Helsinki**
End location:	**Helsinki**

Travel arrangements

We will meet in the Mineral Cabinet, in the Arppeanum Building in central Helsinki.
Street address: Snellmanninkatu 3 (Next to the Lutheran cathedral) at 10 a.m. on Saturday 16.8.

At the end of the excursion (late afternoon on Thursday 21.8) participants will be brought either to the Helsinki airport or to the Helsinki city centre.

Accommodation

We will stay in small hostels and cabins during the archipelago trip. No sleeping gear needed.

Field logistics

From Helsinki, we will go by boat along the southern coast out to the Turku archipelago and the Åland Islands. On our way back, we will be picked up by mini-buses at Kustavi, which will drive us back to Helsinki via Turku.

The weather in Finland is usually pleasant in the middle of August (sunny, about 20 Cº daytime and 10 Cº night time). However, be prepared for wind and rain. There will be no long or strenuous hiking on the trip, so sturdy boots are not really necessary. If windy, it may be difficult to get into and off the boat on small skerries, so that the program may need to be improvised windy days.

A brief regional geological outline

The pre-Cambrian of Finland may roughly be divided into two major provinces – the Archean Karelian craton in the northeast of the country, to which a succession of Paleoproterozoic arc complexes were accreted, between 1.91 – 1.87 Ga, during the Svecofennian orogeny. The former suture zone in central Finland is today characterized by relatively thick crust, with a Moho between 55-60 km, from which it is inferred that thickness during collision may have exceeded 70 km (Korja et al. 1993). This collisional orogenic phase was followed by a further collisional event between 1.84-1.80 Ga, also attributed to continental collision (Lahtinen et al. 2005). Most current interpretations invoke an intervening period of crustal extension between these two collisional events (Lahtinen et al. 2005, Skyttä 2007, Bergman et al. 2008), as well as after the younger event (Eklund et al. 1998, Korsman et al. 1999, Korja & Heikkinen 2005). Irrespective of the validity of these models, the younger (1.85-1.79 Ga collisional phase caused intense reworking of the previously formed crust, manifest as extensive folding, shearing and anatexis associated with a sharply defined zone of enhanced heat flow. The effects of this crustal reworking are a key feature of the present excursion, which for the most part lies within the nearly 100 km wide zone known as the Late Svecofennian Granite-Migmatite Zone (LSGM; Ehlers et al. 1993). Metamorphic overprinting of the older mineral assemblages is recorded by three distinct low-pressure granulite facies domains within the Late Svecofennian Migmatite Zone. From west to east these are the Turku, West Uusimaa and Sulkava domains; the West Uusimaa domain is of additional interest in that it includes the Orijärvi area, where Eskola (1914, 1915) first mapped and defined his metamorphic facies concepts. Only small subareas within the entire zone escaped migmatisation

Subsequent to (or penecontemporaneous with) the metamorphic culmination, the Svecofennian crust of southern Finland and Russian Karelia was intruded by at least 14 small, P-, F-, Ba-, Sr- and LREE-enriched, bimodal, shoshonitic intrusions (Eklund et al., 1998; Väisänen et al., 2000) and carbonatites (Andersson et al., 2006). These small intrusions occur within a relatively narrow 600 km zone extending from Lake Ladoga in Russian Karelia to the Åland archipelago. Based on geochemistry, Eklund et al. (1998) concluded that the shoshonitic magmas stem from an enriched lithospheric mantle affected by carbonate metasomatism. Age determinations indicate that this magmatism occurred between 1815 and 1770 Ma, with most ages centred around 1800 Ma (Eklund et al., 1998; Väisänen et al., 2000). The oldest shoshonitic rocks were emplaced at mid-crustal levels (~4.5 kbar; Väisänen et al. 2000) and the younger in the upper crust, at approximately 2 kbar and less (Eklund et al., 1998; Eklund & Shebanov, 2005; Niiranen, 2000).

After the emplacement of the 1.8 Ga post-orogenic intrusions, there was a magmatically quiet period of 100-200 Ma until the voluminous, anorogenic A-type rapakivi granites and associated anorthosites, gabbros and tholeiitic mafic dyke swarms invaded the crust at roughly 1.6 Ga. The rapakivi granites and associated anorthosites and mafic dyke swarms in SW Finland were emplaced at depths corresponding to pressures of about 1-2 kbar (Väisänen et al., 1994; Shebanov and Eklund, 1997). Consequently, exhumation and uplift between the late

Svecofennian orogenic metamorphic peak and the post-collisional intrusive event must have been fairly rapid, around 3 kbars in 30 Ma (deduced roughly from the range in ages, from 1815 ± 10 Ma to 1770 ± 2 Ma), whereas there seems to have been relatively little exhumation during the 200 Ma prior to rapakiv magmatism.

Excursion Route and Road Log

Our intention on this excursion is to visit some of Sederholm´s key areas in his work on the pre-Cambrian of southern Finland. The major part of the excursion will be in the archipelago of south-western Finland with excellent by ice polished outcrops, where petrographical structures and textures may be studied in detail

Day 1. We will start in the centre of Helsinki for a look at migmatite structures in dimension stones described by Sederholm 1911. In his capacity as Director of the then Geological Commission, Sederholm made great efforts to promote the use of natural stone and to identify appropriate Finnish resources, which were in demand for the nationalist architectural movements in the Nordic countries at the beginning of the 20th century (Ringbom, 1987).

After the city walk, we will board the boat that will take us along the coast to the Obbnäs rapakivi granite where various types of enclaves of Svecofennian rocks are to be found in the local rapakivi granite. The excursion will continue to Barösund in the Inkoo district, where Sederholm made several observations at the spectacular outcrops on the islands. This is the area from where Sederholm conceived the term “ptygmatic”. We will spend the night in Inkoo archipelago..

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Day 2. The whole day will be spent on the migmatites in the Barösund – Tammisaari (Ekenäs) area. This is the area where Sederholm (1926) collected the major part of the data used in his article “On Migmatites and associated pre-Cambrian rocks of southwestern Finland part II, The Region Around the Barösundsfjärd and Neighbouring areas The Åland Islands” (published in 1926 as Bulletin de la Commission Géologique de Finlande N:o 77). We will also visit examples of the high grade rocks on the outermost part of the Hanko peninsula, where the Salpausselkä terminal moraine complex enters the Baltic sea. Night in the guest houses of the company Forcit, Hanko.

Day 3. The day will focus on granites in the Nagu area, which correspond to Sederholm’s group II, nowadays referred to as the late-orogenic S-type granites and migmatites of the Late Svecofennian Granite-Migmatite zone. Night in Pellasgården at Lappo.

Day 4. The earliest supracrustal rocks in SW Finland will be examined on the Enklinge island and surrounding skerries. Sederholm assigned these rocks to the Bothnian series in his 1934 paper “On Migmatites and associated pre-Cambrian rocks of southwestern Finland part III, The Åland Islands”, published as Bulletin de la Commission Géologique de Finlande N:o 107. We will also visit examples of Sederholm’s Group 1 granites, represented by syn-volcanic gabbro-tonalite-granodiorites. Night in Pellasgården in Lappo.

Day 5. Visit to the Åva ring-complex, an example of Sederholms Group III granites and the Vehmaa rapakivi batholith, which represents Sederholm’s Group IV granites. Night in Turku, the oldest city in Finland.

Day 6. During the day, we will examine in detail the formation of the Late Svecofennian Granite-Migmatite zone - the Turku granulite area and west-Uusimaa late orogenic granites. Return to Helsinki.

Excursion Stops

Coordinates are given in Finnish YKJ-coordinate system

Day 1 Helsinki city centre and Obbnäs rapakivi granite

Introduction

The Mineral Cabinet in the Arppeanum building is the house where J.J. Sederholm took his first "geological steps" in 1882 under the guidance of Prof. F.J. Wiik, who was the first Professor of Geology and Mineralogy (1877−1898) at the University of Helsinki. Wiik was also the first scientist in Finland to utilize the polarizing microscope, which enabled in a new way the investigation of mineral composition and texture, leading to more systematic classification and genetic interpretations of rocks. Some of Wiik's talented students, notably J.J. Sederholm and Wilhelm Ramsay applied these techniques in their investigations and continued their studies with well-known W.C. Brögger in Stockholm and Harry Rosenbusch in Heidelberg (Haapala, 2005). Sederholm was in Stockholm in 1885 and again in 1888, and in Heidelberg 1890−91, when he finished his doctoral thesis ("Studien über archäische Eruptivgesteine aus dem südwestlichen Finnland").

Stop No 1: Helsinki city centre (Guide: Martti Lehtinen)

The Senate Square highlights Carl Ludvig Engel's architecture as a unique allegory of political, religious, and scientific power in the centre of Helsinki. The Palace of the Council of State was completed on the eastern side of the Senate Square in 1822. It served as the Senate of Finland and now houses the offices of the Prime Minister of Finland and the Cabinet. The main University building, on the opposite side of the Senate Square, was constructed in 1832. The Helsinki Cathedral on the northern edge of the Senate Square and which dominates the scene, was a more protracted architectural project. Engel was working on it from 1818 until his death in 1840 and it was finally completed in 1852.

The building stones used for the grounds and stairs of the buildings are from local outcrops and boulders. Almost all types of migmatites can be found but also granites, and even large blocks of rapakivi granite (wiborgite). The best weather for appreciating all of this those rocks and their textures is when it is rainy, or you must use a bottle of water to wet their surfaces.

Figure 1. Garnet rich veins (remnants) in a granitic block (ca. 60 cm x 120 cm). Grounds of the Helsinki Cathedral. (N=6674964; E=3386495) Photo: Jukka I. Lehtinen.

Until the last decades of nineteenth century, quarrying and stone working in Finland were pursued with traditional methods. A turning-point was the year 1886 when baron Anton von Alfthan conceived the idea of forming a stone company, which would combine the production of finely worked monumental and building stone. The company adopted the name Ab Granit and started to quarry and work up granitic stone in the harbour region of the town of Hanko (Hangö) (Ringbom, 1987).

Statue of Alexander II

A statue of Emperor Alexander II is located in the centre of the square. The statue, erected in 1894, has built to commemorate his re-establishing the Diet of Finland in 1863, and initiating several reforms increasing Finland's autonomy from Russia. The statue comprises Alexander, known in Finland as "the good czar", on a pedestal surrounded by figures representing the law, culture and the peasants. The pedestal is made of polished Hanko granite. The granite is well-known for its nebulitic or ghost-like gneiss fragments (schlieren).

Figure 2. Statue of Alexander II (Sculptors Johannes Takanen and Walter Runeberg) in centre of the Senate Square. The pedestral is of polished red Hanko granite. The memorial was unveiled on April 29, 1894. (N=6674856; E=3386503) Foto: Jukka I. Lehtinen.

J.J. Sederholm's friend, the engineer Hugo Blankett, founded a new company in 1900 named Finska Stenindustri Ab – Suomen Kiviteollisuus Oy (known in short as "Finska"), which was to play an important role in the Finnish natural stone industry. Sederholm became the first chairman of the company board, a post which he held until his death in 1934 (Ringbom, 1987).

Stop No 2: Obbnäs rapakivi granite (Guide: Paula Kosunen)
(N=6657632; E=3350743)

Svecofennian xenoliths, assimilation and magma mingling and mixing features in the Obbnäs rapakivi granite on coastal outcrops at Obbnäsudden, the southernmost tip of the Obbnäs peninsula (inside a military area).

