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Archean of Greenland and Fennoscandia

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The North Atlantic craton in southern West Greenland mainly consists of a tectonic collage of Mesoarchean continental crustal terranes, which were amalgamated at c. 2.7 Ga and are currently exposed at mid-crustal amphibolite to granulite facies levels. Tonalitic orthogneisses predominate, intercalated with slightly older tholeiitic to andesitic metavolcanic rocks and associated gabbro-anorthosite intrusive complexes. The North Atlantic craton also contains enclaves of Eoarchean, c. 3.86–3.6 Ga orthogneisses and supracrustal rocks including the Isua greenstone (or supracrustal) belt. This is the oldest known assemblage of rocks deposited at the surface of the Earth, comprising mafic pillow lavas, banded iron formations and metasedimentary schists with local disseminated graphite of possible biogenic origin. Eoarchean rocks have not been found in Kola and Karelia in Fennoscandia where most rocks are 2.9–2.7 Ga tonalitic-trondhjemitic-granodioritic orthogneisses with intercalated coeval greenstone belts and amphibolites. Mesoarchean 3.0–3.2 Ga rocks are found in the eastern and western parts of the Karelian province. Subduction-related rocks like the Iringora supra-subduction type ophiolite and basalt-andesite-dacite-rhyolite series volcanic rocks in many greenstone belts, as well as eclogites are found in the Archean of Fennoscandia. A clear distinction between Greenland and Fennoscandia is the abundance of 2.75–2.65 Ga igneous rocks in Fennoscandia which indicates that these two cratons had a separate evolution during the Neoarchean.

Introduction

Archean crust underlies much of Greenland and the eastern part of the Fennoscandian Shield. Williams et al. (1991) proposed that at the end of the Archean there was a supercontinent, Kenorland, whose breakup led to the formation of several minicontinents which were then reassembled together with intervening juvenile terranes in the Paleoproterozoic. Bleeker (2003) argued that instead of one supercontinent there were several distinct, transient, Neoarchean supercratons. He grouped the present Archean cratons into clans based on their degree of similarity, where each clan could represent the progeny of a different supercraton. One of these, 'Superia', probably included both the Karelian craton (including Kola) in the present Fennoscandian Shield and the Hearne and Superior cratons in North America (Bleeker and Ernst, 2006). According to paleomagnetic reconstructions (Mertanen et al., 2006) where Greenland forms part of the Laurentia supercraton together with the Superior craton, the Baltica supercraton could have been assembled with or has been close to Greenland in the late Neoarchean (Figure 1). The reconstruction is based on paleomagnetic results from coeval 2.45 Ga dykes from the Superior and Karelian cratons. The dykes are thought to originate from the same magma source and represent concurrent early Paleoproterozoic rifting of the Archean basement. By using the other paleomagnetic polarity option, Baltica would locate at the other side of the equator on the opposite paleolatitude of about 30º.

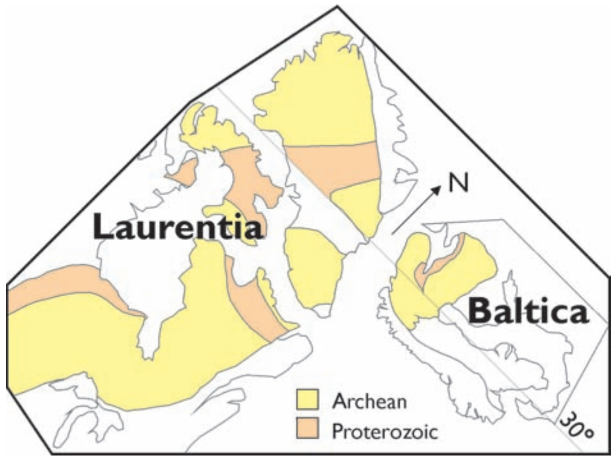

***Figure 1** Positions of Fennoscandian shield (Baltica) and Greenland (part of Laurentia) at 2.45 Ga.*

This review outlines and compares the main Archean tectonic units of Greenland and the Fennoscandian shields. Paleomagnetism does not tell whether these areas belonged to the same supercraton in the Neoarchean at 2.8–2.5 Ga, but similarities and differences between the cratons are important criteria when we are trying to understand the Archean plate tectonic framework and the existence and structure of possible supercontinents and supercratons. Both Greenland and the Fennoscandian shields record significant tectonic events coinciding with the globally recognized 2.7 Ga crustal growth episode. However, the earlier geological histories of these two areas differ in many respects. Eoarchean, 3.8–3.6 Ga supracrustal rocks are well documented in Greenland, but have not yet been found in the Fennoscandian Shield. Indeed, rocks of Paleoarchean (3.6–3.2 Ga) age are altogether relatively scarce in Fennoscandia, with the majority of plutonic rocks and greenstone assemblages being in the age range 2.9–2.7 Ga.

