DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/2

An overview of pegmatite occurrences in Greenland and their economic potential

Agnete Steenfelt, Karsten Secher og Adam A. Garde

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Contents

Abstract

Pegmatites are very coarse-grained magmatic/hydrothermal veins derived from either volatile-rich residual magmatic liquids, or from initial dehydration melting of high-grade metamorphic rocks. Some types of pegmatites are enriched in economically valuable minerals, and certain pegmatite minerals are the most important sources of metals like beryllium and lithium. Pegmatites are also an important source of gemstones such as emerald, topaz and tourmaline.

Pegmatites are abundant in Greenland, but their economic potential is poorly known except in a few cases. This report provides an overview of the genesis and general economic potential of pegmatite occurrences in Greenland. Stream sediment geochemical maps with locations of samples that are enriched in elements characteristic of pegmatites are also presented, and the most prospective areas for pegmatite-hosted mineral occurrences in Greenland are outlined together with recommendations for further evaluation of their economic potential.

Introduction

Pegmatites are suppliers of rare metals like beryllium, lithium and tantalum, which are in increasing demand by the world's high technology industry. Pegmatites also represent an important source of gemstones such as emerald and tourmaline, and some pegmatites are even mined for their large, clean crystals of quartz and feldspar. Pegmatites are abundant in Greenland, but few have been described or studied in detail and hence their economic potential is largely unknown at present.

This report results from a project supported financially by the Bureau of Minerals and Petroleum in Greenland and the Geological Survey of Denmark and Greenland (GEUS). It aims to provide an overview of pegmatite occurrences in Greenland, describe known mineralogy, and suggest prospective areas and suitable methods for further exploration.

The present survey is based on many years of field observations by the authors, supplemented by literature studies and information from colleagues. Existing geological maps and data from the geochemical mapping of Greenland by GEUS have also been used to search for areas hosting pegmatites with economic potential.

Definition and classification of pegmatites

In a strict sense, a pegmatite is a very coarse-grained igneous rock that has crystallised at a late magmatic stage from a residual magma enriched in volatiles and trace elements. Pegmatites may concentrate rare elements such as lithium, boron, fluorine, tantalum, niobium, rare-earth elements (REE), and uranium to economic proportions (Allaby & Allaby (eds) 1990). Besides, large crystals of pegmatite-forming minerals such as feldspars, quartz and micas are commonly exploited as industrial minerals. Magmatic pegmatites usually form veins or pods in the roof zones of intrusive igneous complexes (Fig. 1). Although pegmatites are mostly known from granitic intrusions, they may also be associated with dioritic to gabbroic and alkaline magmatic complexes. The economic potential of pegmatites is primarily attached to those representing residual melts from granitic and alkaline intrusions. Fine-grained aplite veins are commonly formed at the same late stage in the evolution of a granitic magma as pegmatites, and may be equally enriched in lithophile and/or rare elements. In addition to the above mentioned elements, both pegmatites and aplites may hold interesting concentrations of molydenum, tungsten, copper and gold.

In a broader sense, the term pegmatite is used for any coarse-grained vein of approximately granitic composition, with or without a connection to an intrusive complex. Medium- to coarse-grained granitic to pegmatitic veins may be derived from partial melting of their host rocks during progressive high-grade metamorphism. Such veins are also termed migmatitic veins. When supracrustal rocks are metamorphosed to the point of beginning of melting, both volatile, lithophile and rare elements may readily enter the melt phase and subsequently be incorporated into pegmatite minerals like tourmaline, fluorite, lepidolite, spodumene or beryl. Also molybdenite, scheelite, uraninite and REE-bearing minerals may occur in such pegmatites. In the case of aluminous source rocks such as clayey metasedimentary rocks, common aluminosilicates such as kyanite and cordierite may crystallise in gemstone quality.

In the geological mapping of the Precambrian basement of Greenland, coarse-grained veins are commonly termed pegmatites when their dimensions exceed *c.* 0.5 m in width and 2 m in length, regardless of their origin as either residual or partial melts; it is generally difficult to determine if a deformed and metamorphosed pegmatite originally extended from a granite body or if it was derived from anatectic melting of a local host rock. The Precambrian basement in Greenland characteristically contains several generations of pegmatites formed in response to repeated episodes of heating and granite emplacement (Fig. 2).

In this report we deal with pegmatites in their broad sense, i.e. both those derived from residual magmatic melts and those derived from heating during metamorphism of local host rocks. Elements and minerals of economic interest may occur in both genetic types, and we do not have the means to distinguish their origin in each particular case. Pegmatite-related metals and other elements addressed in this report are listed in Table 1.

Lithium	Li	Niobium	Nb	Tantalum	Ta
Beryllium	Be	Molybdenum	Mo	Tungsten	W
Boron	B	Caesium	Cs	Gold	Au
Fluorine	F	Rare-earth elements	REE	Uranium	U
Scandium	Sc	Lanthanum	La	Thorium	Th
Yttrium	Y	Cerium	Ce	Tin	Sn
Zirconium	Zr	Hafnium	Hf		

Table 1. *Pegmatite-related trace elements and their chemical abbreviations*

Figure 1. *Pegmatite of granitic origin with pink feldspar, white to grey quartz and bronish black allanite. South of Attu, Nordre Strømfjord area..*

Figure 2. *Two or more generations of quartz-feldspar-dominated pegmatite veins in grey orthogneis. Likely origin as local partial melts. Godthåbsfjord, Nuuk region.*

Figure 3. *Feldspar-dominated pegmatite veins within mafic metavolcanic rock. Southern Storø, Nuuk region.*

Classification of economic pegmatites

Several classification schemes exist for pegmatites of largely granitic composition The major rock-forming minerals are combinations of feldspars, quartz and micas, and different proportions of several fluids fluids may be involved in their formation (H_2O, CO_2, Cl, F). In an economic-geological context the classification by Cerny (1991) divides the pegmatites into characteristic suites based on their trace element contents, which have an implied genetic connotation. Two suites of pegmatites are recognized by Cerny (1991):

1. The Nb-Y-F suite associated with sub-alkaline granites.
2. The Li-Cs-Ta suite, also enriched in boron, and typically associated with alumina-rich granites.

Another common classification (e.g. used by Robb 2005) divides granitic pegmatites into simple and complex pegmatites:

1. Simple pegmatites, which are dominated by the ordinary silicates and quartz, often exploited as industrial minerals in bulk operations.
2. Complex pegmatites, which contain concentrations of the large ion elements Sn, W, U, Th, Li, Be, B, Ta, Nb, Cs, REE and Zr, giving rise to minerals which are exploited selectively for their metal content (e.g. cassiterite, columbite, uraninite), or minerals of exotic and precious character, such as tourmaline, topaz, and beryl (Robb 2005).

A third group including pegmatites of alkaline and peralkaline heritage will also be used in this report for descriptive purposes.

Exploitation of pegmatites

A suite of characteristic pegmatite minerals has been successfully exploited from pegmatite mines in most parts of the World. Examples of economic pegmatite deposits world-wide are shown in Table 2. Production numbers are not displayed, since accurate accounts are rare and of heterogeneous nature. The examples comprise large-scale operations with peak productions pr. year in the order of at least 10 000 – 50 000 tonnes. Very large operations have reached annual productions of up to 150 000 tonnes.

Locality	**Country**	**Mineral/commodity**	**Age**	**Production year**
Bikita	Zimbabwe	Li-minerals	Proterozoic	1900(?)–
Evje-Iveland	Norway	Feldspars, various minerals	Proterozoic	1890–1980
Hagendorf Süd, Bawaria	Germany	Phosphate minerals, Li	Phanerozoic	1894–1964
Harding Mine, New Mexico	USA	Spodumen	Phanerozoic	1900–1959
Etta Mine, Black Hills, Dakota	USA	Spodumen, micas	Phanerozoic	1883-1959
Tip Top Mine, Black Hills, Dakota	USA	Feldspar, beryl, Li-minerals	Phanerozoic	1880–1980
Tourmaline Queen, Pala, California	USA	Tourmaline, gemstones	Phanerozoic	1903–1971

Table 2. *Examples of pegmatites mined for their minerals or metal content:*

Mineral extraction may take place as conventional mining in large operations or as small-scale mining. Exploration is generally straightforward, because large, economic pegmatites are often easily recognised in the field, and they are often shown on geological maps. Furthermore, pegmatites may sometimes be located directly from aerial photographs due to their distinct appearance.