Introduction

The Obbnäs rapakivi granite pluton lies on the southern coast of Finland, 35 km west-southwest of the capital, Helsinki. The pluton encompasses an area of 50 km^2, with a maximum length of 15 and width of 6 km, and forms a large part of the Upinniemi (Obbnäs) and Porkkala peninsulas (Fig. 1).

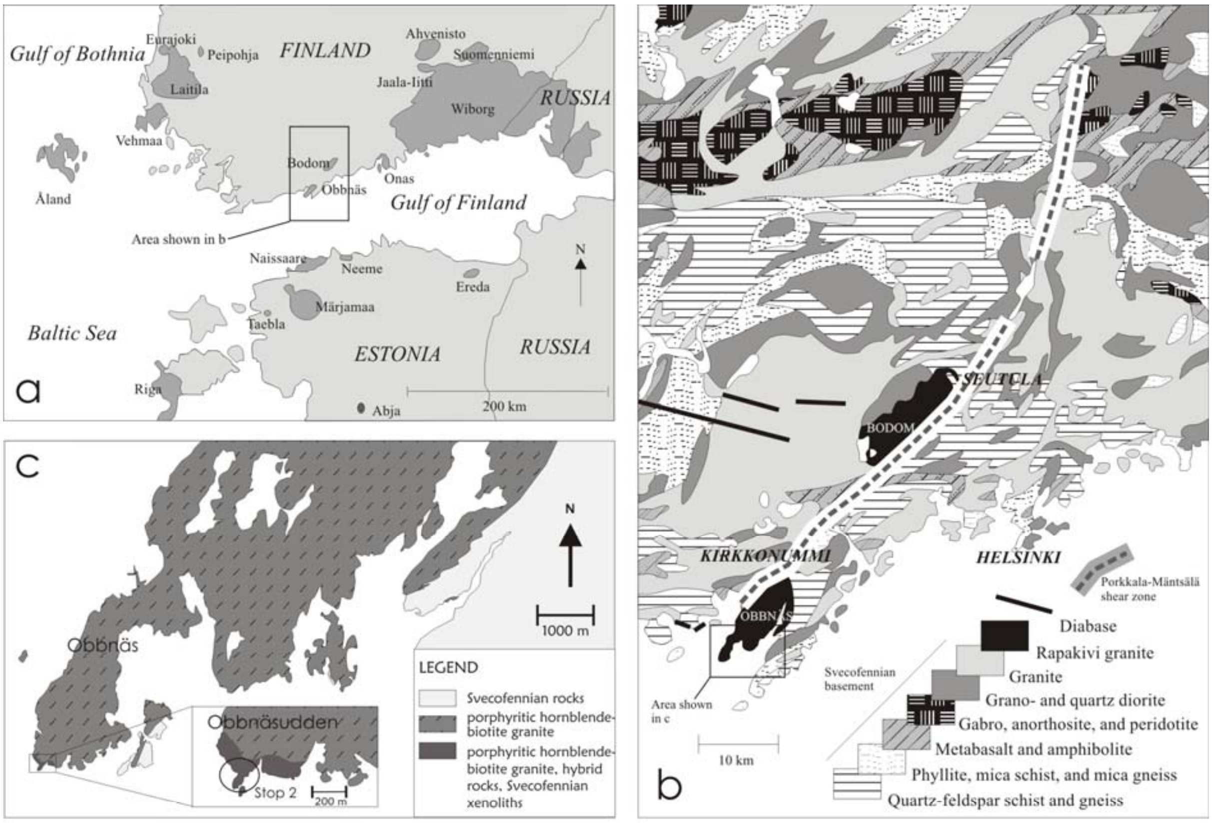

Fig. 1 a) rapakivi granite intrusions of southern Finland, Russian Karelia and Estonia. b) A simplified lithological map of the area around Helsinki showing the location of the Obbnäs rapakivi granite pluton. c) Southern part of the Obbnäs rapakivi granite pluton; the insert shows the area of Obbnäsudden and the location of Stop 2.

Sederholm described the pluton in his 1926 treatise “On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland, Part II”, where he coined the term “Obbnäs granite”. He observed that the Obbnäs granite and a similar pluton found further northeast, Bodom, were clearly younger than the surrounding Svecofennian rocks and wrote: *“The Bodom, as well as the Obbnäs granite, has in the most typical way penetrated the older rock masses, punching holes in them. There are no primary gradations between them and the older* *granitic formations. ...And if the evidence gained at all the contacts, especially at those of the Obbnäs area, are taken into consideration, it seems indubitable that these granites are decidedly younger than the surrounding rocks"* (Sederholm, 1926 p. 101). He did not, however, associate the Obbnäs granite with the classic rapakivi plutons of southeastern Finland, but considered it to "belong to a group of late pre-Cambrian granites intermediate in age between the Hangö type of granite and the rapakivi granites", with no clear genetic connection to either group (Sederholm, 1926, p. 93 and 116). Although later U-Pb -dating revealed the Obbnäs granite to be of the same age as the rapakivi granites of southeastern Finland (1645 ± 5 Ma; Vaasjoki, 1977), Sederholm's age estimate reflects his accurate recognition of features that make the Obbnäs pluton different from the other Finnish rapakivi granites.

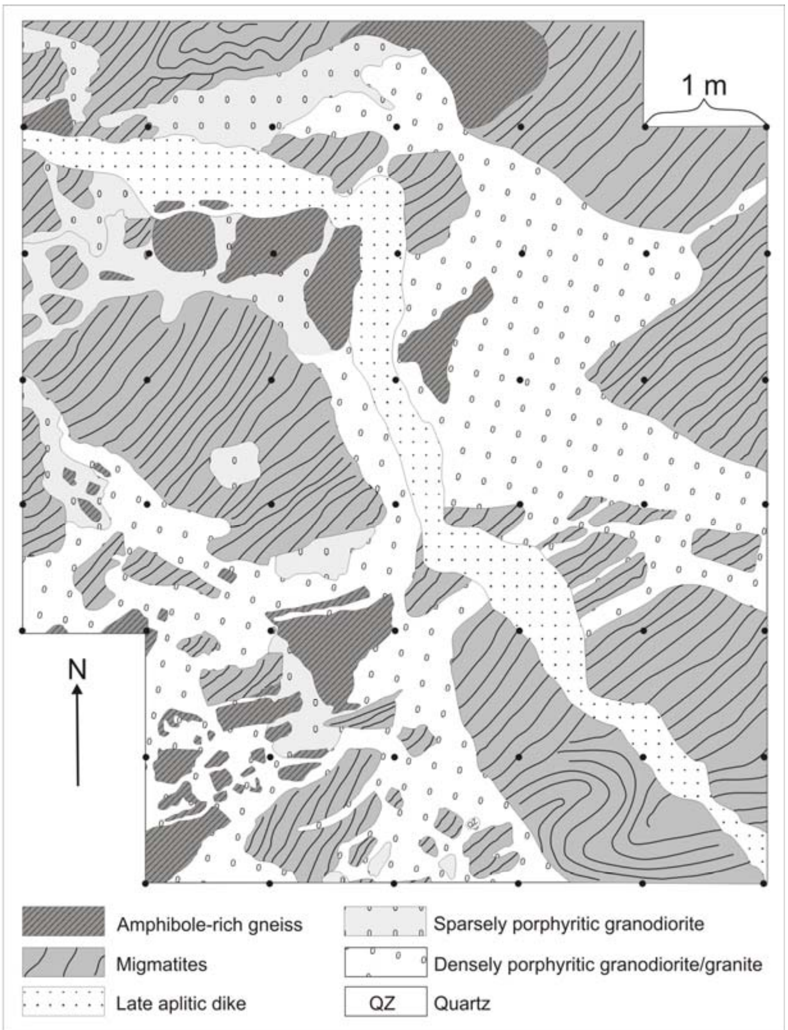

Fig. 2 A detail of the lithological variation at Obbnäsudden, the southernmost tip of the Obbnäs peninsula. A great number of Svecofennian gneiss and migmatite fragments in various stages of assimilation are found within the younger granitoids of the Obbnäs pluton.

The Obbnäs pluton (Fig. 1) is almost entirely composed of porphyritic hornblende-biotite granite, which is distinctly more homogeneous than the older Svecofennian granites in the area and, as Sederholm observed, clearly transects the older lithologies. The granite is coarse-grained with alkali feldspar megacrysts from 2 to 5 cm in diameter, and becomes gradually more mafic toward the southwest. This is accompanied by changes in the appearance of the rock: the red color turns to reddish-brown, ovoidal megacrysts become more abundant and more commonly mantled by plagioclase, and the groundmass becomes finer-grained. Some euhedral plagioclase grains are present in the southern part of the pluton. Zircon, apatite, and ilmenite are common; metamict allanite, interstitial fluorite, and rare ilmenomagnetite are also present. The Obbnäs granite also contains primary titanite, which is lacking in the other Finnish rapakivi granites (Laitakari et al., 1996).Unlike most rapakivi granites, the Obbnäs pluton commonly displays a distinct fabric alignment. Near the contacts, a magmatic foliation is commonly evident in the alignment of alkali feldspar megacrysts and examples of both ductile and brittle deformation are locally seen, especially in the northwestern part of the pluton. The presence of cataclastic deformation was one of the reasons why Sederholm regarded the Obbnäs granite as *"somewhat older than the rapakivi, because the latter is almost entirely devoid of cataclastic phenomena"*. He did, however, write: *"Later the writer found that most of these cataclastic phenomena were due to movements which accompanied, or in any case had not been much later than, the eruption of the same granite"* (Sederholm, 1926 p. 113) and speculated that this may relate to depth of emplacement and that deeper down, the rapakivi granites might assume similar characteristics. Also, most (if not all) of the deformation present in the northwest can be attributed to movements within the adjacent Porkkala-Mäntsälä shear-zone during and after crystallization of the granite (Elminen, 1999).

Geochemically, the Obbnäs granite is a subalkaline, metaluminous to weakly peraluminous A-type granite with major and trace element compositions and features falling within the range of variation shown by the Finnish rapakivi granites. However, some differences occur between the Obbnäs granite and the other Finnish rapakivi granites, the most notable being the generally lower concentration of Rb (96-189 ppm) and higher concentrations of Ba (594-2465 ppm) and Sr (98-335 ppm) in the Obbnäs granite. Rämö and Haapala (1995) presented area-weighted mean compositions of the rapakivi granites of the Wiborg and Laitila batholiths and reported ratios for Rb/Ba of 0.24 and 0.23, and Rb/Sr of 2.23 and 2.50, respectively. They also presented the mean composition of the different granite types of the Suomenniemi batholith (north of the Wiborg batolith), where respective ratios of Rb/Ba and Rb/Sr vary from 0.13 and 1.26 in hornblende granite to 3.45 and 26.5 in topaz-bearing granite. The average Rb/Ba of the Obbnäs granite (0.14) resembles the average value for the hornblende granite of Suomenniemi (with lower SiO_2 than in the Obbnäs granite); the average Rb/Sr (0.89) is clearly lower.