Greenland

Most of Greenland consists of a cratonic Archean core, which was extensively reworked by Paleoproterozoic collisional orogeny in its central and northern parts and is mostly covered by ice. The North Atlantic craton (Figure 2) in southern Greenland includes the intensely studied Godthåbsfjord/Nuuk region, which contains the Eoarchean Isua supracrustal rocks. Its crustal architecture, consisting of individual terranes, was defined during the 1980s (Friend et al., 1988). Prior to the opening of the Labrador Sea, the North Atlantic craton was contiguous with the Nain province in Labrador.

The North Atlantic craton mainly comprises 3.0–2.8 Ga mid-crustal, upper amphibolite to granulite facies rocks. Tonalitic orthogneisses predominate, with subordinate tholeiitic metavolcanic and gabbroic rocks and associated leucogabbro-anorthosite complexes, whereas clastic metasedimentary rocks are scarce. The craton therefore has previously been designated as representing a 'high-grade grey gneiss-amphibolite association' in contrast to the lower-grade granite-greenstone associations found in most other cratons. In addition to tonalite-trondhjemite-granodiorite (TTG) rocks, orthogneisses rich in P, Ba, Sr and light rare-earth elements (LREE) are also present and have been interpreted as containing a component of carbonatite-metasomatised mantle (Steenfelt et al., 2005). In the Nuuk region, some mafic metavolcanic complexes were formed in supra-subduction environments (Polat et al., 2008), and relicts of a large oceanic andesitic arc have recently been discovered (Garde, 2007). This suggests that the high-grade amphibolite-gneiss terrain simply represents the deeper part of a similar arc-type geodynamic setting as inferred in most other Archean cratons.

The North Atlantic craton forms a complex collage of individual tectono-stratigraphic terranes of different age which were amalgamated around 2.7 Ga, each having distinctive crustal components and geological histories. These terranes are best understood in the Nuuk region and have only been defined at reconnaissance level elsewhere in the western part of the craton (Nutman et al., 2005); the following account therefore mainly deals with the Nuuk region.

Eoarchean supra- and infracrustal rocks (3.86–3.6 Ga) occur in the Færingehavn and Isukasia terranes in the Nuuk region (Figure 2), and 3.7 Ga orthogneisses are exposed in the Aasivik terrane c. 200 km farther north. Eoarchean detrital zircons in younger sedimentary rocks in other parts of West Greenland may indicate that other very old terranes remain to be found. Whether the zircon ages of the early Archean orthogneisses record inheritance from earlier mantle-crust differentiation (Whitehouse and Kamber, 2005) or represent actual crystallisation ages of the rock units in which they are found (Nutman et al., 2000; Crowley, 2003), is a matter of vigorous debate. If the latter interpretation is accepted, the oldest rocks in West Greenland occur in the Færingehavn terrane as enclaves of supracrustal rocks within 3.86 Ga tonalitic orthogneisses, which were formerly known as the Amîtsoq gneisses (Figure 3). Eoarchean orthogneisses in the geographically separate Isukasia terrane (Friend and Nutman, 2005) host the Isua greenstone or supracrustal belt. This includes components with ages of both 3.8 and 3.7 Ga and is the largest known coherent area of Eoarchean rocks formed at the surface of the Earth. The supracrustal rocks have been metamorphosed and hydrothermally altered at least twice, at around 3.7 Ga and 2.8 Ga and are mostly intensely deformed, such that relict primary depositional features are rare. Important components of the Isua belt include boninitic and tholeiitic metabasalts, locally with well-preserved pillow structures, chemical metasedimentary rocks dominated by BIF, and metasedimentary schists with local disseminated graphite of probable biogenic origin (Rosing, 1999).