Of economic importance are especially minerals containing lithium, beryllium, scandium, uranium and REE, which are commodities with a variety of high-technology uses. Quartz, feldspars and mica are used as industrial minerals, e.g. in ceramics. Several pegmatite mineral species may also be used as gemstones. Furthermore, a number of odd and rare minerals typically occur in pegmatite environments and are locally of great importance.

Greenland itself only comprises one example of pegmatite exploitation which is however outstanding, namely the cryolite deposit adjacent to an alkaline granite of Mesoproterozoic Gardar age at Ivittuut, South Greenland (Fig. 5). This deposit supported an extremely profitable mining operation for as much as 130 years. The first account on the economic potential of pegmatites in Greenland was published by Ball (1922), who underlined the Ivittuut cryolite deposit and the peralkaline rocks in South Greenland, but only mentioned a few pegmatite mineral occurrences elsewhere.

Pegmatite occurrences in Greenland

Although pegmatites are abundant in many parts of Greenland, only few have been studied or described from a mineralogical, genetic or economic point of view. Some general features of pegmatites in Greenland are presented here, while more information is given later on a regional basis.

Granitic pegmatites

The most common pegmatites in the Precambrian basement of Greenland (Fig. 5) are approximately granitic in composition. They essentially consist of very coarse-grained quartz, alkali feldspar and mica; the amount and variety of additional minerals depend on the origin of the pegmatite in question. Magnetite, zircon and allanite are commonly seen, while minerals such as monazite, tourmaline, fluorite, apatite, sulphides, uraninite, beryl or topaz are more rarely seen. Table 3 lists minerals seen or expected to occur in pegmatites in Greenland.

Genetically, most pegmatites in the basement are results of melting during prograde metamorphism. Their mineralogy and economic potential depend to a large extent on the character of the source rock. Pegmatites derived from reworking of tonalitic to granitic orthogneiss usually have a simple mineralogy of quartz, alkali feldspar and biotite and may be classified as simple pegmatites. Small proportions of accessory phases such as magnetite, allanite, apatite, rutile and zircon are also commonly present. Because the pegmatites are closely linked to some of the most common rocks in the middle continental crust, they rarely have economic importance, possibly except large, inclusion-free single crystals of quartz or mica in postkinematic pegmatites.

Especially the Palaeoproterozoic orogens in Greenland comprise turbiditic metagreywackes derived from erosion of magmatic arcs. Such rocks are very common and voluminous in the Rinkian fold belt in central and northern West Greenland, and in the south-eastern part of the Ketilidian orogen of South Greenland. Prograde metamorphism of clastic sedimentary rocks with significant contents of clay minerals leads to progressive dehydration and generation of metamorphic fluids, and when high amphibolite facies P–T conditions are reached, pegmatites are commonly formed. These pegmatites are different from those derived from granitic rocks or magmas: they are more aluminous than the latter and therefore in addition to quartz, alkali feldspar and biotite typically also contain muscovite, tourmaline and garnet, and more rarely andalusite and/or cordierite. Besides common accessory minerals such as magnetite, apatite and zircon, which are also found in simple granitic pegmatites, these pegmatites may comprise additional beryl, topaz and flusspar, in order to accommodate minor elements like B, Be or F from their pelitic precursors, and some of them therefore may be grouped as complex pegmatites. Some of the minerals found in this group of pegmatites may potentially be of gem quality and commercially exploited.

In the Caledonian orogen of central and northern East Greenland, a considerable number of granite and pegmatite bodies of Mesoproterozoic and early Silurian ages, respectively, were formed by melting of Mesoproterozoic supracrustal rocks (Kalsbeek *et al.* 2001a). The alumina-rich sediments sourcing the pegmatites would favour crystallisation of aluminosilicates such as kyanite and cordierite, and potentially also lithium-, tin- and tungsten-bearing minerals. Their genesis thus suggests that many of them may be of the complex type, but very few have been investigated.

Figure 4. *Examples of minerals from granitic pegmatites in Greenland.*

A. Beryl (variety aquamarine) crystal, 17 cm long.
B. Tourmaline crystal (variety dravite) , 14 cm long.
C. Aggregate of allanite crystals.
D. Cerium-rich monazite (orange) and biotite. The monazite crystal is 3 mm across.

In summary, veins derived from melting of orthogneiss become simple pegmatites, while melts sourced by supracrustal rocks of volcanic and/or sedimentary origin have a potential to become complex pegmatites with economically valuable minerals.