In its Ba-Rb-Sr -budget, and some other features, the Obbnäs granite bears resemblance to the older, shoshonitic intrusions, which intruded the Svecofennian crust of southern Finland and Russian Karelia between 1815 and 1770 Ma (Eklund et al., 1998; Väisänen et al., 2000). Sederholm noticed this similarity, which was a major factor in his age estimation for the granite: *"All the granites of the Åland Islands which resemble the Obbnäs and Bodom granites petrologically and in their geological behaviour, viz. the Lemland, the Mosshaga and the Åva granites, may now be regarded as certainly being older than the rapakivi granites"* (Sederholm, 1926 p. 114). He was proven wrong as far as the age of the Obbnäs pluton goes, but his other observations were accurate and the Obbnäs granite remains an anomaly among the Finnish rapakivi granites. Interestingly enough, some of the Estonian rapakivi granites show features similar to the Obbnäs granite, for example the accessory titanite, high contents of Ba, and a low Rb/Sr (Soesoo and Niin, 1992; Kirs and Petersell, 1994; Rämö et al., 1996).

Description

The southern margin of the Obbnäs pluton is beautifully exposed in the coastal outcrops at Obbnäsudden, the southernmost tip of the Obbnäs peninsula (Fig. 1). Several interesting features can be seen on the glacially-polished surfaces, including various Svecofennian xenoliths in different stages of assimilation and magma mingling and mixing features.

Most of the area is composed of granitic to granodioritic rocks with variable amounts of alkali feldspar megacrysts. These "porphyritic granodiorites" form large, irregular pillows within the "proper" Obbnäs granite, and have characteristics typical of hybrid rocks resulting from magma mixing and mingling. Besides alkali feldspar megacrysts (2 to 5 cm in diameter), the "porphyritic granodiorites" contain quartz phenocrysts (diameter up to 1 cm) and microphenocrysts of plagioclase. The alkali feldspar and quartz crystals are commonly rounded and slightly corroded. Needle-like apatite is present, and the larger quartz crystals are locally rimmed by dark amphibole. The "porphyritic granodiorites" can be separated into two main varieties based on the amount of alkali feldspar phenocrysts: a densely-porphyritic type and a sparsely-porphyritic type. Contacts between these two types are usually distinct but not sharp. In addition to the "porphyritic granodiorites", a rather mafic, even-grained granodiorite is found on the small island just off Obbnäsudden, where it is in distinct, gently undulating contact with the "porphyritic granodiorites". Smaller (diameter usually 10-40 cm), intermediate magmatic microgranular enclaves with variable amounts of incorporated alkali feldspar megacrysts are also found within the porphyritic hornblende-biotite granite in the southern part of the pluton.

Both the "proper" Obbnäs granite and the hybrid rocks contain a large number of variably sized Svecofennian xenoliths, mostly migmatites, rather mafic gneisses and older granite (Hangö-Ingå granite). Some of the fragments are unchanged, but most are in different stages of assimilation into the surrounding granite/granodiorite. Sederholm studied the various assimilation phenomena in the area and dedicated an entire chapter to Obbnäsudden. He wrote: *"The rock of the fragments in part retains its former composition, in part it is more or less strongly changed, passing by gradations into massive rocks of dioritic composition", "In the neighbourhood of a rather basic migmatite, the granite passes by gradations into a dioritic rock which still shows the great porphyritic crystals characteristic of the Obbnäs granite" and "…the existence of a great number of fragments…more or less changed by the influence of the granite, and on the other hand a basic facies of the granitic magma, makes it probable that there is a genetical connection between them"* (Sederholm, 1926, p. 103-104).

The most intensively assimilated gneiss fragments are commonly surrounded by zones rich in dark minerals and it seems the "sparsely-porphyritic" type of granodiorite is in many places associated with them, suggesting that assimilation has played a role in its formation. It seems that the two processes, magma mingling and mixing and assimilation, have operated together in Obbnäsudden to create the various types of rocks observed in the area, and that further, more detailed work would be required to shed light on their relative roles in the whole process.

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Night in Inkoo. In a small cottage in the outher arhipelago on the island Trutharun or at cottages inland.

Day 2 The Barösund area (Guides: Carl Ehlers, Olav Eklund)

Introduction

The second part of J.J.Sederholms treatise ”On migmatites and associated pre-cambrian rocks of southwestern Finland” (Sederholm, 1926) is devoted to the rocks of the Barösund area some 40 kilometres W of Helsinki. Sederholm paid several visits to the area between 1908 and 1911 and studied a number of key localities. He organized international excursions to the localities in 1911 and 1924, and among internationally well known geologists taking part in the trips, he mentions Alfred Harker. During this excursion we intend to visit a selection of the localities described by Sederholm (1926). This means taking a calculated risk as many of these localities are on rather exposed headlands and islands and not easily accessed if weather conditions are unfavorable. The area has not been seriously remapped since Sederholm's days although a brief study was made during the preparation of the general geological map sheet 1: 100 000 by the Geological Survey of Finland (Laitala, 1961).

Sederholm recognized and described two main phases of granitoids, both of which occur as migmatites within the older country rocks. The oldest schists, of supracrustal origine (defined as Svionian by J.J.) were intruded by gabbros and granodioritic gneisses, forming the *gneissose granites* and resulting in the formation of agmatitic breccias. All of these rocks are transected by sets of metadiabase (metabasaltic) dykes of different ages, recording episodic intrusion of mafic magmas into the crust. Intrusions of a younger microcline granite "the Hanko granite" represents a significant later phase in crustal development, being younger than the metabasaltic rocks and forming migmatites within all the earlier rocks.

Recent U-Pb zircon ages in southern Finland indicate that J.J's gneissose granites belong to an age group roughly around 1885-1888 Ma while the Hanko granite belongs to the so-called Late Svecofennian Migmatite Zone, which comprises a zone of younger (1840 - 1805 Ma) migmatite forming microcline granites, overprinting the older sequence of supracrustals, gneissose granites and metadiabases. The Late Svecofennian Granite-Migmatite Zone forms a distinct crustal domain about 500 kilometres long and 100 km wide, and can be traced along the southern coast of Finland and across the national border towards Lake Ladoga..

Stop No 3: The islet of Brändöharun

(N=6657490; E=3345404)

Migmatites between the younger Hanko-granite and older granites and supracrustal rocks. Several examples of ptygmatic folding (another term introduced by Sederholm!) of thin pegmatitic veins.

Stop No 4: The islet of Påvskär

(N=6651777; E=3335351)

In his paper on migmatites and associated pre-cambrian rocks of southwestern Finland, Part II, Sederholm (1926) present detailed drawings of this outcrop (Figs. 15 and 17 in the paper). Sederholm principally descibe the outcrop as "Metabasltic dykes in gneissose granites and agmatitic breccias"

Our pre- excursion to the area (june 2008) interpret the locality as a bimodal magmatic system, where more mafic magmas invade a crystallizing tonalite-granodiorite forming basaltic-andesitic mafic magmatic enclaves. Mafic and intermediate dykes in the host tonalite-granodiorite are back-veined and sometimes disintegrate into trains of enclaves so called disrupted dykes. The magmatic rocks were deformed during the later Svecofennian regional metamorphism. In southern Finland, similar rocks are interpreted as Svecofennian pre-orogenic rocks formed in volcanic arcs 1900-1880 Ma ago. The only younger rock found at the islet are crosscutting late-orogenic pegmatites and aplites formed roughly 1850-1815 Ma ago.

Stop No 5: The southern shore of W-Bågaskär

(N=6650173; E=3333325)

Sederholm (1926) describe this area as agmatite or eruptive breccia.

The rocks comprise different types of migmatites; metatexites (melanosome present), agmatites (fragments in leucosome); stromatic migmatites (banded melanosome and leucosome). The mesosome of the area consists of mafic and felsic volcanites with interlayers of marble/calc-silicates and metapelites.

Gently dipping fold axes in the fragmented metasediments combined with the low topography, give the area its heterogenous character.

A gently folded metabasaltic dyke sends in apophyses into the migmatite (Fig. 13 in Sederholm, 1926), indicating a late intrusion close to the regional metamorphic culmination.

Stop No 6: The islet of Lövgrund

(N=6650561; E=333240)

This area was described by Sederholm (1926) as migmatites comprising supracrustal rocks and gneissose granite intersected by metabasic veins.

The outcrops show pre-orogenic mafic and felsic volcanics with carbonate-rich interlayers cut by synorogenic gabbro – tonalite dykes. All rocks are later folded and migmatized. The metavolcanites and the carbonates are metamorphosed into large (20 cm across) pods of garnet, which, in turn, react to epidote in contact with granitic melts.

In one part of the outcrop, the general tectonic relation between different generations of rocks in S-Finland can be observed: folded syn-orogenic tonalite dykes crosscut the schistosity of the pre-orogenic supracrustal rocks and are subsequently folded. Late-orogenic granites subsequently intrude along the axial planes of the folded tonalite dyke.

Stop No 7: The small islets of Spikarna.

East of Hanko peninsula (N=6633592; E=3287503)

Description

Sederholm describe these small islets in detail in his work from 1907: “Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia” Bulletin de la Commission Géologique de Finlande 23. His general comment of the area was: *“Hitherto the geotectonics of this region always appeared to me to be so complicated that to untangle the skein seemed a hopeless task. The bedrock consists of a diffuse mixture of different granitic and gneissose rocks, hornblende schists, limestones, hälleflintas, mica shists, quartzites and* *most probably other sedimentary rocks also. Almost everywhere these rocks lack basement that can be identified as such. They are surrounded upon every side and apparently ´swim´in great masses of eruptive rock. The region which I had studied earlier in 1884 and 1885 in detail provided no clues for the solution of the problem, partly perhaps because of my inexperience, but partly because the skein was even more tangled".*

Sederhom continue about the small islets Spikarna: *"Spikarna are localities where the mixed rocks can be studied particularly well. There I first discovered the clue I was seeking and have later tried to follow. The small cliffs here are washed clean by the sea, and consist essentially of an augen-gneiss-like rock type, in which there occur several zones of a veined gneiss-like rock 10 to 30 metres broad, striking E.N.E. Within these zones the rock is intersected by a dence network of veins consisting of a granite, partly pegmatic and aplitic and partly medium-grained, pink in colour and in every respectsimilar to Hangö granite. The veins are generally parallel to the main direction of the zones, but a close inspection shows veins with a perpendicular position. Veins also branch out fom other veins. In certain places the mixture contains a readily distinquishable hornblende shist; thus all the three components in the region are present."*

With new eyes, Spikarna represent a migmatite consisting of 1.9 Ga volcanites and sediments *(Sederholm´s hornblende shists and mica shists),* 1.89 – 1.87 Ga synorogenic tonalites to granodiorites *(Sederholm´s gneiss granite).* These older materials were migmatized during the metamorphic culmination at roughly 1.85 – 1.81 Ga whereupon the granitic leucosome was formed. In places the leucosome is concentrated into dykes *(Sederholm´s dence network of veins consisting of a granite).*

Stop No: 8 Hanko late-orogenic granite (Guide Matti Kurhila)
(N=6640146; E=3269851)

Description

The Hanko granite is red, medium- to coarse-grained, and in places porphyritic. Close to its margins, mostly at the northern contact zone, it forms migmatites with the surrounding older supracrustal rocks. On the islands south of Hanko town, the granite is more homogeneous, but has nebulitic structures of assimilated country rocks. Unlike most of the late-orogenic granites, the Hanko granite contains only minor amounts of garnet.