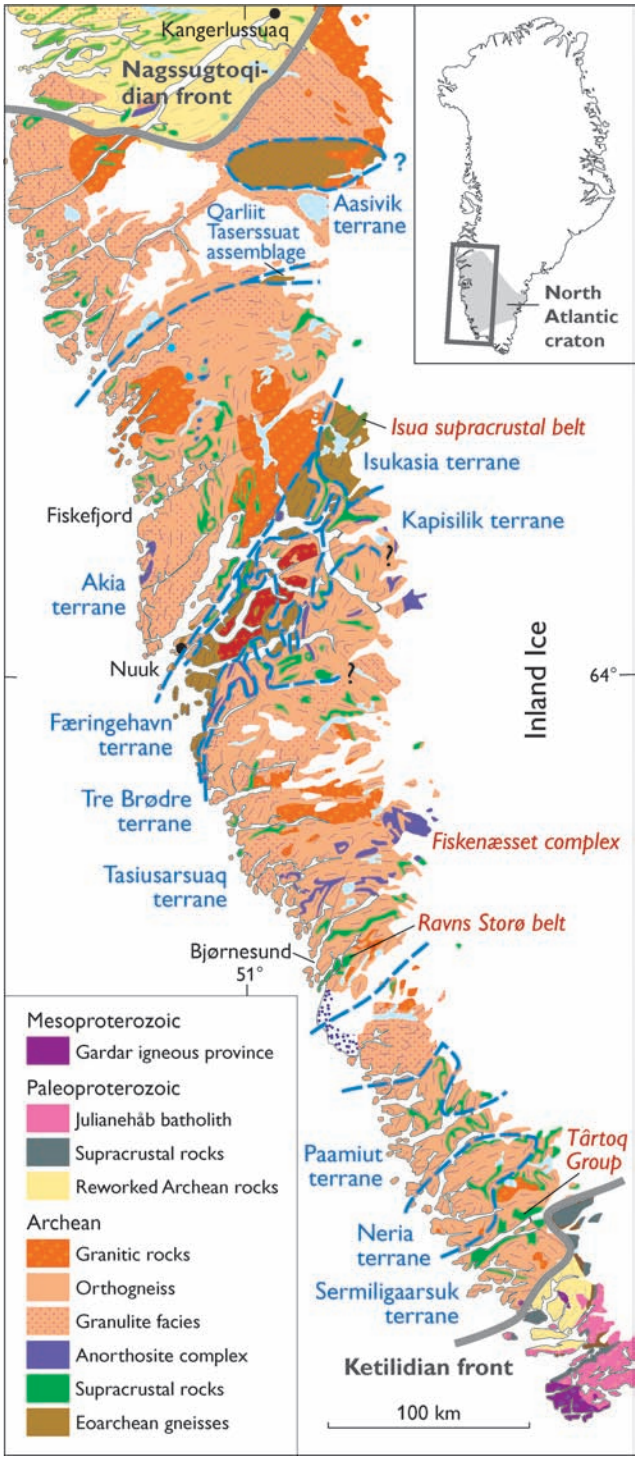

Figure 2 Archean terranes and rock units in the North Atlantic craton of southern Greenland.

The Akia terrane northwest of Nuuk contains a 3.2 Ga granulite facies core surrounded by younger supracrustal rocks and the still younger, 3.05–2.97 Ga Nûk orthogneisses and related granitic rocks. A relict mafic-ultramafic complex south of Fiskefjord contains a platinum group element (PGE) mineralisation, while an extensive supracrustal belt north of Nuuk, interpreted as a 3.07 Ga andesitic island arc, hosts gold mineralisation. The recently defined 3.07–2.96 Ga Kapisilik terrane, to the east of Nuuk (Friend and Nutman, 2005) shares many features in common with the ≤ 3.07 Ga parts of the Akia terrane.

The Tre Brødre and Tasiusarsuaq terranes east and southeast of Nuuk are composed of younger Mesoarchean rocks. The former consists of the 2.82 Ga amphibolite facies Ikkattoq granodioritic orthogneisses and a disrupted anorthosite complex. The tectonically overlying, but higher-grade Tasiusarsuaq terrane extends southwards for >100 km and contains 2.92–2.86 Ga orthogneisses (in part retrogressed from 2.795 Ga granulite facies metamorphism), a major granitoid body emplaced under granulite facies conditions (Iivertalik granite), and also the Fiskenæsset anorthosite complex (Myers, 1985), notable for its occurrence of layered chromitites and metamorphic ruby. Large metavolcanic belts occur farther south at Bjør-

Figure 3 Eoarchean orthogneiss (Amîtsoq gneiss) of TTG-type, intensely migmatised and folded, and cut by undeformed, c. 2550 Ma pegmatite. Ameralik fjord, southern West Greenland.

nesund and Ravn Storø. Three or four additional terranes occur in the south towards the northern front of the Paleoproterozoic Ketilidian orogen in South Greenland. One of these terranes contains the >3.0 Ga metavolcanic greenstones of the Târtoq Group, with low-grade gold mineralisation. Metasedimentary units derived from contemporaneous continental crust and/or andesitic arcs predominantly occur in the boundary zones between terranes.

Archean rocks are also exposed along the eastern side of the North Atlantic craton in Southeast Greenland, within the Paleoproterozoic Nagssugtoqidian-Rinkian collisional orogenic complex in central–northern West Greenland, and as basement windows within the Caledonian orogen in East Greenland.