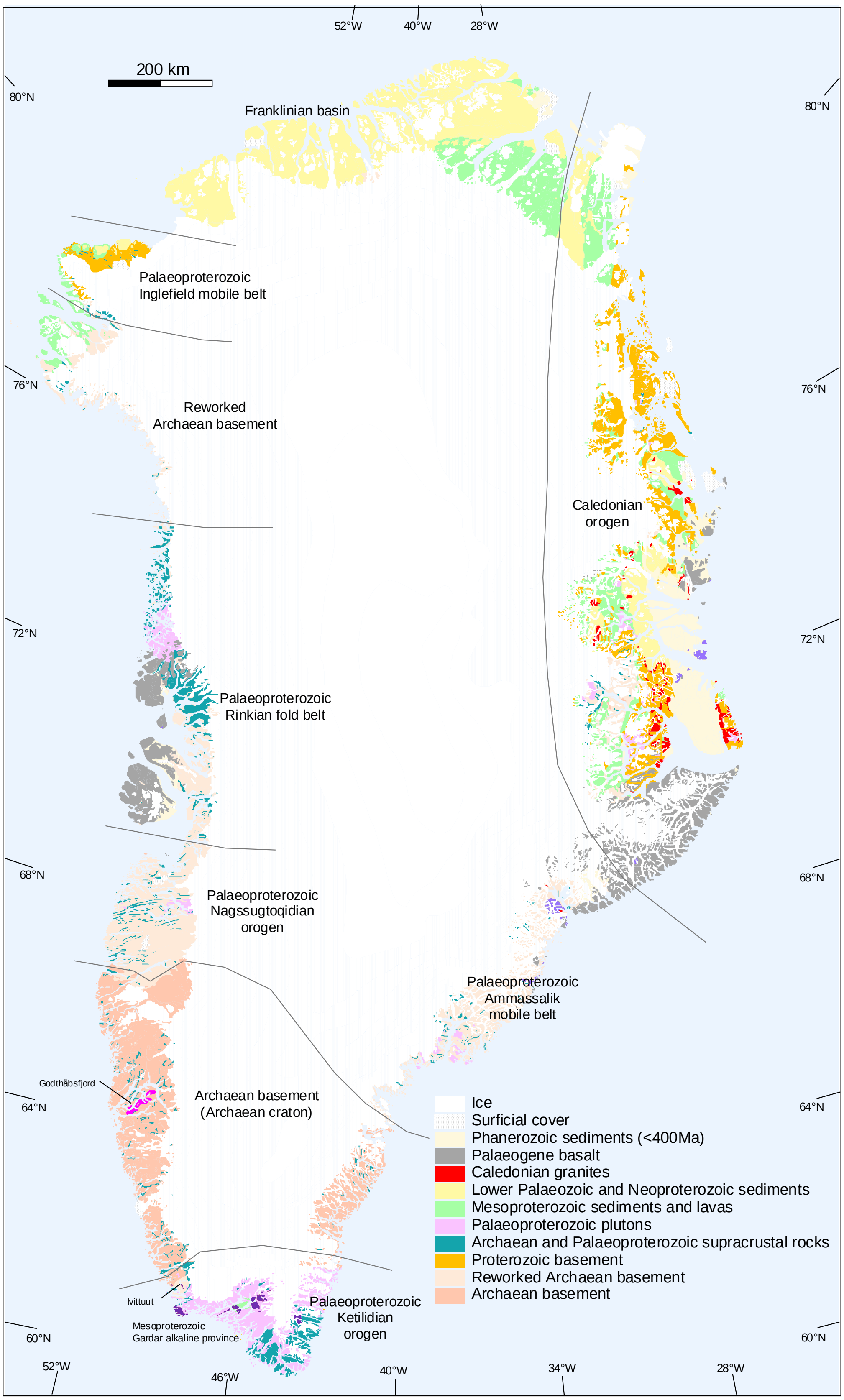

Figure 5. *Major lithostratigraphical and tectonic division of Greenland.*

Pegmatites associated with alkaline igneous intrusions

Alkaline magmatic rocks result from crystallisation of melts generated in the lithospheric mantle. Melting in this part of the lithosphere commonly takes place due to pressure release associated with crustal-scale rifting. Magmas formed in this way are often silica-undersaturated and characterised by high concentrations of the alkali metals K and Na. Like granitic melts they are enriched in lithophile elements including U and Th, but also in high field strength elements such as Y, Zr, Hf, and Nb, Ta and REE. The concentration of these elements may reach economically interesting levels in pegmatites formed in the terminal stages of magmatic crystallisation - in fact, economic concentrations of such elements may also be found in non-pegmatitic rock units and hydrothermally altered zones within or in the surroundings of the alkaline complexes. Alkaline rocks contain rare minerals that have a value as specialised industrial minerals or in the mineral collectors' market. In addition, certain minerals have found use as semi-precious stones, e.g. amazonite and tugtupite (see frontispiece).

In Greenland, the largest and most important group of alkaline rocks is the Mesoproterozoic Gardar province in South Greenland (Upton 1974; Upton & Emeleus 1987). Others comprise the Palaeogene alkaline province in East Greenland (Nielsen 1987, 2005) and the Neoarchaean Skjoldungen province in Southeast Greenland (Nielsen & Rosing 1990; Blichert-Toft *et al.* 1995). Alkaline intrusions in both provinces are shown in Fig. 5.

Two different local types of pegmatites were formed during the crystallisation of the large intrusive complexes within the Gardar Province. One type, 'facies pegmatites', was developed as layers or irregular veins and pockets within the complexes themselves, where volatiles were trapped and the rocks became unusually coarse-grained.

The other type, 'phase pegmatites', was developed where residual liquids and volatiles left the crystallising magma chamber to form pegmatite veins in the surrounding host rocks. The mineralogy of both types of pegmatites reflects the accumulated incompatible elements and compounds. However, the physical conditions (temperature, volatiles, confinement) prevailing within the magmatic complex were different from those in its margin and in the surrounding rocks, and this influenced the mineralogy of the resulting pegmatites.

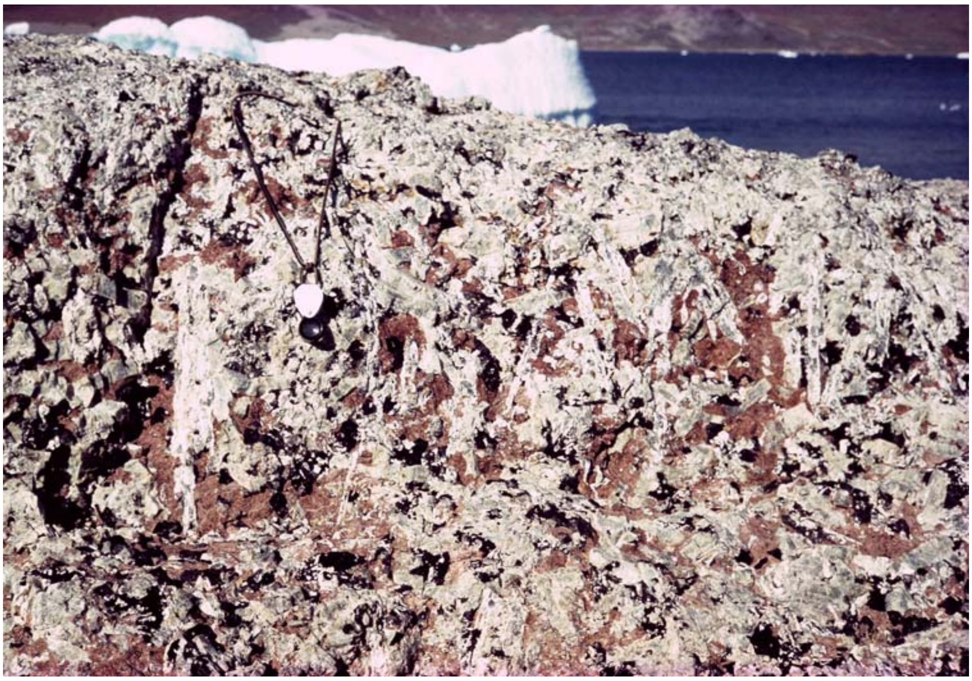

Figure 6. *Facies pegmatite within the alkaline Ilímaussaq complex, South Greenland. The pegmatite contains greyish white, lath-shaped feldspar, red eudialyte, and black arfvedsonite.*

Figure 7. *Phase pegmatite in the margin of the alkaline Ilímaussaq complex, South Greenland. Large black crystals of arfvedsonite up to 60 cm long are intergrown with equally large crystals of white feldspar.*

Geochemical criteria for identifying favourable areas for economic pegmatite occurrences

Large parts of Greenland outside the Inland Ice have been covered by stream sediment surveys (Steenfelt 2001). Sediments from the bottom or banks of second to third order streams have been collected systematically, at densities of 1 sample per 2.5 km^2 in a small part of East Greenland, 6.5 km^2 in South Greenland, 30 km^2 in most of West and parts of North Greenland, and at lower densities in other areas. The samples were screened and the < 100 µm fraction analysed by a variety of methods (Steenfelt 1999). Most samples have been analysed by the neutron activation method, and several of the elements determined by this method are usually concentrated in pegmatites; the elements of interest in this context are Cs, Mo, La, Yb, Hf, Ta, Th and U. Thus, the distribution of high values of these elements may indicate where pegmatites or other rocks with economic potential are located. While Mo mineralisation is mostly associated with granitic rocks, interesting concentrations of the remaining elements may occur in both granitic and alkaline rocks. Unfortunately, the analytical programme did not include determination of B, Be, Li, F.

The distribution of Cs (Fig. 8) reflects the distribution of granitic and syenitic rocks, and the highest values suggest areas favourable for pegmatite formation. These high values form clusters in the metasedimentary rocks of the Karrat Group in the southern Rinkian fold belt, the central and southern Ketilidian orogen, and in the Caledonian belt of northern East Greenland.

Quartz veins have been described from the southern Rinkian fold belt (Thomassen & Lind 1998), but very limited information exists about pegmatites. In the other areas of high Cs, pegmatites have been observed in connection with postkinematic granitic or syenitic igneous complexes.

Lithium (Li) is the most economically valuable of the lithophile elements because of its rarity and use in the electronics industry e.g. in rechargeable batteries. GEUS' stream sediment database does not contain data for Li, but the distribution of Cs serves as a good indicator of environments generally enriched in lithophile elements. Maps of Li and Cs in till and stream sediment in the geochemical atlas of Finland (sampling density 1 sample per 300 km^2, Koljonen (ed.) 1992; Lahermo *et al.* 1996), confirm that the distribution patterns of the two elements are very similar. An area in south-eastern Finland is most enriched in the two elements, and here Cs > 4 ppm in grid values based on stream sediment data corresponds to Li > 32 ppm. By comparison, the values for till samples are 6 ppm for Cs and 50 ppm for Li.