U-Pb dating of the Hanko granite has been attempted by Hopgood et al. (1983), Huhma (1986), Suominen (1991) and Kurhila et al. (2005). The ages have generally large error limits and fall between ~1.80 Ga and 1.85 Ga. In this rock, the zircon is very U-rich, and tends to be metamict. Thus earlier results, especially those made by the TIMS method, are very discordant. Even with single-crystal analysis (Kurhila et al, 2005), no definite age could be discerned. A tentative age of 1852 ± 18 Ma was obtained for a granite sample from Tulliniemi, the southernmost tip of the Finnish mainland. This is in agreement with the result obtained east of Hanko by Hopgood et al. (1983), where a zircon age of 1841 ± 5 Ma was measured for the Innerskär rock. Monazite ages are consistently younger, ranging from ~1790 Ma in Trekobb island on the east side of Hanko (Hopgood et al., 1983), to ~1830 Ma at Märaskär south of Hanko (Suominen, 1991).

Whole-rock geochemical data are available for the Tulliniemi and Märaskär samples. They represent rather typical members of the late-orogenic leucogranites (Sederholm's 2nd group), being peraluminous (A/CNK values are 1.15 and 1.08, respectively), rich in SiO_2 and

K_2O and have rather steep REE profiles ($[La/Yb]_N$ ratios of ~31 and ~76, respectively), with pronounced negative Eu anomalies.

The Tulliniemi granite has an initial ε_{Nd} value of -1.1 (at 1852 Ma). Another analysis from the island of Märaskär gives a slightly more radiogenic result of -0.8, but within the error limits of the analysis method, these values are the same. These results imply that recycled older crust contributed substantially to the source of these granites. The somewhat heterogeneous zircon U-Pb results, with some direct evidence of inheritance, supports this notion.

Night in Hankoo. At the company FORCIT´s guesthouses.

Day 3 Deformed Microcline granites in the Nagu region (Guides: Carl Ehlers and Tom Stålfors)

Introduction (Stålfors and Ehlers, 2006)

The middle and lower crust along the area of the present south coast of Finland was heated and partially melted 1.840 -1.805 Ma ago due to crustal thickening and subsequent extension. During this event, S-type migmatites and granites were formed along a distinct zone 100 km wide and 500 km long, known as the Late Svecofennian Granite–Migmatite zone The LSGM zone is characterised by roughly E–W trending sub-horizontal migmatites and granites and high grade metamorphism. Combined ductile E–W shear movements and NNW–SSE compressional movements defined a transpressional tectonic regime during the emplacement of the granites. Partial melts that moved through the crust pooled as granite sheets or froze as migmatites (Johannes et.al, 2003). Major transpressive shear zones border the LSGM zone, which forms a tectonic and metamorphic zone that crosscuts the earlier Svecofennian granitoids. Based on field observations and geochemical data we show that the great volumes of late-orogenic granites and migmatites in southern Finland were repeatedly transported and emplaced as small chemically variable batches, possibly extracted from slightly different protoliths. These melt batches were transported along re-activated channels and collected at some horizontal level in the crust. In the Nagu area, the melt batches were trapped under a roof layer of amphibolite and the whole complex was synchronously folded into open F3 folds with steep axial surfaces and E–W trending fold axes. The sheets of microcline granite are, in places, strongly sheared; the microcline phenocrysts are imbricated and subsequent deformation of the microcline phenocrysts indicates syntectonic movements of the layers as well as a syn-tectonic mechanism for the late-magmatic fractionation.

The Nagu area, earlier described by Edelman (1972, 1973) is characterised by a series of synforms, dominated by amphibolite and metagabbro, enclosing mostly un-migmatized garnet-mica schists. The synforms are tectonically sandwiched amphibolite layers or nappe structures with a sub-horizontal enveloping surface as a result of the regional F_2 folding (Ehlers et al. 1993). The amphibolite synforms ‘‘float’’ on top of a composite sheet of banded and deformed (sheared) granites that grade downwards into partially melted less sheared pelitic migmatites. The observed maximum thickness of these composite granitic sheets is about 2 km. The sequence of coarse-grained granites is dominated by banded, porphyritic microcline granites with large feldspar phenocrysts that are tiled and subsequently strongly sheared. The tiling indicates syn-tectonic emplacement of the granite sheets permitting the phenocrysts to rotate after which the continuing deformation resulted in the strongly sheared fabric, squeezing out the last melt fractions. We therefore propose a tectonic origin for this late-magmatic fractionation. The granite banding forms a concentric pattern around the Nagu schist and amphibolite synform, indicating that the banding was formed and the granite

intruded before or concurrently with the regional D3 deformation. The banded granite sheets are, in places, cut by younger granites and pegmatites, which become increasingly abundant closer to the granite–migmatite contact at the bottom of the sequence. Higher up in the sequence, even though gradually more and more obliterated, there are occasional granitic (and pegmatite) veins cutting the strong E–W striking layering of the porphyritic granites. This feature provides compelling evidence that the granite sequence is made up of several successive generations of melt.
Dark, sheared sills are composed of biotite-rich granite. Such sills are relatively fine-grained and equigranular and contain abundant biotite compared to the porphyritic granites. These late granites are slightly discordant, transecting the banding in the porphyritic granites. Leucocratic veins consist mostly of quartz, microcline, some residual plagioclase and in places garnet. The veins vary in appearance in throughout the area and vary in orientation from layer-parallel to discordantwith respect to the porphyritic granites. In places, there are two or more generations of leucocratic veins that have exploited the same zone of weakness (zones of extension) resulting in a zoned vein, in which the older pulse may
be garnet-bearing whilst the later one is garnet absent, perhaps indicating continued filter-pressing that leaves a garnet-rich residue behind. Structurally beneath the banded granite sequence, there are migmatitic mica gneisses. The contact between the migmatites and the granite is very sharp, and the discordant granitic veins penetrate the overlying granite. There are, however, well preserved remnants of mica gneisses higher up within the sheeted granites. They occur as fragments or layers that show no evidenc of melting, , even though they are sometimes migmatized, , and are usually concordant with the sheets of porphyritic granite. The preservation of these layers within this the kilometre-thick sequence suggests a structure built up by repeated influxes of small melt batches intruding the mica gneisses concordantly beneath the impenetrable ‘‘roof’’ of amphibolites.

Stop No 9: Kaiplot

Northern Nagu (N=6688924; E=3218424) (Optional)

Banded and sheared coarse grained microcline granite with a less deformed gabbro sill concordantly intruding the granites.

Stop No 10: Snäckholm

Northern Nagu (N=6688320; E=3207954)

Well banded and deformed coarse-grained granite with garnet-rich leucocratic veins.

Stop No 11: Vandrock

Northern Nagu (N=6689157; E=3207810)

Banded deformed granite with leucocratic veins and later slightly discordant bands of medium grained biotite-rich granite.

Night in Pellasgården, Lappo (N=6704754; E=3168128)

Day 4 The earliest magmatism in southern Finland (Guides: Carl Ehlers, Olav Eklund, Markku Väisänen)

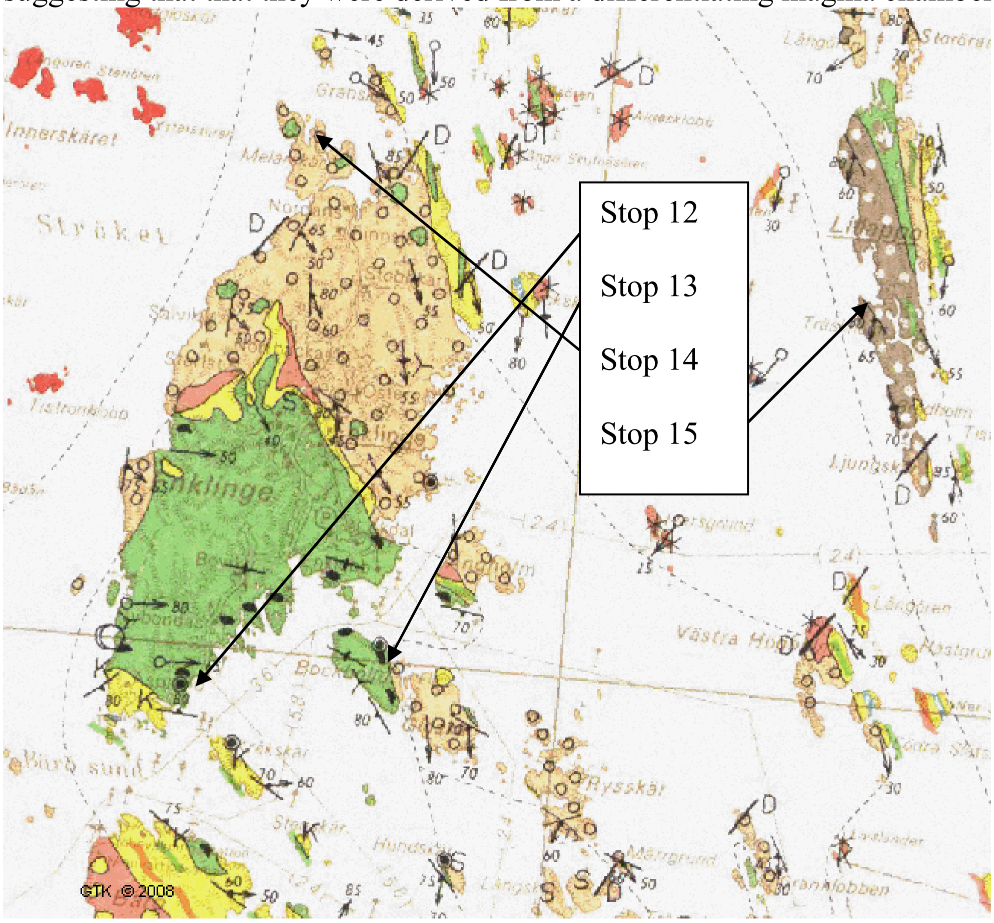
Introduction

Enklinge is an island divided into a plutonic part in the north and a supracrustal part in the south. Sederholm described the supracrustal rocks as belonging to the Botnian series, representing a better preserved, less metamorphosed, supracrustal sequence unconformably overlying the surrounding, highly metamorphosed Svionian series. New age determinations however indicate that the entire volcanic-plutonic sequence on the island represents the earliest magmatism in the area. The plutonic rocks have been dated to 1884±5 Ma and the volcanic sequence to 1885±6 Ma (Ehlers et al. 2004). The geochemistry and Nd isotope composition of the felsic rocks as well as for the mafic rocks are virtually identical, from which we infer that the plutonic rocks are the deep level equivalents of the volcanic rocks.

The plutonic rocks are interpreted as a tonalitic to granodioritic magmachamber replenished with mafic magma, giving rise to magma mingling structures.

The volcanic part of the island consists of rocks ranging from basalts, andesites, dacites to rhyolite in composition. Primary structures such as pillow lavas, columnar jointing and peperites are preserved.

There is a large compositional variation in the mafic microgranular enclaves, suggesting that that they were derived from a differentiating magma chamber at depth.



Geological map of the Enklinge area. Green = mafic and intermediate metavolcanites; Yellow = acid gneisses. Dark and light bown = Diorite and tonalite respectively. Light red = late-orogenic micocline granite. Dark red = rapakivi granite. From the interactive map of Geological Survey of Finland (http://maps.gtk.fi/gtk/eexpert).

Stop No 12: Enklinge, southern part of the island

(N=6706786; E=3155693)
On the southern shore of Enklinge, the exposed supracrustal rocks include examples of graded bedding in turbidites with carbonate interlayers. Volcanic structures are represented by pillow lavas, columnar jointing and peperites.