To conclude, each terrane in the North Atlantic craton typically comprises four main components: a) remnants of older, predominantly mafic crust and oceanic arcs derived from mafic oceanic or back-arc crust, or representing the mafic roots of andesitic volcanic arcs generated in subduction- related settings), b) orthogneisses, which form the bulk of the crust, c) granitic rocks formed by anatexis of the orthogneisses, and d) mafic dykes, which attest to younger episodes of crustal extension. Most terranes were metamorphosed in upper amphibolite to granulite facies, corresponding to relatively deep crustal levels.

Fennoscandia

Archean rocks comprise much of the eastern and northern parts of the Fennoscandian Shield and have been divided into five provinces, which were variably affected by Paleoproterozoic orogenic reworking—the Karelian, Belomorian, Kola, Murmansk and Norrbotten provinces (Figure 4). The Norrbotten province has not been studied in detail and is not discussed in this review. The Archean of the Fennoscandian Shield is dominated by the TTG association covering about 80% of the area, with subordinate greenstone belts, paragneisses, granulite complexes and migmatitic amphibolites.

Karelian province

In this paper, we follow Slabunov et al. (2006) in subdividing the Karelian Province into the Western Karelian, Central Karelian and Vodlozero terranes, each of which differ in terms of lithology, structure and ages of granitoids and greenstone belt volcanism (Figure 4). Large areas of the Western Karelian terrane and most of the Vodlozero terrane comprise Mesoarchean 2.8–3.2 Ga lithologies, while 3.5 Ga gneisses have been found in the Western Karelian terrane. In contrast, the Central Karelian terrane is mainly Neoarchean, both TTGs and greenstone belt volcanic rocks being 2.75–2.70 Ga in age. Subduction-related sanukitoids of age 2.74–2.70 Ga are common in the Central Karelian terrane and occur sporadically in the Western Karelian terrane. In contrast, the Vodlozero terrane is characterized by the absence of both sanukitoids and TTG granitoids of this age.

Except for some greenstone belts with lower or middle amphibolite facies peak metamorphic assemblages, most of the Karelian province record metamorphism under upper amphibolite facies and granulite facies conditions. U-Pb ages on titanites, monazites and zircons from granulites and migmatite leucosomes indicate that peak metamorphism coincided with protracted emplacement of monzogranites from 2.72–2.62 Ga (Käpyaho et al., 2007 and references therein). The highest grade rocks are the granulites in the western part of the Iisalmi complex, where thermobarometric results indicate crystallization at c. 800–850°C and 8–11 kbars.

Most parts of the Western Karelian terrane and the Belomorian province were reworked during Proterozoic tectonic events. In the Western Karelian terrane amphiboles and micas mostly yield K-Ar ages of c. 1.9–1.8 Ga (Kontinen et al., 1992). The Belomorian province yields Paleoproterozoic titanite and rutile ages of 1.9–1.8 Ga (Bibikova et al., 2001). Exposed Proterozoic igneous rocks are rare in the Karelian and Belomorian provinces, but lower crustal xenoliths from c. 500–600 Ma old kimberlites near the southern boundary of the Western Karelian terrane show that the Archean mafic lower crust has been repeatedly intruded by Proterozoic magmas, now consisting of Paleoarchean to Paleoproterozoic mafic granulites. Zircon ages of