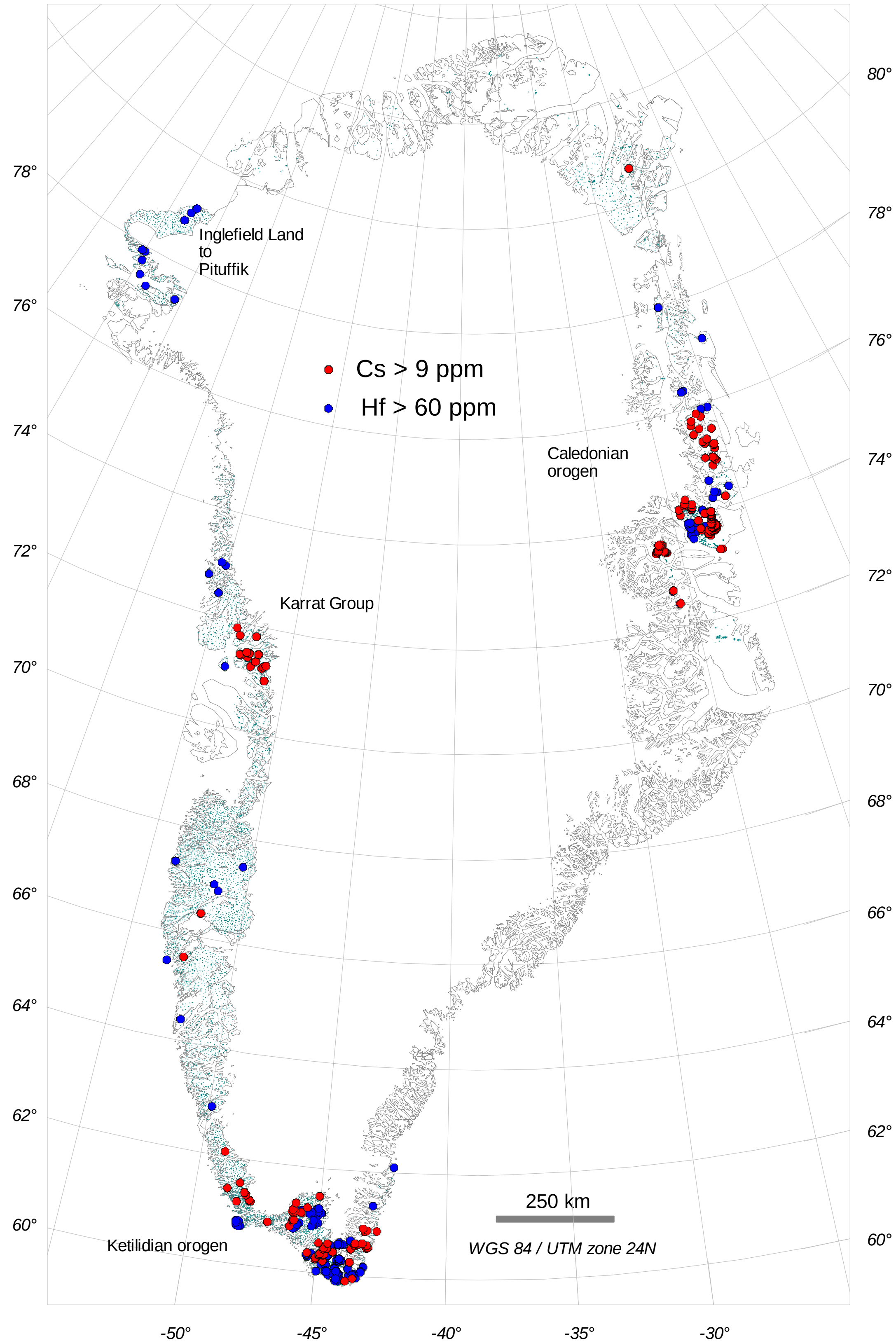

Figure 8. *Locations of stream sediment samples with high concentrations of Cs and Hf in the < 0.1 mm fraction. Green dots mark location of samples analysed by neutron activation.*

In South Greenland, both granitic and alkaline intrusions have high Cs, hence the possibility of finding concentrations of Li minerals seems to be good. The metasedimentary Karrat Group in the Rinkian fold belt appears to be another environment with an obvious potential for Li-bearing pegmatites. Analysing available stream sediment samples from Cs-enriched areas for Li would allow an identification of targets for detailed Li exploration.

The trace element Hf has chemical properties similar to those of Zr, and the two elements are both concentrated in the mineral zircon. The stream sediment analytical data for Hf are more consistent than those for Zr, hence the Hf data are shown here (Fig. 8). Zircon is a heavy mineral and very resistant to weathering and abrasion, and is therefore concentrated in clastic sediments. Accordingly, areas of high Hf commonly reflect the presence of clastic (meta)sedimentary rocks.

Melts formed within metasedimentary rocks have a good chance of becoming enriched in elements contained in rare minerals such as spodumene or cassiterite. High Hf values occur in stream sediments draining sedimentary rocks in the Inglefield Land – Pittufik region, which also show high values of REE (Fig. 10) and Th (Fig. 11). However, low concentrations of the granite-indicating element Cs suggest that a granitic component is absent, and pegmatites are rare.

Hf is also enriched in alkaline rocks together with Cs, Li, Nb, Ta, U, Th and REE. Elevated concentrations of many of these elements in the same stream sediment samples in South Greenland reflect the alkaline rock complexes of the Gardar province.

The economically interesting elements Ta and Mo (Fig. 9) may both be concentrated in pegmatites, although these elements may also be enriched in other rock types. Ta may also be indicative of Nb concentrations, because Ta and Nb are geochemically very similar. Molybdenite, MoS2, typically forms as an accessory mineral in certain granites, pegmatites and aplites, commonly in high-temperature vein deposits associated with cassiterite, scheelite, wolframite and fluorite. Mo is enriched in the Rinkian metasedimentary Karrat Group, where Mo has been found in pegmatites (Allen & Harris 1980). Mo-bearing pegmatites are also known from the northern part of the Julianehåb batholith.

The Ta distribution patterns of Fig. 9 show that the Gardar province is strongly enriched in Ta, but interestingly, high Ta is also found in samples from streams draining metasedimentary and sedimentary rocks in East Greenland. The few scattered stream sediment samples with high Ta in other parts of Greenland coincide with known occurrences of Ta-Nb bearing carbonatites in West Greenland (i.e. not pegmatites). The samples with high Ta in northern West Greenland are presently unexplained.