Stop No 13: Bockholm

(N=6706142; E=3157062)

Sederholm described this spectacular otcrup as a conglomerate indicating that the schists of Enklinge are younger than the gneissose granite (stop 13). Ehlers (1979) describe Bockholm as a hydraulic breccia formed penecontemporaneoulsy with the other volcanigenic formations in the area. Bockholm was visited by a group of geologists from University of Turku in may 2008 (Eklund, Väisänen, Kilpeläinen). They suggest that the structures seen were formed by fluids eroding their host tonalite in shear zones formed in the contact between supracrustal and infracrustal rocks.

Stop No 14: Enklinge, northern part of the island

(N=6711752; E=3155948)

Bimodal mafic felsic magmatism in a plutonic environment. Different types of mafic and hybrid enclaves and a mafic disrupted dyke in tonalite and granodiorite. Enclaves of felsic gneisses are also abundant in the area.Sederholm described the enclaves as leptite fragments.

Stop No 15: Lill-Lappo

(N=6709753; E=3161919)

Mafic plutonic rocks, principally quartz-dioritic in composition. The mafic rocks have differentiated into more felsic varieties. Fragments of ultramafic rocks (probably cumulates) are also present

Excursion dinner in the evening.
Night in Pellasgården, Lappo

Stop No 16: Thrust planes

Islet west of Torsholma (N=6708982; E=3171740)

Day 5 The post- and anorogenic magmatism in southern Finland

(Åva ring-complex and the Vehmaa rapakivi granite)

Introduction

At least 14 small (1-11 km across) 1.8 Ga Svecofennian post-collisional bimodal intrusions have been identified within the accretionary arc complex of southern Finland, extending from the Åland islands to the NW Lake Ladoga region. The intrusions form a shoshonitic rock series with total alkali abundances >5%, ratios of $K_2O/Na_2O>0.5$, and $Al_2O_3>9\%$ over a wide range of SiO_2 (32 - 78%). The end members of this rock series are ultramafic, shoshonitic, apatite-rich lamprophyres and peraluminous HiBaSr granites. All rocks in the association are strongly enriched in LILE, Ba and Sr, and in LREE, and conversely, depleted in the HFSE Ti, Nb and Ta. The trace elements follow a fractionation trend where LIL- and LRE-elements are depleted with increasing SiO_2. Initial Sr values for the lamprophyres and granitesare similar and low (~ 0.7033 - 0.7047), while γNd values are slightly positive and overlapping (+0.7 - +0.3, Andersson et al. 2006).

In the Ålands archipelago, four post-orogenic intrusions have been found; Lemland, Mosshaga, Seglinge and Åva. These intrusions were classified as Group III granites by Sederholm, since they crosscut the migmatite-related Group II granites of. We will examine the famous Åva ring complex intrusion.

The Åva ring complex

Geochemistry, petrography and age

The Åva ring complex is one of three bimodal shoshonitic ring complexes situated along a northeast-trending shear zone in southwestern Finland; Åva, Seglinge and Mosshaga. The Åva ring complex is approximately 7 km in diameter. The complex comprises hundreds of ring dykes of coarse porphyritic (HiBaSr) granites including pillows of monzodiorite, monzonite, quartz-monzonite and granodiorite. These more mafic rocks are collectively referred to as “monzonite”. The ring complex is cut by shoshonitic lamprophyres exhibiting a radial pattern. Using the geochemical method developed by Liégeois et al. (1998), it is possible to separate rocks of alkaline affinity from those having shoshonitic affinities; when compared to a reference rock series, the former are relatively enriched in Zr, Ce, Sm, Y and Yb while the latter are relatively enriched in Rb, Th, U and Ta. The post-collisional ring complexes in southwestern Finland plot within the field of shoshonitic rocks and may thus, according to Liégeois et al., (1998) be interpreted as having been derived from a source in the lithospheric mantle that had previously been enriched in phlogopite and amphibole.

The granite contains K-feldspar megacrysts up to 3 cm in size. The megacrysts are rounded, corroded and, sometimes, subhedral (tabular) in shape. Inclusions in the megacrysts comprise amphibole, mica, plagioclase, sphene and accessory apatite and zircon. Plagioclase occurs either as small phenocrysts or as a mantle surrounding the K-feldspar megacrysts. The matrix consists of quartz (often bluish), biotite, minor plagioclase, K-feldspar and Fe-Ti oxides (mainly titanomagnetite). Occasionally, amphibole is present as inclusions in mica within the matrix. Both K-feldspar megacrysts and groundmass contain apatite, pyrite, titanite, zircon and fluorite as accessory phases.

In places, HiBaSr and sometimes S-type granites also form dykes radial to the ring-complex (Skyttä, 2002). The HiBaSr granite was emplaced broadly coeaval with palingenic crustal melts, forming a mingled area between these two granites in the central part of the intrusion. Ehlers and Bergman (1984) and Bergman (1986) suggested that the Åva intrusion centres on a gneissic ring structure formed by diapiric emplacement of a late-orogenic S-type microcline granite pluton that deformed the surrounding gneisses into a steep inward dipping ring.

The Åva monzonite was dated at 1799±13 Ma and the granite at 1803±10 Ma (U-Pb in zircon, Suominen, 1991). Field evidence for magma mingling indicates that monzonite and granite magmas intruded contemporaneously, which is clearly consistent with the isotopic data. Suominen (1991) also reported younger $^{207}Pb/^{206}Pb$ titanite ages, between 1754 and 1789 Ma for the monzonites, and between 1759 and 1782 Ma for the granites.

In the Åva area, boulders of a coarse grained rock consisting of plagioclase, orthopyroxene, biotite, amphibole, apatite and minor clinopyroxene have been found. A SIMS age determination shows that rims of zircons have the same age as the monzonite. Mineralogical correlations considering substitution mechanisms in micas and hornblendes imply that the boulders belong to the Åva complex, as discussed in sections 6.1 and 6.2.

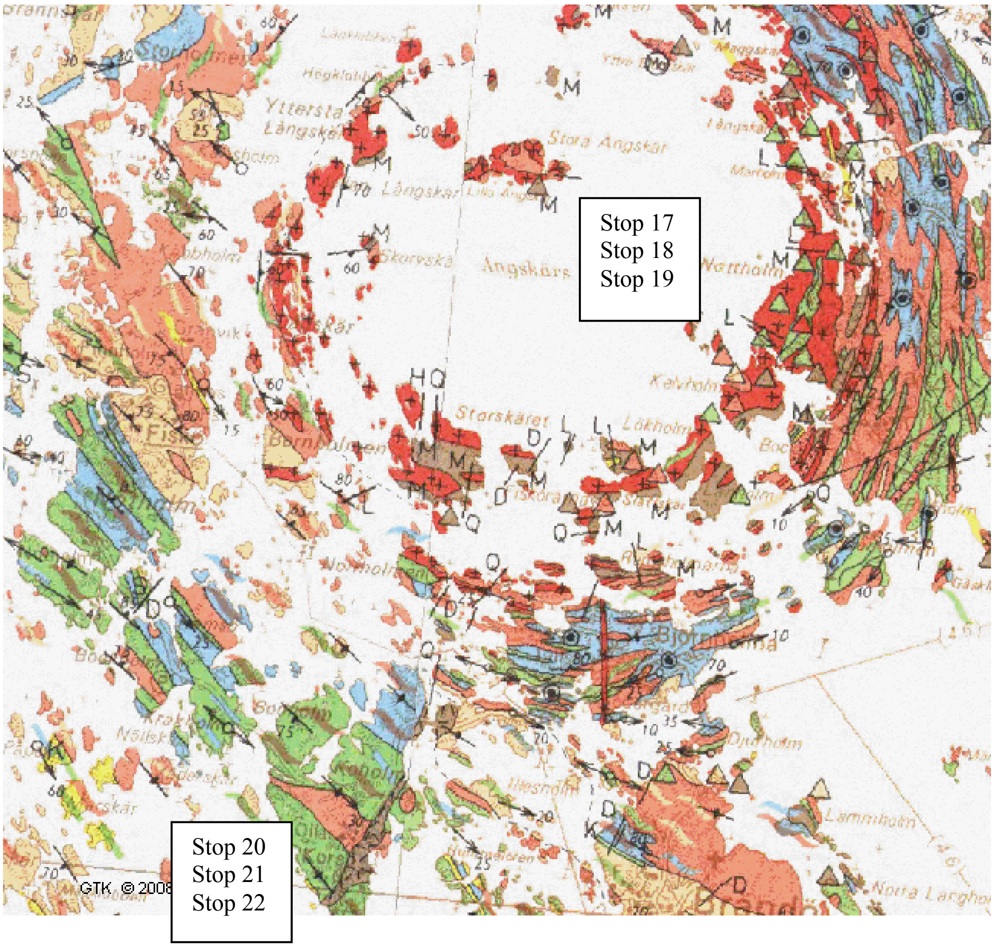
Eklund et al. (1998) and Rutanen (2002) have suggested that the HiBaSr granite formed by crystal fractionation of amphibole, biotite, plagioclase, apatite, sphene and magnetite from a mafic shoshonitic magma. In this scenario, it is most probable that the boulders represent the high-density cumulus part of a stratified magma chamber formed deep in the crust.

The ring structure is cut by 33 known radial lamprophyre dykes. However, lamprophyres were also emplaced prior to the ring dykes and some lamprophyres were intruded into semi-crystallised granite (Kaitaro, 1953). Petrographically the lamprophyres are spessartites, vogesites and minettes (Hollsten, 1997). Based on geochemistry (Eklund et al., 1998) and mineralogy (Eklund & Shebanov, 2005) it has been shown that the monzonites have essentially the same composition as the lamprophyres, which is why they are considered to be plutonic varieties of the lamprophyres.

Petrogenesis

It is suggested that the lithospheric mantle was metasomatised during the subduction stage of the Svecofennian orogeny. An increased thermal gradient melted this lithospheric mantle, enriched in phlogopite and amphibole, at roughly 1.80 Ga, and shoshonitic magmas intruded the earlier crust and were emplaced at mid-crustal levels. There has been considerable speculation about what caused the melting of the enriched lithospheric mantle. Both Väisänen et al (2000) and Eklund & Shebanov (2002) have suggested that the thermal perturbation was a consequence of slab breakoff (evidenced by rapid uplift in combination with shoshonitic magmatism). However, since the crustal heating around 1.80 Ga seems to have affected major parts of the Baltic shield, extensive lithospheric delamination may have been the source of the heat.

Magma differentiation took place in a mid-crustal magma-chamber (4-7 kbar) about 30 Ma before the time of emplacement of the ring complex in the upper crust (deep assemblage ~1790 Ma, shallow assemblage ~1760 Ma, Eklund and Shebanov 2005). When about 50% of biotite, amphibole, plagioclase, magnetite, apatite and titanite were fractionated from the initial magmas, peraluminous HiBaSr granites were generated. Crustal assimilation during the fractionation process is considered to have been minimal The alkali activity was elevated and the environment was relatively reducing in the mid-crustal chamber when compared to the conditions of emplacement in the upper crust. It appears that the juvenile Svecofennian crust was invaded by pulses of shoshonitic magmas from an enriched lithospheric mantle over a long period of time. Some of these magmas were stored and differentiated in the middle crust before transportation to the upper crust.