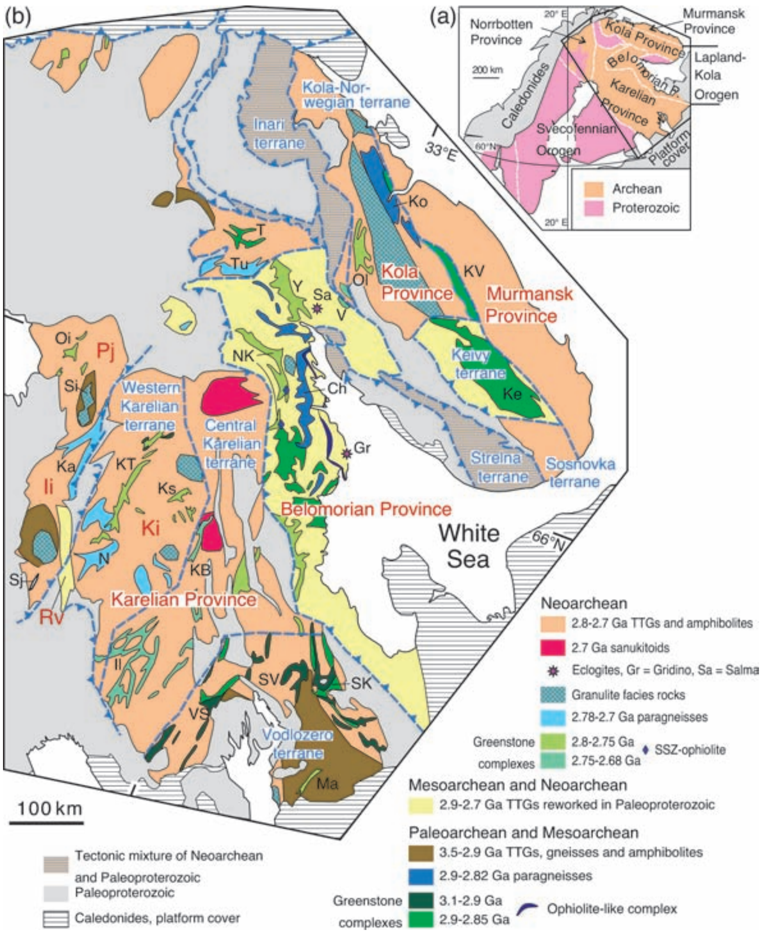

Figure 4 (a) Principal tectonic units of the Fennoscandian shield. (b) Geological scheme of the eastern Fennoscandian shield and representation of main Archean terranes, and greenstone, schist and paragneiss belts: Ch = Chupa; Il = Ilomantsi; KB = Khedozero-Bolsheozero; Ke = Keivy; Ko = Kola; Ks = Kostomuksha; KT = Kuhmo-Suomussalmi-Tipasjärvi; KV = Kolmozero-Voronya; Ma = Matkalahta; N = Nurmes; NK = North Karelian; Ol = Olenegorsky; Oi = Oijärvi; SK = Sumozero-Kenozero; SV = South Vygozero; Tu = Tuntsa; T = Tulppio; V = Voche-Lambina; VS = Vedlozero-Segozero; Y = Yena. Complexes of the Western Karelian terrane: Ii = Iisalmi; Ki = Kianta; Pj = Pudasjärvi; Rv = Rautavaara; Sj = Siilinjärvi carbonatite; Si = Siurua gneiss.

up to 3.5 Ga and whole rock Nd (TDM) model ages of c. 3.7 Ga of some xenoliths are equivalent to the age of the oldest gneisses in the Pudasjärvi area (Pj in Figure 4) in the northwestern part of the Western Karelian terrane.

Western Karelian terrane

The Western Karelian terrane, comprising much of eastern Finland and the westernmost part of Russian Karelia, is a diverse mosaic of rock units, although the nature and significance of boundaries between various subterranes are not yet adequately constrained. Migmatitic TTG orthogneisses and amphibolites predominate, with some medium to low pressure granulite areas in the western part of the terrane. Crustal architecture inferred from seismic data, as well as bedrock structural data, suggest thrust stacking and transpression during late orogenic deformation around 2.7 Ga. Tectonic transport was towards NE and SE, with evidence that the Western Karelian terrane was emplaced eastwards over the Central Karelian terrane, which generally has W-vergent polarity.

The oldest exposed rocks in the Karelian province—and indeed in Fennoscandia—are 3.5 Ga trondhjemitic gneisses (Mutanen and Huhma, 2003) at Siurua in the Pudasjärvi area (Figure 5). The Iisalmi area (Ii in Figure 4) contains 3.2 Ga TTG gneisses, with mafic intercalations that were derived from protoliths whose geochemical features resemble those of enriched mid-ocean ridge basalt. However, most of the region consists of 2.8–2.7 Ga orthogneisses, including 2.72–2.70 Ga enderbites and diorites with highly fractionated REE and high Sr/Y ratios, indicating that their parental melts were produced at high pressures in the garnet stability field. The youngest Archean igneous rock is the 2.61 Ga Siilinjärvi carbonatite (Figure 4), although the tectonic significance of this magmatic event is not clear. The Pudasjärvi–Iisalmi area also contains some supracrustal assemblages, including the Oijärvi greenstone belt (Oi in Figure 4), with amphibolite facies mafic and ultramafic oceanic plateau type volcanic rocks, and the Kalpio complex (K in Figure 4), which consists of migmatitic metasedimentary gneisses, including thin-bedded turbidites and quartzites.

The 3.2 Ga rocks of the Iisalmi area are juxtaposed sharply against the Rautavaara complex (Rv in Figure 4) from which the oldest known rocks are 2.75 Ga in age, suggesting that the boundary is of considerable tectonic significance. Supracrustal gneisses of the Rautavaara complex are characterized by cordierite-orthoamphibole mineral assemblages and Al-rich ultramafic rocks, indicating extensive hydrothermal alteration of protoliths. Their precursors were arc-type basalts and andesites which now form mafic interlayers in TTGs. Intrusive rocks include 2.74 Ga sanukitoids.