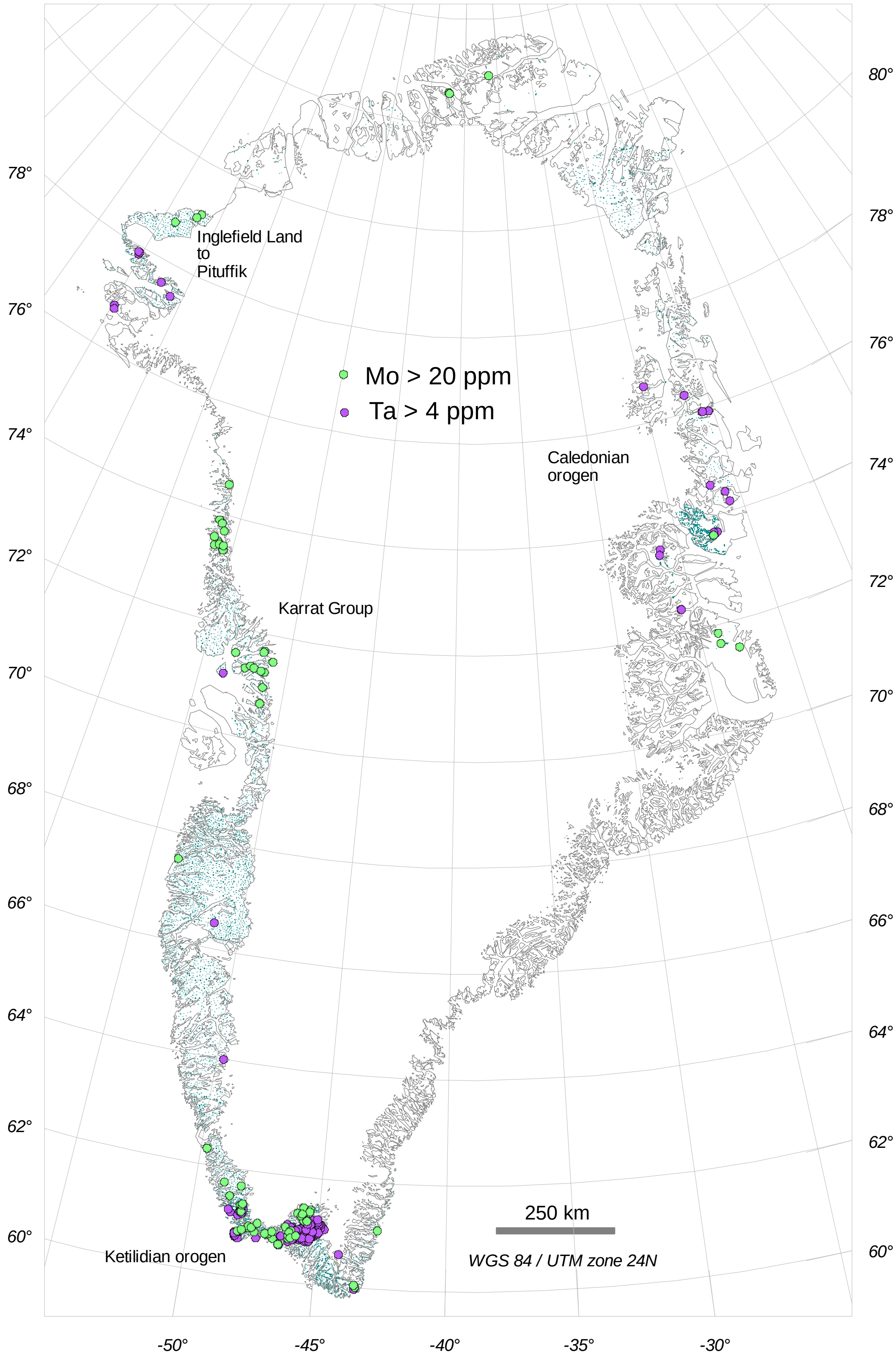

Figure 9. *Locations of stream sediment samples with high concentrations of Mo and Ta in the < 0.1 mm fraction. Green dots mark location of samples analysed by neutron activation.*

In simple pegmatites related to granites the minerals allanite and monazite are commonly enriched in REE, whereas a whole range of rare REE minerals occurs in alkaline pegmatites. The light REE La and Ce are geochemically very similar, so that high concentrations of La also indicates high Ce; presently Ce has greater industrial use than La. The heavy REE Yb is similar to yttrium (Y), which is eonomically more interesting. There is an interesting difference in the distribution patterns of the light and heavy REE, exemplified by La and Yb (Fig. 10). Thus, in metasedimentary environments, La is enriched in the Rinkian fold belt, while Yb is enriched in south-eastern Ketilidian and Caledonian orogens. Many of the Gardar rock units are enriched in both light and heavy REE.

Fig. 11 displays U and Th distributions. The two elements are concentrated in granites and their pegmatites, but also in alkaline rocks. In addition, Th minerals such as allanite may be accumulated in sediments. In the map, high Th values are distributed in areas of sedimentary rocks, whereas high U values reflect occurrences of granitic rocks. Large Neoarchaean pegmatites with high U contents in the Nuuk region are the source of the high U found in stream sediments there.

In summary, the stream sediment data suggest that granitic pegmatites in the Palaeoproterozoic Karrat and Ketilidian supracrustal sequences, and in the Neoproterozoic Krummedal supracrustal sequence seem to have the best potential for hosting economically interesting minerals.

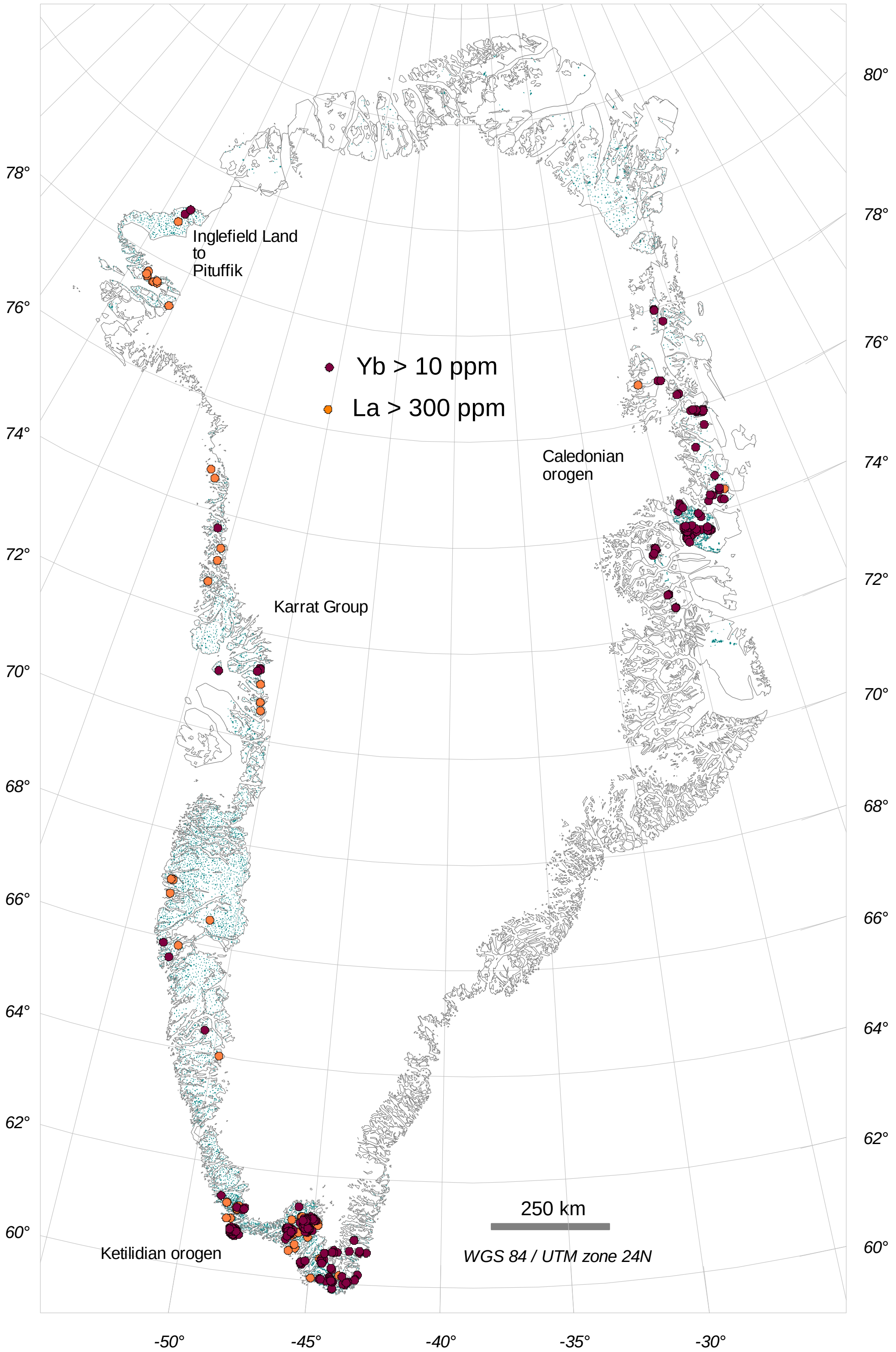

Figure 10. *Locations of stream sediment samples with high concentrations of Yb and La in the < 0.1 mm fraction. Green dots mark location of samples analysed by neutron activation.*