Geological map over the Brändö area with the post-orogenic Åva ring intrucion in center. Stops, 16, 17, 18 are dedicated to the Åva Ring intrusion and stops 19, 29 and 21 are dedicated for the anorogenic Korsö dyke. From the interactive map of Geological Survey of Finland (http://maps.gtk.fi/gtk/eexpert).

Stop No 17: A small island between Björnholma and Söderholmen

Rönnskärs grundet (N=6718579; E=3173376)

The outcrop shows two ring dykes representing the outer part of the ring-intrusion complex. The dykes are between 40 and 100 cm across and dip steeply towards the centre of the intrusion. They are composed of coarse porphyritic (K-feldspar) granite. The K-feldspars are euhedral but often mechanically abraded. Towards the contacts the K-feldspar megacrysts are show cumulus features.

Stop No 18: Bimodal lamprophyre – granite magmatism in ring dykes

Åva harbour (N=6720222; E=3174029)

This outcrop shows a mixture of three components

1. Amphibolite fragments
2. Monzonite
3. Porphyritic granite

The monzonite forms pillows elongated parallel to the dyke direction in the host porphyritic granite. The amphibolite fragments impinge upon the monzonite pillows, suggesting that the monzonite was behaving as a plastic material, while the amphibolite was solid. K-feldspar megacrysts from the porphyritic granite were assimilated into the monzonite as well as blue quartz grains, forming ocelli texture. These structural and textural features provide strong evidence for coeval intrusion of the monzonitic and granitic magma within the upper crust.

Stop No 19: Nottholm

(N=6720892; E=3173346)

Roof pendants of country rock in the central part of Åva intrusion

- In some of the roof pendants contact metamorphism has altered calcite to wollastonite.

The intimate relationship between a monzonitic magma and a cooling granitic magma.

- Small mafic and hybrid magmatic enclaves, less than 5 cm in size in the granite
- Mafic magmatic enclaves in the granite up to several meters in size
- Lamprophyre dykes intruded into the semi-solid granite
- Crosscutting lamprophyres.
- Boulders representing deep mafic assemblages

Late stage processes in the granite ring intrusion.

- Vesicles, from small cm scale to meter-sized scapolite-bearing vesicles
- Pegmatites
- Post-emplacement mylonites

The anorogenic magmatism in SW Finland

About 200 Ma after the intrusion of the postcollisional shoshonitic intrusions, an episode of anorogenic magmatic activity commenced, recorded by the Mesoproterozoic rapakivi complexes and associated diabase dyke swarms. The extensive 1.58 Ga rapakivi granite intrusions of Åland, Vehmaa and Laitila, and the smaller Kökar and Fjälskär intrusions dominate the anorogenic rocks in southwestern Finland. The Åland rapakivi granites are estimated to cover more than 5500 km^2 and comprise a great variety of granite types ranging from plutonic to volcanic (Bergman, 1981). The rapakivi massifs are accompanied by about 500 tholeiitic dykes in the Åland-Åboland diabase dyke swarm which traverse the archipelago from the Kökar area towards the Vehmaa rapakivi massif. The dykes consist predominantly of narrow and fine-grained hornblende-pyroxene diabases (Ehlers and Ehlers, 1977) having both olivine and quartz normative compositions (Lindberg et al., 1991). Similar diabase dykes are associated with other rapakivi massifs in the Svecofennian domain, for example the Häme swarm associated with the Wiborg rapakivi complex in SE Finland (Rämö and Haapala, 1995). In addition to the fine-grained diabase dykes, the anorogenic mafic rocks in the Åland region include leucogabbros and anorthosites (Bergman, 1981). Although the outcrops of these gabbro-anorthosites are small (less than 5 km^2 in all), the presence of these rock types within the anorogenic rapakivi-association is important. Age determinations for the felsic anorogenic magmatism in southwestern Finland cluster at about 1575±10 Ma (Suominen, 1991).

Field relationships provide evidence for the contemporaneity of felsic and mafic activity; composite dykes, and mingling of mafic and felsic magmas have been described from southwestern Åland (e.g. Eklund, 1993; Lindberg and Eklund, 1992). Fragments of leucogabbro and anorthosite are common within the studied diabases, and plagioclase megacrysts (labradorite) in mafic magmatic enclaves within rapakivi granite varieties of the Åland complex are similar in composition to plagioclase within nearby gabbro-anorthosites (Eklund et al. 1994.

The Korsö dyke - An example of a bimodal dyke within the anorogenic Åland-Åboland dyke swarm, consisting of high-alumina basalt and a megacryst free granitic melt.

Of the 500 dykes in the Åland-Åboland dyke swarm Korsö dyke is one of the most extensive and chemically least evolved. The dyke is bimodal. In its central part it contains a phenocryst-free A-type granite variety (rapakivi-type?) with miarolitic cavities. The presence of autoliths of anorthosite and norite (senso stricto) is restricted to the chilled margin and fine grained parts of the dyke. Between the granite and the diabase there is a hybrid zone with sinuous contacts towards the granite as well as toward the diabase.

The Korsö dyke carries several types of plagioclase cumulates, such as noritic fragments and plagioclase megacrysts, and displays a chilled margin which represents one of the most primitive mafic rock compositions found in the region. The diabase, or leucogabbroic rock, is occasionally very rich in plagioclase, the volume proportion of plagioclase beeing about 70±5%. The plagioclase is typically about $An_{65\pm5}$, usually forming platy laths about 2.5 cm in length. Plagioclase spherulites, indicative of plagioclase over-saturation or supercooled liquids (Berg, 1980; Lofgren, 1974) are also present. The observed “stellate” (star-like) plagioclase texture is similar to the “snowflake” textures in the Jonathon Intrusion (Berg, 1980) and the Reid Brook intrusion (Emslie, 1996) of the Nain Plutonic Suite, Labrador, Canada, and in mafic dykes in the Suomenniemi complex, Finland (Rämö, 1991). There is thus ample evidence for the occurrence of high-Al basalts (as noted in the literature) and a close association between this texture and massif-type anorthosites - as is generally attributed to plagioclase supersaturation in mafic magmas of similar age to associated anorthosites.

Polybaric evolution

In a fine-grained part of this dyke a noritic fragment was found in which Al-rich orthopyroxene (Al_2O_3=4-6%; Mg# ~57) enclose laths of plagioclase (An_{55}). The high Al content indicate crystallization at mid- to lower crustal depths (Fram and Longhi, 1992), which also is consistent with the lower An content of the plagioclase (Longhi et al., 1993) compared to the dyke as a whole. This indicates that plagioclase was on the liquidus at considerable depth, followed by orthopyroxene.

The dyke also contains large euhedral plagioclase laths (labradorite in composition), up to 7 cm in size. Thermobarometrical investigations on mineral inclusions in these megacrysts indicate a crystallization pressure around 5 kbar, i.e. mid-crustal levels (Shebanov & Eklund 1997). According to phase diagrams developed by Shkodzinsky (1985), magmatic boiling in phenocryst-free A-type granitic melts occurs at pressures less than 0.5 kbar. The presence of miarolites in the granitic part of the dyke indicates that the emplacement level of the dyke was at 0.5 kbar or less.

It may thus be concluded that the Korsö dyke represents a record of polybaric evolution and rapid magma transfer through the whole crust.

Geochemistry

Roughly 170 chemical analyses are available from the Åland – Åboland dyke swarm. The dykes can be characterised as subalkaline continental tholeiites and as transitional to alkali basalts. However, in multi element diagrams, the dykes show negative Nb, Ta and Ti anomalies, which may suggest either significant crustal contamination or an origin within a subduction-related mantle. Mg-numbers vary between 61 and 25. The most primitive dykes have compatible element concentrations of Cr= 520 ppm, Ni = 140 ppm and incompatible element concentrations of P_2O_5 = 0.07-0.26 wt%, Zr = 25-80 ppm. The most evolved dykes have compatible element concentrations of Cr = 50 ppm, Ni = 30 ppm and incompatible element concentrations of P_2O_5 = 1.40 wt%, Zr = 420 ppm.

Stop No 20: Korsö (Optional)

(N=6715875; E=3168965)

- Major phase of the Korsö dyke. Coarse ophitic texture with plagioclase laths and intercumulus olivine, clinopyroxene, orthospyroxene and pigeonite.
- Crosscutting dykes enriched in Ti, P, Fe and incompatible trace elements.
- Accumulation of plagioclase laths towards the contact of the dyke
- Leuconorite fragments at the contact.

Stop No 21: Korsö helioport. (Optional)

(N=6716097; E=3169661)

- Leuconorite fragments with euhedral plagioclase crystals and high-Al orthopyroxene.
- Labradorite megacrysts

Stop No 22: The northern part of the Korsö dyke. (Optional)

(N=6716961; E=3170104)

- Phenocryst-free A-type granite with vesicles
- Hybrid varieties between the granite and the diabase
- Snowflake plagioclases

Stop No 23: Korsö dyke (Optional)

(N=6716977; E=3170198)

- Various types of gabbroic autoliths in the dyke
- Large euhedral plagioclases.

The chemistry of the multiple Korsö dyke falls within the compositional range listed above. The chilled margins comprise the most primitive composition and crosscutting thin fine grained dykes the most evolved varieties.

The 1583 Ma Vehmaa rapakivi batolith

Five different rapakivi types can be discerned in the Vehmaa batolith: Pyterlite (rounded K-feldspar ovoids, sometimes having plagioclase rims), two varieties of porphyritic rapakivi granite, even-grained rapakivi granite and porphyry aplite. They all have different textural, mineralogical and geochemical characteristics. The batholith exhibits a concentric pattern, with the pyterlite along the margins and the younger porphyritic granites in the central areas. The porphyritic aplites intruded the pyterlite as minor bodies, except for the semicircular occurrence between two porphyritic rapakivi varieties (Stop 18). Even-grained rapakivi granites (Uhlu granite) form, together with porphyritic aplite, a satellite intrusion east of the main batholith (Linderg & Bergman 1993).

Stop No 24: The upper part of the Vehmaa rapakivi batolith

The harbour at Vousnainen, Kustavi (Optional)

(N=6724763; E=3184462)

The uppermost part of the Vehmaa rapakivi batholith, representing a typical example of pyterlite.

- abundant of melt depleted xenoliths of country rock in pyterlite
- aplite dykes with pegmatic pockets
- areas of degassing of the batholith

Stop No 25: The Järppilä aplite (quartz-feldspar porphyry) dyke
(N=6734769; E=3201669)

This coarse porphyritic aplite intruded between two rapakivi varieties. It contains large (up to 5 cm across) megacrysts of K-feldspar and micaceous clots in a fine-grained (aplitic) matrix. The mineralogy of the clots and mafic silicates inside the K-feldspar megacrysts differs from the mineralogy of rapakivi granites in general. The micas have a low Fe-index and high Ba contents. (Usually the mafic silicates in rapakivi granites have a high Fe-index).. The mineralogy of the clots is therefore more “post-orogenic” than “anorogenic” in character.

Texturally, the porphyry consist of scattered K-feldspar megacrysts (ovoids), small micaceous clots, and plagioclase megacrysts, scattered through a fine-grained granitic matrix. Geochemically, the porphyries are remarkably enriched in Ba (1900-3700 ppm), Sr (420-780 ppm), and Ti (0.68-1.38 wt. %) when compared to the rapakivi granites in the batholith. These “primitive” features appear somewhat anomalous given the late intrusive nature of the Järppilä dyke and are attributed to the rather unusual composition of the abundant mica.