The Kianta complex (Ki in Figure 4), contrasts with the Rautavaara complex to the west and the Central Karelian terrane to the east in terms of the relative abundance of 2.85–2.78 Ga tonalitic gneisses, migmatites and volcanic rocks (Sorjonen-Ward and Luukkonen, 2005). The Kianta complex includes the Tipasjärvi, Kuhmo, Suomussalmi and Kostomuksha greenstones belts (KT and Ks in Figure 4). These 2.84–2.79 Ga greenstone belts include oceanic plateau type komatiitic and tholeiitic basalts, and sediments with BIF. The basalts are juxtaposed with arc type felsic associations. The youngest granites in the Kianta complex are dated at 2.71–2.68 Ga.

Figure 5 Paleoarchean Siurua trondhjemitic orthogneiss, cut by Neoarchean pegmatite dykes.

Much of the southern part of the Kianta complex consists of the metasedimentary Nurmes paragneisses, which are chemically identical to the global average for Neoarchean greywackes. The SHRIMP and TIMS U-Pb age determinations on zircon grains from mesosomes of migmatitic paragneiss and crosscutting granitoid plutons constrain deposition of the protolith wackes to 2.71–2.69 Ga. Trace element and U-Pb data suggest that the source terrains comprised mainly 2.75–2.70 Ga TTG and/or sanukitoid-type plutonic and mafic volcanic rocks. The presence of MORB-type volcanic intercalations in Nurmes wackes suggests they were deposited in a back- or intra-arc setting (Kontinen et al., 2007).

Central Karelian terrane

The Central Karelian terrane differs from the Western Karelian terrane in the west and from the Vodlozero terrane and the Belomorian province in the east on the basis of its somewhat younger age and the affinities of greenstone belt volcanism. The seismic structure of the terrane is characterized by subhorizontal reflections, which are interpreted to represent thrust-nappe system, with a northwestward tectonic transport during thrusting (Samsonov et al., 2001).

The oldest dated granitoids in the Central Karelian terrane are 2.76 Ga, although these contain xenocrystic evidence of crustal inheritance up to 3.3 Ga. In the Central Karelian terrane sanukitoid intrusions are strongly differentiated and vary in composition from ultramafic to felsic. They seem to be slightly older (2.73–2.75 Ga) than their counterparts in the Western Karelian terrane where sanukitoid intrusions formed mostly between 2.70–2.74 Ga and their compositions vary from diorite to granite (Lobach-Zhuchenko et al., 2005).

Volcanic rocks of the greenstone belts in the Central Karelian terrane are also younger than in the western and eastern parts of the Karelian province. Felsic volcanic rocks in the Ilomantsi and Khedozero-Bolsheozero greenstone belts are dated at 2.75–2.73 Ga. The presence of basalt-andesite-dacite-rhyolite series volcanic rocks and high abundances of greywackes in the Ilomantsi and Khedozero-Bolsheozero greenstone belts suggests that they represent arc type tectonic settings (Samsonov et al., 2001).

Vodlozero terrane

The Vodlozero terrane is poorly exposed, but several age determinations indicate that large areas of its core comprise 3.2–3.1 Ga granitoids, which include both migmatitic TTG gneisses and relatively homogenous intrusives. Granitoids and pyroxenite-gabbronorite-diorite intrusions of 2.98 Ga age, and coeval calc-alkaline amphibolite inclusions, which may represent mafic dyke remnants, are present in the central part of the terrane. Positive $\varepsilon_{Nd}(t)$ values for these mafic rocks and granitoids indicate that they represent juvenile material derived from a depleted mantle. The younger generations of TTGs in the area were intruded at 2.85 Ga, an event accompanied by regional metamorphism (Sergeev et al., 2007).

The sialic nucleus of the Vodlozero terrane is surrounded by three generations of greenstone belts. The first generation is 3.10–2.90 Ga in age and is charactertized by both oceanic plateau-type komatiites and basalts and island arc-type basalt-andesite-dacite-rhyolite (BADR) series volcanic rocks and adakites. The island arc system was formed during subduction of an oceanic plate under the western margin of the Vodlozero sialic continent, with concomitant back arc spreading setting, producing thick mafic and ultramafic lava units. Continuing subduction led to closure of the back arc basin, and the plateau-type volcanic rocks of the spreading center obducted onto the volcanic arc rocks. The second generation of greenstones is 2.90–2.85 Ga in age and represents continental margin-type volcanism with dacites, rhyolites and adakites; 2.85 Ga tonalites were also emplaced during this event. The third generation of greenstones erupted at 2.80–2.65 Ga, presumably in transpressional-transtensional pull-apart basins (Svetov, 2005).