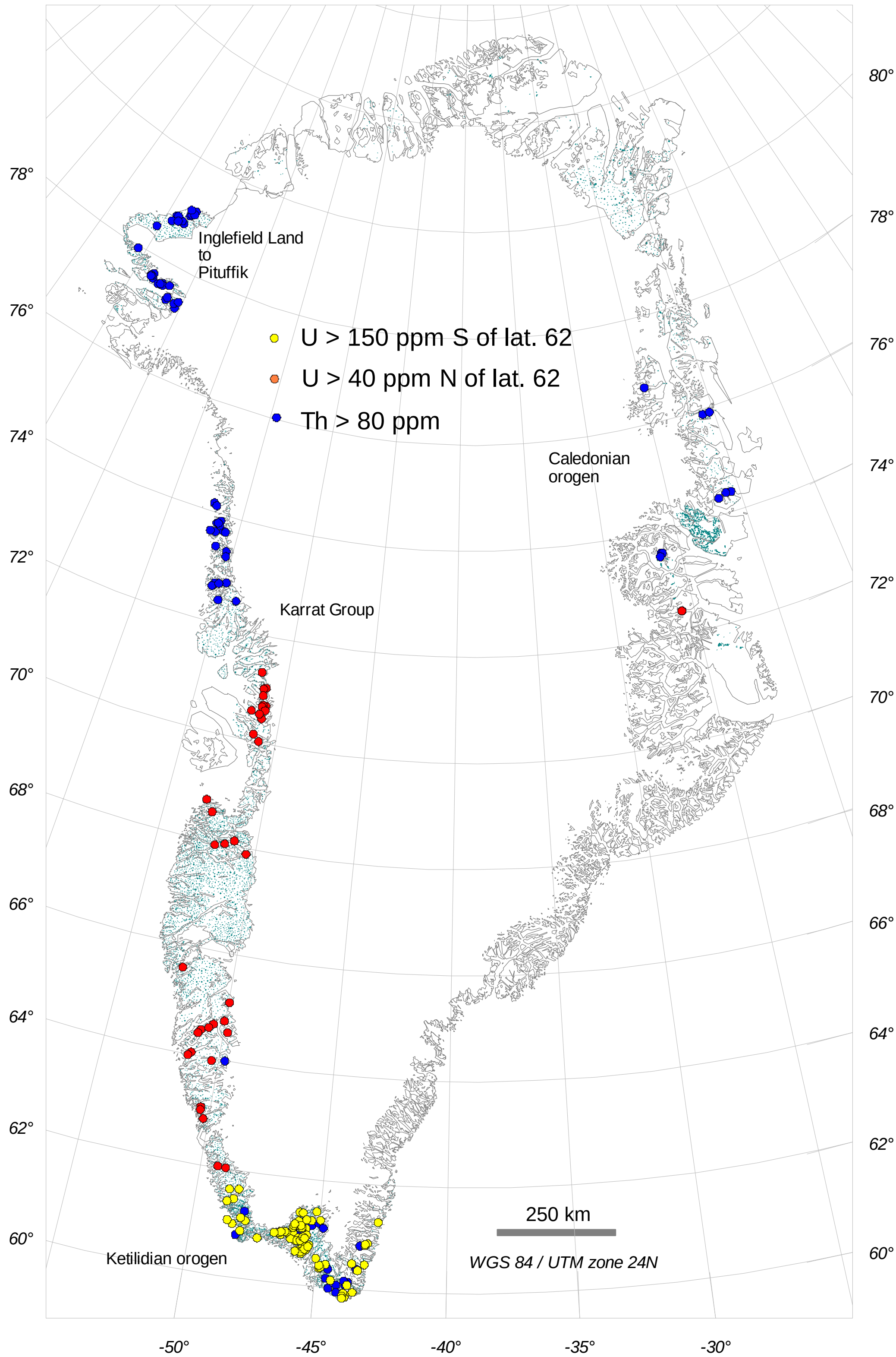

Figure 11. *Locations of stream sediment samples with high concentrations of U and Th in the < 0.1 mm fraction. Green dots mark location of samples analysed by neutron activation. Two thresholds are chosen for U because the background for U is extraordinarily high in South Greenland.*

Overview of known pegmatite occurrences in different regions of Greenland

Most of the information about pegmatites is found in the published geological maps, and in map manuscripts and field diaries in the archives of the Survey. Limited additional information exists in reports by mineral exploration companies. Much information is stored in the minds of field geologists. The authors of this report have worked with Greenland geology for 30 years, and allowed us to draw on collective field observations of pegmatites in most parts of Greenland. For other areas we have looked into relevant sources of information residing in GEUS archives, and we have asked colleagues about their observations. Here we provide an overview region by region of pegmatite occurrences known to us, including their type and observed mineralogy. The regions addressed in the following are shown in Figs 12 and 19.

Some references to key publications for each region are given here. Additional references of general or introductory character concerning geological units in Greenland may be found in Henriksen et al. (2000).

Palaeoproterozoic Inglefield mobile belt and Archaean basement between Inglefield Land and Pittufik

Inglefield Land supracrustal rocks

Garnet-rich granulite facies metasedimentary rocks (predominantly metasandstones and metagreywackes) have common migmatitic veins and leucocratic quartz-feldspar pegmatites with variable amounts of garnet (Dawes 2004). The migmatitic veins and pegmatites were formed in at least three pre-, syn- and post deformation generations. Undeformed simple pegmatites and small outcrops of granite carry pink K-feldspar and may be associated with hidden larger granitic plutons. One pegmatite has radioactive minerals (Steenfelt & Dam 1996).

Archaean basement

At Nunatarsuaq south-east of Inglefield Bredning many migmatitic veins and K-rich pegmatites are hosted by Archaean tonalitic to granodioritic orthogneiss in amphibolite facies. Stream sediment and gamma-radiation data confirm elevated large-ion lithophile elements (LILE) in Nunatarsuaq, suggesting an upper-crustal level of prograde amphibolite facies (Steenfelt *et al.* 2002). Pegmatitic gneiss has also been described from Carey øer (Bendix-Almgreen *et al.* 1967; Dawes 2006).

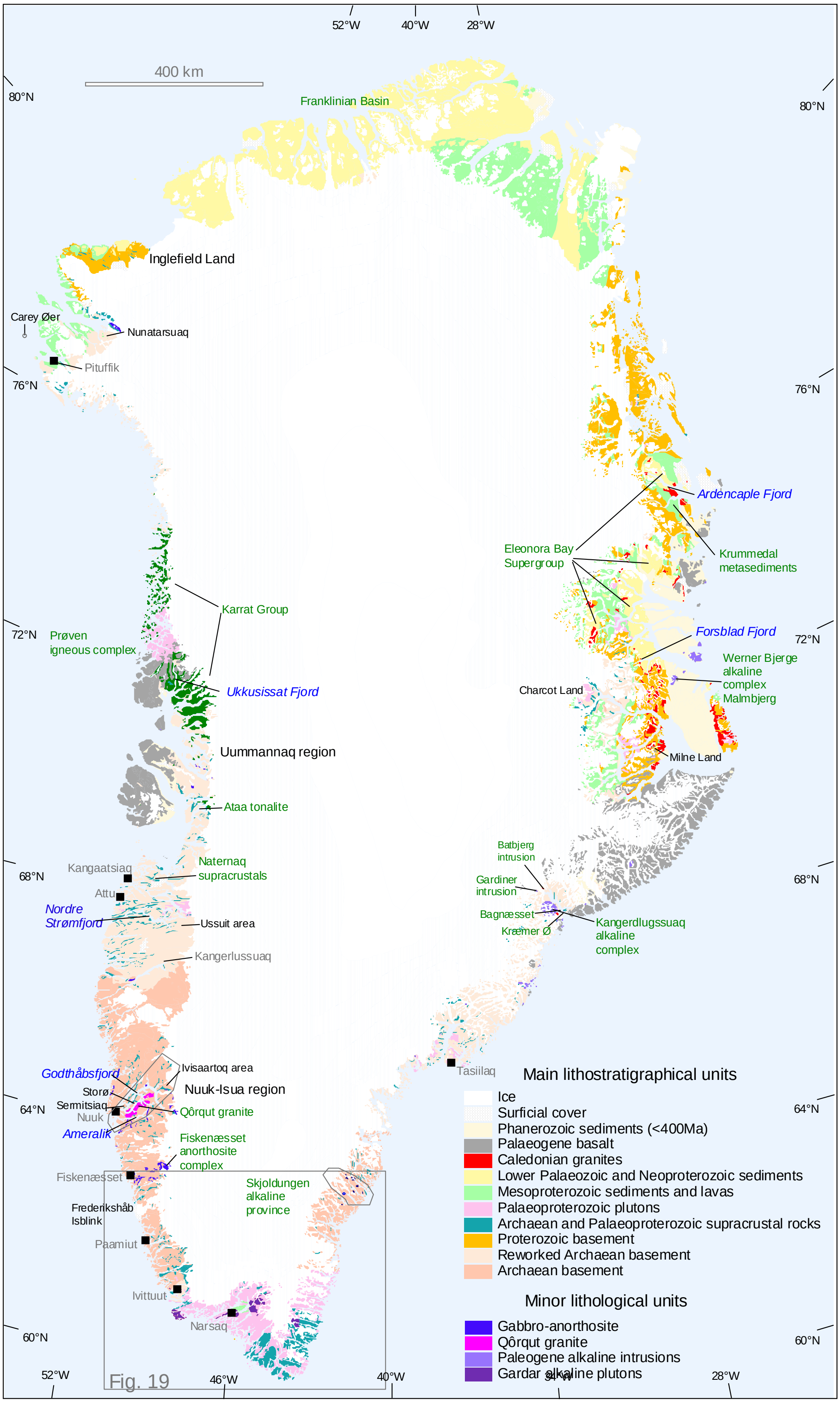

Figure 12. *Geological map with names. Geological formations in green, fjords in blue, settlements in grey, and other place names in black text.*