The studied biotites are characterized by brittle mica substitions (Ba, Ca, Sr) in interlayer sites, with an apparent deficiency in tetrahedral site, and relatively low Fe/(Fe + Mg)-ratio (average 0.69). Substitution of Ti^{3+} in the tetrahedral site of the most Ba-rich micas is proposed in order to maintain charge balance. These characteristics differ markedly from the restricted compositional space of rapakivi biotites elsewhere. However, Järppilä biotites are nearly identical to barian biotites recognised in the postorogenic (1.77-1.80 Ga) bimodal granite-lamprophyre complexes with shoshonitic affinity, which are often spatially related to the rapakivi batholiths in the area.

This fact suggests a restitic origin for barian-titanian biotite-bearing assemblages, pointing to the postorogenic granitoid suite as a potentially suitable protolith for the Järppilä porphyries. In attempt to verify this assertion, U-Pb dating with the NORDSIM IMS-facility has been undertaken.

Two distinguishable populations of zircons have been investigated: a) nearly stoichiometric, Hf-poor crystals found mainly as inclusions within K-feldspar ovoids b) zircons exhibiting elevated Zr/Hf and peculiar disturbances in stoichiometry; these zircons predominately occur in the matrix. Zircons of the first population sometimes contain inclusions of Ba-enriched minerals and yields a discordia with an upper intercept of 1616 +/- 7 Ma, MSWD = 1.2. The second group does not seem to belong to the barian mica - bearing paragenesis and yields an age of emplacement, defined by a separate discordia with an upper intercept of 1579 +/- 6 Ma, MSWD = 0.47. These two events seem to be reflected in the clustering of different mineral assemblages in their isotope compositions. Rb-Sr isotope data for mineral inclusions within the ovoids plot on a reference line with an age of 1604+/- 30 Ma and ISr=0.7018+/-0.0004, whereas the remainder form a separate errorchron defining an age of 1577 +/-19 Ma, ISr = 0.7040+/-0.0001 (MSWD = 1.26). The former value indicates the presence of a mantle-derived component for the first assemblage encapsulated within the feldspar ovoids. This is in accord with a significantly more positive time-integrated value for eNd(1.58 Ga) of +2.0 for the first assemblage, compared to the second assemblage, which yielded eNd(1.58 Ga) = –1 0 - -4.0. The latter range is equivalent to that of common bulk-probe characteristics for Finnish rapakivi granites.

In summary, the data from the relic mineral assemblage in the Järppilä rapakivi porphyries favours a mantle-derived initial source (late postorogenic?) that experienced a relatively short residence time in the crust, not long before the anorogenic 1.58 magmatic event. Our data suggest that postorogenic magmatic activity might have continued until approximately 1.62 Ga.

Stop No 26: Helsinginranta quarry
(N=6734683; E=3200449)

An example of porphyritic rapakivi granite.

Stop No 27: Marjuksenranta quarry
(N=6724948; E=3205957)

An example of pyterlitic rapakivi granite with scarce plagioclase-mantled K-feldspar ovoids.

Day 6 Turku granulite area and West-Uusimaa late-orogenic granites (Guides: Markku Väisänen, Pentti Hölttä and Matti Kurhila)

Introduction

The Turku granulite area is the westernmost of the granulite facies areas in the LSGM. It mainly comprises pelitic sedimentary rocks that now are polyphase deformed and highly migmatized. It is emphasized here that the Turku granulite area as presented in Väisänen & Hölttä (1999) was based on thermobarometric data available at that time . It now seems probable that the granulite facies rocks occur over a wider area, covering most of the Archipelago and the Rauma area, NW of the Laitila rapakivi batholith.

Lithology

Mica gneisses are the most common rock types in the area. Compositional layering with alternating pelitic and psammitic layers, inferred as relict primary bedding, is locally preserved. This may indicate a turbiditic origin for the sediments (Väisänen & Hölttä 1999). The mica gneisses are highly migmatitic and show a wide range of migmatitic structures, e.g. phlebitic, stromatic and schlieren structures (Johannes et al. 2003).

The mica gneisses are intercalated with thin mafic and intermediate metavolcanic rocks which show chemical compositions transitional between volcanic arcs and mid-ocean ridge basalts and were interpreted to indicate a rift setting (Väisänen & Westerlund 2007).

During the arc-accretional stage of deformation, the supracrustal rocks were intruded by sheets of magmatic rocks of granodioritic-tonalitic-quartzdioritic compositions. In the Turku area they have been dated at 1.87 Ga (van Duin 1992, Nironen 1999, Väisänen et al. 2002). On the Sr/Y *vs* Y and La/Yb *vs* Yb diagrams these rocks lie within the adakitic fields, interpreted to indicate a deep-seated source region (Väisänen et al. 2006).

Rock types restricted to the granulite area are the pyroxene-bearing granodiorites-tonalites-quartz diorites, referred to as charnockites and first described by Hietanen (1947). In detail, their mineralogy ranges from charnockites to enderbites and orthopyroxene-quartz diorites (Helenius et al. 2004). They were previously interpreted as a separate magma type, but are now regarded as metamorphic counterparts of the 1.87 Ga tonalites (Väisänen et al. 2002, Helenius et al. 2004).

Due to the high metamorphic grade, garnet- and cordierite-bearing 1.84-1.815 Ga S-type granites derived from crustal melting are very common in the area (Huhma 1986, Suominen 1991, Väisänen et al. 2000, Kurhila et al. 2005). They often occur as dykes, semi-concordant sheets and irregular patches (Ehlers et al. 1993, Johannes et al. 2003, Stålfors & Ehlers 2006).

Rather rare and small elongated 1.815 Ga monzodioritic plutons intrude the supracrustal rocks in the Turku area (Väisänen et al. 2000). They are associated with coeval S-type granites. The Turku monzodiorites are the oldest intrusions belonging to the post-collisional shoshonitic magmatic series in southern Finland (Andersson et al. 2006 and references therein).

The youngest rocks are the Mesoproterozoic 1.60-1.58 Ga rapakivi granites and diabase dykes.

Structural geology

The structural evolution of the LSGM evidently reflects a two-stage collisional tectonic history and following extensional periods. During the early stage of northwards arc-accretion, the volcanic, synvolcanic plutonic and sedimentary rocks were folded and pervasively foliated. In a number of studies, this deformational stage is referred to as D_1+D_2 and the associated foliations as S1+S2. In most places the deformation produced recumbent or gently dipping structures, apart from competent volcanic units that were folded into upright orientations (Skyttä et al. 2006). The younger (1.84-1.80 Ga) collisional event refolded the previous subhorizontal structures into upright D_3 folds, probably within a dextral transpressional stress field (Ehlers et al. 1993). The direct field evidence for the existence of extensional structures between the collisional events (D_2 and D_3) have so far only been described from the West Uusimaa area (Skyttä 2007), where seismic FIRE-profiles have also been interpreted to indicate extension (Nironen et al. 2006). Extensional shear zones formed after the younger collisional event were described by Väisänen & Skyttä (2007).

In the Turku area the early arc-accretion stage is manifested by recumbent F_2 folds and the associated penetrative S2 axial planar foliation, which is the main foliation in the area. The S_1 foliation has only been observed as inclusion trails in porphyroblasts. In places thin leucosome veins are also folded. The 1.87 Ga tonalites also intruded during this stage. The younger collision generated intense crustal shortening which deformed earlier structures into upright F_3 folds, which is responsible for the prominent ENE-WSW structural grain throughout southern Finland. Associated S_3 foliations are only locally developed, while later deformations are localised in ductile and brittle shear zones (Väisänen & Hölttä 1999, Väisänen & Skyttä 2007).

Metamorphism

The present erosion level in the Turku area attained low pressure-high temperature granulite facies metamorphic conditions during late Svecofennian time. Peak metamorphism has been estimated at ~ 800 °C and 6 kbars (Väisänen & Hölttä 1999, Johannes et al. 2003), which resulted in intense crustal melting. Zircons extracted from leucosome intruding the upright F_3 folds were dated by ion microprobe and yielded an age of 1824 ± 5 Ma. This was interpreted to indicate the age of peak metamorphism as well as the F_3 folding (Väisänen et al. 2002). No earlier metamorphic events have been verified by zircon dating (Nyström et al. 2005), indicating that the metamorphism during earlier arc-accretion stage was too low for growth of metamorphic zircons.

The following prograde reactions are considered to have been effective in generating the observedd leucosomes and granites by dehydration melting (Väisänen & Hölttä 1999, Kriegsman 2001, Johannes et al. 2003, Nyström & Kriegsman 2003):

Bt + Sil + Qtz + Kfs = Grt + Liq
Bt + Sil + Qtz +(Plg) = Crd + Kfs + Liq
Bt + Pl + Qtz = Grt + Liq (±Kfs)
Bt + Crd + Qtz + Kfs = Grt + Liq

Bt + Sil + Qtz = Grt + Crd + Kfs + Liq

The P-T-tpath is inferred to have commenced with near-isobaric heating followed by near-isobaric cooling (Johannes et al. 2003). The same kind of P-T-t path has also been presented for the West Uusimaa granulite area to the east (Cagnard et al. 2007 and references therein). This implies that during peak metamorphism no severe extensional exhumation occurred, as has been inferred to have taken place in the West Uusimaa area (Nironen et al. 2006, Skyttä 2007, but see also Cagnard 2007).

The heat source for the high grade metamorphism within the LSGM has been the subject of much speculation. Korsman (1977) stated that heat was provided by crustal thickening. This idea was expanded by Kukkonen & Lauri (2006) who proposed that crustal thickening and magmatism at c. 1.87-1.86 Ga was followed by radioactive decay that provided heat for later metamorphism. Schreurs & Westra (1986) proposed, based on the existence of a gravity anomaly within the West Uusimaa area, that a large amount of mafic magma was intruded into the middle crust beneath the granulite area. Mafic magmatism assisted by CO_2 flux could provide the necessary heat for metamorphism. In the Turku area the charnockites were considered as a heat source by Van Duin (1992) and Väisänen et al. (2000) proposed that shoshonitic mantle derived magmatism found in the Turku granulite area was a heat source for metamorphism. The latest models from the West Uusimaa granulite area emphasize the role of extensional tectonism and formation of metamorphic core complexes (Nironen et al. 2006, Skyttä 2007).

Each of these models have potential shortcomings; the challenge for interpretations involving crustal thickening and thermal incubation lie in explaining the long duration of metamorphism, from c. 1.85 Ga (Torvela et al. 2008) to c. 1.795 Ga (Baltybaev et al. 2006, Väisänen et al. 2008), i.e. c. 20-70 m.y. after thickening. On the other hand, invoking mafic magmatism and underplating as heat source is difficult to reconcile with the small small number and size of known intrusions and the lack of known mafic plutons of 1.85-1.815 Ga. The recognition and significance of widespread extensional structures at the present erosion level, particularly in the light of evidence for isobaric cooling also require further assessment..

Stop No 28: Charnockite

Naantali, Kalela (N=6721773; E=3228270)

Van Duin (1992) dated zircons from two charnockite localities and obtained ages of 1849 ± 10 Ma and 1821 ± 39 Ma, from which it was deduced that the charcokites were responsible for high-grade metamorphism. Väisänen et al. (2002), using the ion microprobe SIMS method, established that zircons from the Kakskerta charnockite sample contained zircons showing multistage growth histories, with 1.87 Ga core domains and 1.82 Ga overgrowths, thus verifying the observations of Suominen (1991) that they are in fact metamorphosed older rocks. Helenius et al. (2004) stated that charnockites were formed from tonalitic granitoids through charnockitisation reactions.