The youngest (2.7–2.6 Ga) Archean rocks are granites and mafic dykes, which are tholeiitic and ultramafic in the NW part of the Vodlozero terrane and low-Cr, SiO_2-rich gabbronorites (e.g. the Shala dyke) in the central part. A mafic dyke yielded a Sm-Nd whole rock age of 2.61 Ga. Young granites have enclaves of enderbitic granulites and mafic and ultramafic amphibolites.

Belomorian province

The Belomorian province consists largely of Meso- and Neoarchean TTG gneisses, greenstones and paragneisses. The province is characterized by intense polyphase deformation and both Neoarchean and Paleoproterozoic high- and moderate-pressure metamorphic events. The province is dominated by granitoids which have U-Pb ages on zircon and Nd (T_{DM}) model ages with the range 2.93–2.72 Ga. The Belomorian province differs from other provinces of the Karelian and Kola cratons having ophiolites and eclogites that have not been discovered elsewhere in the Fennoscandian shield. Reflection seismic studies suggest that the Belomorian province is structurally formed of eastward plunging subhorizontal nappes and thrusts, being separated from the underlying Central Karelian terrane by a detachment zone (Mints et al., 2004).

Three greenstone generations are distinguished in the Belomorian province, dated at 2.88–2.82 Ga, 2.8–2.78 Ga and 2.75–2.66 Ga, with an additional 2.89–2.82 Ga paragneiss complex. The oldest, Mesoarchean 2.88–2.82 Ga greenstone complexes consist of arc-type BADR rocks and basalts-basaltic andesites with greywackes, oceanic plateau-type komatiites and basalts, the mafic-ultramafic Seriak complex with ophiolite-like compositional features and a metagreywacke unit interpreted as a fore-arc complex (Slabunov et al., 2006). The 2.8–2.78 Ga greenstones belts are represented by various arc type calc-alkaline and adakitic volcanic rocks, the suprasubduction ophiolites of the Iringora complex and metagreywackes and komatiitic-basaltic associations. The Iringora ophiolite sequence includes gabbro, sheeted dykes and massive and pillow lavas which belong to the boninite series (Shchipansky et al., 2004).

Neoarchean 2.72 Ga eclogites are known in two areas in the Belomorian province (Figure 6; Volodichev et al., 2004). Eclogites belong to a suite of rocks that is interpreted to have formed in a subduction zone. The 2.73–2.72 Ga granulite-enderbite-charnockite complexes and hypersthene diorite massifs of the Belomorian province were formed in a suprasubduction setting. Layered gabbro massifs and dykes of 2.7 Ga are considered to have formed at the initial stage of orogenic collapse (Slabunov et al., 2006).

The youngest greenstone complex is c. 2.66 Ga and comprises sediments with polymictic conglomerate lenses and a wide spectrum of volcanic rocks from rhyodacites to basalts, including subalkaline volcanic rocks and thus resembles molasse deposits. The youngest 2.68–2.64 Ga granitoids consist of small tonalite, trondhjemite and diorite veins and postkinematic granites in the northern Belomorian province. Coeval subalkaline granite massifs occur in the southern Belomorian province. Archean rocks of the Belomorian province were exposed at the present erosion level at around.1.8 Ga during the Paleoproterozoic Lapland-Kola orogeny.

Kola

The Kola area is a mosaic of Mesoarchean and Neoarchean tectonostratigraphic terranes, together with some Paleoproterozoic components, which consitute the Kola and Murmansk provinces (Figure 4; Kozlov et al., 2006; Slabunov et al., 2006, and references therein). These provinces reflect growth of continental masses from 2.9 Ga to 2.7 Ga, partly due to subduction of oceanic crust. They were first accreted to each other and subsequently collided with the Karelian Craton at 2.72 Ga, as indicated by high-pressure granulites in the intervening Belomorian Province. A mature intraplate setting developed at 2.67 Ga, and crustal growth continued until around 2.6 Ga.

The Archean crust of the Kola and Murmansk provinces is 36–43 km thick. Horizontal layering and listric seismic reflectors are characteristic of the upper part of the Kola-Norwegian terrane. This terrane records only slight Paleoproterozoic deformation, which enables good correlation between seismic reflectors and Neoarchean structures at the surface. Orthopyroxene-kyanite assemblages developed in Al-rich rocks at the very end of the Neoarchean and indicate pressures of 9–10 kbars in tectonically thickened crust at this time.