Northern Rinkian fold belt

Metasedimentary rocks of the Karrat Group

Metasedimentary rocks of the Palaeoproterozoic Karrat Group (Grocott & Pulvertaft 1990), mostly in granulite facies, are widespread in most of the Rinkian fold belt and contain abundant granitoid veins of migmatitic or pegmatitic origin, besides numerous quartz veins and pods (Thomassen *et al.* 1999). The metasedimentary setting has an excellent potential for the formation of complex pegmatites.

Prøven igneous complex

The most prominent and best exposed example of pegmatites adjacent to a large orogenic intrusion in West Greenland occurs adjacent to the Palaeoproterozoic Prøven igneous complex in the Upernavik region of the northern Rinkian fold belt (Fig. 8). The Prøven igneous complex is a huge granitic lopolith about 100 km across that was emplaced into the core of the Rinkian fold belt at 1.87 Ga (Kalsbeek 1981; Thrane *et al.* 2005) Isotopic studies by the same authors have shown that the complex consists of remelted Archaean crust. The granitic magma was emplaced synkinematically with respect to the flat-lying, collisional tectonic fabrics in its host rocks. Due to the large heat flow, swarms of pegmatites were also generated by local melting in the country rocks up to tens of kilometres away from the presently exposed margins of the igneous complex.

Figure 13. *Swarm of syn- to postkinematic Rinkian pegmatites on the west coast of Ukkusissat Fjord c. 20 km south of the Prøven igneous complex. The coast side is c. 1000 m high.*

Central and southern Rinkian fold belt

Metasedimentary and metavolcanic rocks of the Karrat Group

The Karrat Group south of the Prøven igneous complex comprises large areas of lower amphibolite facies metagreywacke of the Nukavsak Formation together with quartzite and marble, the latter hosting lead-zinc-sulphides (Henderson & Pulvertaft 1987). Pegmatites are most abundant in the northern part close to the Prøven igneous complex (see the previous section). According to Allen & Harris (1980), a swarm of peraluminous granite pegmatite dykes cuts Umanak gneiss and Karrat Group rocks in the central part of southern Rinkian fold belt. The pegmatites have quartz-rich centres and are associated with quartz veins, and are composed of quartz, muscovite, biotite, feldspar, garnet and variable tourmaline, they. Molybdenite is found commonly within 30 cm of the margins of the veins, and 0.1 – 0.5 % MoS_2 over 4–5 cm have been recorded (Allen & Harris 1980).To the south, quartz veins derived from metamorphic dehydration of the sedimentary rocks are more common than pegmatites (Thomassen & Lind 1998; A.A. Garde, field notes 2002–2003). Farther south, a pegmatite with tourmaline has been observed at the contact between the metagreywacke and underlying basement of orthogneiss (A. Steenfelt, field notes 1997).

Archaean basement in the Uummannaq region

The amphibolite facies Archaean orthogneisses in the Uummannaq region contain several generations of migmatitic veins and pegmatites in the broad sense.

Ataa area

The Archaean basement consists of amphibolite facies migmatitic orthogneiss. Common simple pegmatites are likely to have been mobilised from the orthogneiss. The Ataa tonalite is an intrusive plutonic complex which is in part exposed near its roof, where granitic and aplitic to pegmatitic veins are locally abundant and may extend into the surrounding country rocks (Kalsbeek & Skjernaa 1999). The mineralogy of these simple pegmatites is dominated by quartz, feldspars and biotite. Migmatite veins are common in the metavolcanic rocks adjacent to the Ataa tonalite and also occurs in the supracrustal sequences at Eqi near the margin of the Inland Ice.

Central and northern Nagssugtoqidian orogen

The Nagssugtoqidian orogen in central West Greenland mainly comprises Archaean crust that has been partly reworked during the Palaeoproterozoic heating and deformation, besides Palaeoproterozoic supracrustal rocks and remnants of two magmatic arcs (van Gool *et al.* 2002). Both Archaean and Palaeoproterozoic pegmatites occur, and examples of both simple and complex pegmatites are known. In some areas two different groups of pink and white pegmatites have been distinguished, but this distinction based on colour can only locally be related to the age, type, or genesis of the pegmatites in question. Furthermore, it may be difficult to distinguish Archaean pegmatites within areas of unreworked Archaean rocks from Palaeoproterozoic pegmatites in reworked areas. This is illustrated in Figs 14 and 15. Figure 14 shows a group of Archaean synkinematic granite-pegmatite sheets up to about 30 cm wide, which cut Archaean orthogneiss and are in part folded with their host. The outcrop is located south-east of Kangaatsiaq within an area that was heated but not deformed during the Palaeoproterozoic, and the pegmatites are regarded as derived from late Archaean granitic plutons.

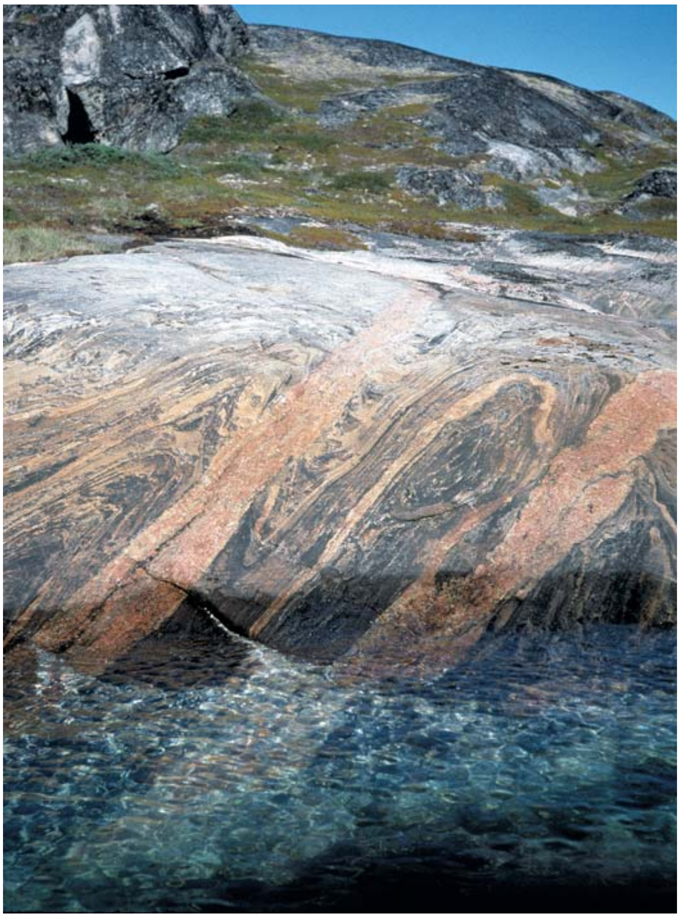

Figure 14. *Archaean, syn- to postkinematic granite–pegmatite sheets c. 30 cm thick in Archaean orthogneiss. North coast of Saqqarput, 30 km south-east of Kangaatsiaq*

Figure 15 shows a coastal outcrop in the northern Nagssugtoqidian orogen displaying Archaean orthogneiss and Palaeoproterozoic dykes that were intensely deformed in the Palaeoproterozoic orogeny. Two prominent, steeply inclined postkinematic pegmatites of Palaeoproterozoic age are visible in the centre of the photo, which cut the flat-lying, relict dykes and reworked orthogneiss. These pegmatites have presumably been derived from reworking of Archaean orthogneisses in Palaeoproterozoic time, since no large Palaeoproterozoic granites are exposed in the northern Nagssugtoqidian orogen. Older, pre- or synkinematic felsic sheets are also visible as thin, pale layers within the orthogneisses, and may be either Archaean or Palaeoproterozoic in age.