The road cutting and adjacent outcrops show the typical brownish weathering surface characteristic of pyroxene-bearing rocks. The rock is moderately deformed and foliated, interpreted to be the S2 foliation. The foliation is locally obliterated by more homogeneous opx-bearing patches, probably melts. Geochemically, the rock has high Sr *vs* Y and La *vs* Yb ratios and therefore resembles adakites.

Stop No 29: Garnet-cordierite gneiss migmatized by granitic leucosome

Masku, Riviera. (N=6724734; E=3233489)

This outcrop demonstrates the high-grade pelitic migmatites in the Turku granulite area. The mineral assemblage in the mesosome is grt-crd-bt-sil-and-kfs-pl-qtz. The rims of the garnets are often altered to cordierite and in the remaining garnet the Mg-content decreases towards the margins. The mineral assemblage in the leucosome conists of kfs-pl-qtz±grt±crd±and. Garnets are poikilitic with quartz inclusions and cordierites are rectangular-shaped. Cordierites are altered into green biotite and andalusite at rims.

Bedding, composite S_1+S_2 and isoclinal F_2 folds are openly to tightly folded by F_3. Early leucosomes and garnets in the mesosome are folded by F_3 but majority of stromatic leucosomes are syn to late D_3. Heterogeneous diatexite fills narrow D_3 shear zones.

The thermobarometry of migmatitic rocks in the Turku area indicates maximum temperatures and pressures of c. 800 °C and 6 kbars. This locality, however, is exceptional as here the values are < 700 °C and c. 4 kbars, probably because of retrograde reactions (Väisänen & Hölttä 1999).

At an analogous locality at Lemu, some 10 km WSW from the present locality, a U-Pb SIMS zircon study of the granitic leucosome yielded an age of 1824 ± 5 Ma (Väisänen et al. 2002).

Another rock type in these outcrops is tonalitic gneiss, which contains mafic enclaves and also showing the S_2 foliation folded by F_3. These correspond to the rocks that were dated at 1.87 Ga further to the NE.

Stop No 30: Post-collisional monzodiorite and granite

Turku, Urusvuori (N=6718772; E= 3241921)

These outcrops demonstrate the bimodal post-collisional magmatism in SW Finland. The mafic magmatism (1814.7 ± 2.1 Ma) is represented by shoshonitic monzodiorite highly enriched in Fe, P, Ti, F, LREE and incompatible trace elements. The coeval felsic magmatism (1814.3 ± 2.7 Ma) is garnet-bearing S-type anatectic granite. Both rock types have initial ε_{Nd} values of between 0 and +1 (Rutanen et al. 2008). It was argued that the mafic magmatism is derived from subcontinental lithospheric mantle, was intruded into the middle crust at 4.1 kbars, and caused the high heat flow and crustal anatexis, consistent with the S-type character of the granites. This conclusion was then applied more widely to invoke mafic magmatism as a heat source for metamorphism within the LSGM (Väisänen et al. 2000).

Stop No 31: Migmatitic mica gneiss and granitic leucosome

Turku, Ravattula (N=6715483; E=3245554). (Modified from Kriegsman, 1999)

This outcrop shows migmatitic (stromatic) metapelites alternating with metapsammites and demonstrates the subhorizontal D_2 structures refolded by open upright D_3 structures. Thin veins of leucosome (mm scale) are parallel to gently dipping S_2 and have been intrafolially folded. Thicker garnet-bearing leucosomes (dm scale) do not show the folding but the melts have migrated into the vertical conduit where they were subsequently arrested . This locality is considered to be a good example of the transition from melt percolation to dyking. Melt in the conduit encloses elongated rafts of metasediments with vertical axes parallel to the flow direction. The melt conduit is subparallel to local and regional D_3 folds.

The late-orogenic granites of southwestern Finland

(Guide, Matti Kurhila)

Introduction

In the early 20th century, J.J. Sederholm proposed a fourfold classification for the Palaeoproterozoic intrusive rocks of the Finnish Svecofennian (Sederholm 1926). His first group consisted of granodioritic-tonalitic bodies, which intruded the Svecofennian supracrustal rocks. Both rock types were intensely metamorphosed by the microcline granites of his second group, and all of these rocks were cut by largely undeformed stocks which formed the third group. On the basis of the contact relationships of the Lemland granite, belonging to the third group, and the Åland rapakivi batholith in southwestern Finland, Sederholm concluded that the rapakivi granites were even younger and thus formed a fourth group of intrusive rocks. This classification is still colloquially used in field work, although the current scientific nomenclature was created by Simonen (1971), who named the first three granite groups syn-, late- and postorogenic, and regarded the rapakivi granites as anorogenic intrusions.

Stops 5-7 on day 6 concentrate on granites belonging to Sederholm's second group, or late-orogenic granites. Stop 5 is within the Perniö granite and stops 6 and 7 in the Veikkola granite area. Between these two intrusions is an area of granulite-grade supracrustal rocks, the so-called West Uusimaa complex (Parras 1958), in which the age of metamorphism coincides with those of the granite intrusions (Kurhila et al. 2005). It is thought that the late-orogenic granites were formed from crustal material after the amalgamation of the Svecofennian crustal segments, either during transpressional intraplate tectonism (Ehlers et al. 1993) or extensional collapse after the cessation of the main compressive phase (Korja & Heikkinen 1995, Korsman et al. 1999). According to Selonen et al. (1996) and Nironen et al., (2006), both the Perniö and Veikkola granite areas represent generally flat-lying rather thin sheets.

Stop No 32: The late-orogenic Perniö Granite

Kistola, Muurla (N=6698769; E=3294014)

Introduction

An outcrop at the carpark of Pohjoismainen Solumuovi Oy headquarters. The Perniö granite is a relatively large (> 600 km^2) granite body. The granite cuts the surrounding infracrustal and supracrustal rocks and forms migmatites with them. Inclusions of supracrustal rocks are common. Selonen et al. (1996) attribute the emplacement of the Perniö granite to successive injection of magma batches into one or more active subhorizontal shear zones at mid-crustal levels.

Description

The rock is medium-to coarse-grained, pinkish, and slightly porphyritic. The granite consists of nebulitic darker and lighter coarse-grained layers. Plagioclase phenocrysts are up to 7 cm long and display a magmatic fabric. Abundant biotite patches are concentrated in the lighter layers and commonly contain garnet.

Geochemically, the granite is peraluminous (A/CNK = 1.10), rich in SiO_2 (72.4 %) and K_2O (6.36 %), and slightly ferroan according to the classification of Frost et al. (2001). It has a negative Eu anomaly and strong enrichment in LREE. Whole-rock Nd isotope analyses indicate a moderate input of older crust in the source of this granite, with initial ε_{Nd} value of -0.5.

The age of the granite is well constrained at 1835 ± 12 Ma by single crystal U-Pb isotopic analysis on zircon (Kurhila et al. 2005). No inherited ages were detected, although they would have been expected based on the Nd isotope composition. The zircon age is supported by a monazite age of 1829 ± 3 Ma. According to Lu-Hf isotope studies, the Hf isotope composition of zircon is almost chondritic (ε_{Hf} values range from -0.2 to 1.7) and thus consistent with the Nd result.

Stop No 33: The late-orogenic Haapajärvi Granite

Veikkola, Kirkkonummi (N= 6686909; E=3359067)

Introduction

The outcrop is a road cut along the old main road from Helsinki to Turku. The Veikkola granite area is located to the southeast of the granulite-grade West Uusimaa Complex. In the Veikkola area, there are four different granite intrusions, which are in places difficult to discern from each other. However, the age difference (on the basis of which the different intrusions were first recgnized) between the oldest and youngest of these is ca. 30 Ma, which clearly indicates separate granite-forming events.

The Haapajärvi granite is surrounded by the older Nuuksio granite (Stop 7), and is the most homogeneous of these granites. Although the Haapajärvi granite contains a few schlieren-like remnants of partially fused host rock, these are not as abundant as in most other late-orogenic granites of southern Finland. In the southern margin of the Haapajärvi granite, there is also evidence of mingling with a pyroxenitic rock.

Description

The granite comprises light-coloured microcline granite of varying grain size. The primary dark mineral is biotite, now argely chloritized (~5 % modally). There are felsic, garnet-bearing veins in the granite and the texture varies from faintly layered to net-veined. The youngest veins are pegmatitic. Outside the veins, garnet is sparse or absent.

The granite is silica-rich (74.6 %) and slightly peraluminous (A/CNK = 1.07). It has a marked negative Eu anomaly and the REE pattern shows a moderate slope [$(La/Yb)_N$ = 14.8]. The initial ε_{Nd} value is -0.4, implying an older crustal source similar to that inferred for the Perniö granite. The U-Pb isotopic age of this granite is 1829 ± 7 Ma, measured from zircon with the TIMS method. Monazite is coeval at 1825 ± 3 Ma (Kurhila et al. 2005).

Stop No 34: The late-orogenic Nuuksio Granite

Solvalla, Espoo (N=6689610; E=3365141)

Introduction

The outcrop is within the carpark at the Solvalla sports centre. This rock represents the Nuuksio phase of the Veikkola granite area. The Nuuksio granite is the most widespread granite type and covers the northern and eastern part of the granite area. It envelopes the younger Haapajärvi granite (Stop 31) and at its margins, it grades through migmatites into garnet-cordierite gneisses to the west and pyroxene-bearing granodiorites to the northeast. According to interpretations of reflection seismic data (Nironen et al., 2006), the Nuuksio granite is a shallow (~1.5 km thick) sheet-like intrusion, much like the Perniö granite (stop 4).

In general, the planar features seen in the Veikkola granites form a bowl-shaped structure with horizontal foliation in the centre. A notable feature is that foliation is rarely pervasive (usually layering or preferred orientation of phenocrysts) and that the oldest Nuuksio granite phase has only a weak fabric.

Description

The rock is medium-grained, pinkish, banded granite with darker, biotite-bearing parts as the main type, and leucocratic, garnet-rich, nearly horizontal bands. The felsic bands are coarse-grained, up to 20 cm thick, with gradational boundaries to the host granite. Anhedral to subhedral garnet in felsic layers range in size from 2 mm up to 20 mm and is commonly partly replaced by biotite (relics of garnet occur in the centre of biotite aggregates). Although the layering is typically distinct, the rock is not strongly deformed.

Geochemically, the rock is almost identical with the Haapajärvi granite. The SiO_2 content is 74.1 % and A/CNK is 1.07. The REE pattern is slightly more depleted in HREE with $[La/Yb]_N$ = 45.3; also the Ba and SR levels are slightly elevated. The felsic layers have more even REE patterns, which is due to their high garnet content. The initial ε_{Nd} value is -0.4, again equivalent to the Haapajärvi granite. However, the age of the Nuuksio granite is distinctly older compared to the other granites in the Veikkola area. The U-Pb isotopic age of zircon is 1853 ± 7 Ma, and monazite is coeval at 1851 ± 5 Ma (Kurhila et al. 2005). A thermobarometric study on this rock shows that it was emplaced at ~15–20 km depth and at 700–750 °C.

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