The individual Archean terranes consist of upper amphibolite to granulite facies supra- and infracrustal complexes which were variably reworked during the Paleoproterozoic Lapland-Kola collisional orogeny. Given its high metamorphic grade and the extent of reworking the Archean of the Kola region is distinct from the adjacent Karelian province but resembles the North Atlantic craton. Paleoarchean material is represented only by solitary 3.6 Ga detrital zircons in Mesoarchean and Paleoproterozoic granulite facies sediments, whereas the oldest preserved rocks are 2.92 Ga gabbro-anorthosites in a transitional zone between the Kola and Murmansk provinces. Whole rock Nd (T_{DM}) model ages from Archean rocks throughout the region are not older than 3.1 Ga, suggesting negligible input from Paleoarchean protoliths.

Figure 6 Eclogite layer in amphibolite, crosscut by pegmatite dike, Gridino, island of Stolbikha, White Sea.

Murmansk Province

The Murmansk Province comprises Neoarchean amphibolite facies TTG granitoids, diorites, enderbites and minor supracrustal rocks with 2.77–2.72 Ga zircon ages. The province is largely free of Paleoproterozoic deformational and thermal effects.

Kola Province

The Kola Province is a collage of Neoarchean terranes (Figure 4). The Kola-Norwegian and Kolmozero-Voron'ya terranes are almost unaffected by Paleoproterozoic events, whereas part of the Keivy terrane has been considerably reworked. The Kola-Norwegian terrane is made up of TTG granitoids, diorites, enderbites and peraluminous metasedimentary rocks typical of other Neoarchean granulite-gneiss regions. The metasedimentary rocks are interpreted as former greywackes and mudstones. The oldest metamorphic zircons in these rocks have ages of 2.8 Ga. The Olenegorsk greenstone belt is composed of basalts and rhyodacites dated at 2.76 Ga, paragneisses, and economically exploited BIF with gold mineralisation. TTG rocks of 2.8–2.9 Ga were formed by partial melting of mafic lower crust, with pressures varying over a broad range. Younger, 2.72–2.63 Ga granitoids are also present.

The Kolmozero-Voron'ya terrane is a Mesoarchean, c. 2.83 Ga collisional suture zone comprising mantle plume komatiitic rocks, arc-type tholeiitic basaltic-andesitic-dacitic metavolcanic rocks, and conglomerate-bearing terrigenous rocks, intruded by 2.73 Ga monzodiorites and granites.

The Keivy terrane contains 2.87 Ga felsic metavolcanic rocks resembling those formed in active continental margins, and a distinctive suite of alkaline granitoids, including aegirine-arfvedsonite and lepidomelane-hastingsite granites, together with gabbro-anorthosites and spectacular coarse-grained kyanite-, staurolite- and garnet schists, which are not known from elsewhere in Fennoscandia. These granites are the oldest anorogenic alkaline rocks in the world. Together with subsequent subalkaline series they yield ages of 2.67 Ga, identical to those from adjacent syenitic granites and gabbro-anorthosites and were derived from interaction between a mantle plume and continental crust under intraplate conditions (Mitrofanov et al., 2000; Vetrin et al., 2007).

The Sosnovka terrane is composed of poorly studied TTG rocks. Granitoids of 2.69 to 2.77 Ga occur in the Strel'na and Inari terranes located to south of the province (Figure 4).

Summary

Greenland and the eastern Fennoscandian Shield have some similarities in their Mesoarchean and Neoarchean crustal evolution. Large volumes of crust were generated in subduction-related settings in the Mesoarchean (3.1–2.8 Ga), and later in the Neoarchean (2.8–2.7 Ga). However, there are also clear distinctions. Eoarchean 3.8–3.6 Ga supracrustal rocks and granitoids, which are well known from Greenland have not been found in the Fennoscandia, or, if present, they are very scarce, because detrital zircons from paragneisses have not yielded Eoarchean ages. Paleoarchean (3.6–3.2 Ga) rocks are also relatively rare in Fennoscandia. During the c. 2.75–2.65 Ga period both cratons were intensely deformed and they underwent high-grade metamorphism during accretional and collisional processes. However, in contrast to Greenland, where igneous rocks are mostly 2.8 Ga or older, Neoarchean 2.75–2.67 Ga granitoids are common in Fennoscandia. These include mantle derived 2.75–2.70 Ga sanukitoids and related TTG rocks and even arc-type volcanic rocks in some greenstone belts, as well as large volumes of crustally derived 2.70–2.68 Ga granites. Extensive and rapid sedimentation occurred during or immediately prior to these events, recorded by widespread paragneiss suites throughout at least the western part of the Karelian province. The lack of these Neoarchean crust-forming processes in Greenland may indicate that Fennoscandia and Greenland were not parts of the same supercontinent at c. 2.7 Ga, or if they were, they were tectonically in a very different position.

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