Figure 15. *Pink Palaeoproterozoic pegmatites cutting reworked, migmatised Archaean orthogneiss and deformed Palaeoproterozoic mafic dykes. South coast of island 11 km east of Aasiaat.*

Naternaq

The Palaeoproterozoic Naternaq supracrustal belt (Østergaard *et al.* 2002) was deformed and metamorphosed during the Nagssugtoqidian orogeny, and local pink granites as well as both pink and white pegmatites were formed as result of local melting in the area of a prominent fold hinge in the south-western part of the belt. Several of these pegmatites are white and commonly contain decimetre-sized crystals of black tourmaline (A.A. Garde, field notes, 2002). However, no detailed studies have been carried out on such pegmatites, some of which may be complex in their mineralogy.

Kangaatsiaq – Nordre Strømfjord

Pink pegmatites are common in the outer fjord zone from Kangaatsiaq to south of Attu, where the Archaean orthogneiss is intruded by granite and simple pink pegmatites of unknown age. The pegmatites occur mostly as discordant decimetre- to metre-thick bodies within the gneiss, at contacts between major lithological units, and within supracrustal rocks where they are clearly cross-cutting. The dominant minerals are K-feldspar (commonly more than 10 cm in size), quartz, biotite and subordinate allanite, titanite, apatite, magnetite and Fe-sulphides. Zonation is occasionally seen, with quartz-rich centres bounded by K-feldspar-rich parts.

White pegmatites are generally concordant (but locally discordant) to the foliation of the adjacent country rocks (typically grey orthogneiss and supracrustal rocks). The white pegmatites are 5–20 m wide and 50–200 m long, with a general trend of NW–SE all over the Nordre Strømfjord and Ussuit areas. Gradual contacts to the host rocks are common.

Quartz and plagioclase dominate the white pegmatites, with garnet, biotite, monazite, magnetite and zircon as characteristic minor constituents. Monazite is found as 0.5–5 mm orange crystals that mainly occur in plagioclase-biotite-rich pegmatites. The monazite crystals are euhedral and occur in lens-shaped layers accompanied by biotite, set in a granoblastic matrix of primarily plagioclase (Secher 1980). Both pegmatite types have ages of *c.* 1800 Ma (Pb-Pb age determinations of allanite and monazite, Stendal *et al.* 2006).

Southern Nagssugtoqidian orogen

Kangerlussuaq

Pegmatite dykes, veins and schlieren occur throughout the southern Nagssugtoqidian boundary area, and vary considerably. Locally, simple quartz-feldspar-pegmatites host garnet and apatite (Noe-Nygaard & Ramberg 1961).

Archaean basement rocks in the Nuuk–Isua region

The Nuuk–Isua region represents the highest crustal level in the North Atlantic craton in southern West Greenland, and pegmatites are abundant and voluminous in some areas, especially within supracrustal rocks at western Godthåbsfjord. They were formed during several thermal episodes in the time interval *c.* 2750–2600 Ma (Hollis *et al.* 2006), and again at around 2550 Ma in connection with the intrusion of the multiple Qôrqut granite sheets.

Pre-Qôrqut granite pegmatites

The earlier pegmatites (Figs 16 and 17) most likely represent local melting of a package of metavolcanic and metasedimentary rocks. The pegmatites are leucocratic and dominated by quartz and white feldspar, and they contain a variety of accessory minerals including biotite, magnetite, garnet, tourmaline, allanite and uraninite. At a couple of localities also uraninite has been found, frequently altered to yellow β-uranophane (Secher 1980). Pegmatites in the Ivisaartoq area are known for their local accumulation of beryl (var. aquamarine), which at one locality has delivered large well-shaped crystals of up to 4 x 17 cm (Fig. 4). Tourmaline (var. dravite) is well known from Sermitsiaq and the southern part of the Nuuk region around Ameralik. A typical feature of this tourmaline is its black colour, the well-developed crystal faces with shiny surfaces, and the large sizes. Crystals of up to nearly 2 kg a piece have been recorded (Petersen & Secher 1993). The economic potential of these pegmatites has not been evaluated.

Figure 16. *White pegmatites dated at c. 2630 Ma within Archaean supracrustal rocks on central Storø, Nuuk region.*

Figure 17. *Close-up of white pegmatite, clearly intrusive into deformed grey gneiss.*

Pegmatites related to the Qôrqut granite

The Qôrqut granite in Godthåbsfjord is a multiply intruded sheeted complex around 2550 Ma in age. The granite is rich in lithophile elements like K, U and Th (Steenfelt *et al.* 1990) and with many pink pegmatites rich in K-feldspar (Fig. 18). A number of minerals of possible economic significance have been located within the pegmatites. Both inside and around the Qôrqut granite the biotite-rich parts of its pegmatites often contain magnetite, garnet, pyrite and rarely molybdenite.

Figure 18. *Pink pegmatite related to the Qôrqut granite complex. Godthåbsfjord, Nuuk region.*

Archaean craton in the Fiskenæsset–Paamiut region

In the southern part of the Archaean craton in southern West Greenland, quartz- and plagioclase-rich pegmatites intrude both the orthogneisses and the Fiskenæsset anorthosite complex, where they typically form conformable bodies along lithological contacts within the complex. Numerous light coloured quartz-plagioclase-biotite pegmatites with varying sizes up to 30 m wide often have accessory (up to 10 vol%) allanite and rare garnets. Garnets typically occur in marginal layers. Molybdenite and beryl are rarely seen, and the pegmatites are considered barren in an economic geological context. Similar pegmatites are found locally in the easternmost part of the region. These pegmatites are often wide (10–15 m) and can be followed for several hundred metres, and are characterised by their more or less stable allanite contet of 5–10 vol%. (Windley *et al.* 1973; Secher, field notes 1970).

Ketilidian orogen and Gardar igneous province in South Greenland

The evolution of the Palaeoproterozoic Ketilidian orogen and the subsequent Mesoproterozoic Gardar igneous province in South Greenland has favoured the formation of pegmatites, both simple pegmatites related to granitic magmas, simple and complex pegmatites formed by melting of metasedimentary rocks, and pegmatites related to alkaline intrusions. The most interesting pegmatite-forming events are late-kinematic Ketilidian granites related to the Julianehåb batholith and the granites contemporaneous with the late- to postkinematic rapakivi suite, both of Palaeoproterozoic age, and the Mesoproterozoic Gardar magmas. The location of geological formations and places in South Greenland is shown in Fig. 19.

Ketilidian orogen

Much of the information about pegmatites in South Greenland has been provided by uranium exploration campaigns by the Survey in 1979–1986, as many pegmatites and veins turned out to have elevated concentrations of U- and Th-bearing minerals ((Nyegaard & Armour-Brown 1986).

Northern Ketilidian Border Zone (Frederikshaab Isblink – Kobberminebugt)

Isorsua

The Isorsua area is covered by 1:100 000 scale geological map 61 V.2 Nord Midternæs. the map shows that large pegmatites occur in both metavolcanic and metasedimentary rocks. A large granite body of unknown, but presumably Archaean age was found to be enriched in U and Th (Steenfelt *et al.* 1994; Stemp 1997). The granite could be the source of the pegmatites, or the source of heat by which partial melting took place within the supracrustal rocks.

Taartoq

The 1:100 000 scale geological maps show that pegmatites occur frequently in the basic metavolcanic rocks of the Taartoq Group. These pegmatites are likely to have formed as result of local melting during prograde metamorphism of the volcanic sequence.

Sanerut, Storø, Pyramidefjeld

Granites formed during the convergent subduction phase of the Ketilidian orogeny have intruded the Archaean continental margin in what is known as the Ketilidian Border zone. Pegmatites associated with these granites are expected to exist, but further information has presently not been identified. Many pegmatites are shown in the two published geological maps at scale 1:100 000 of the Border zone, and may include migmatitic veins as well as true pegmatites.

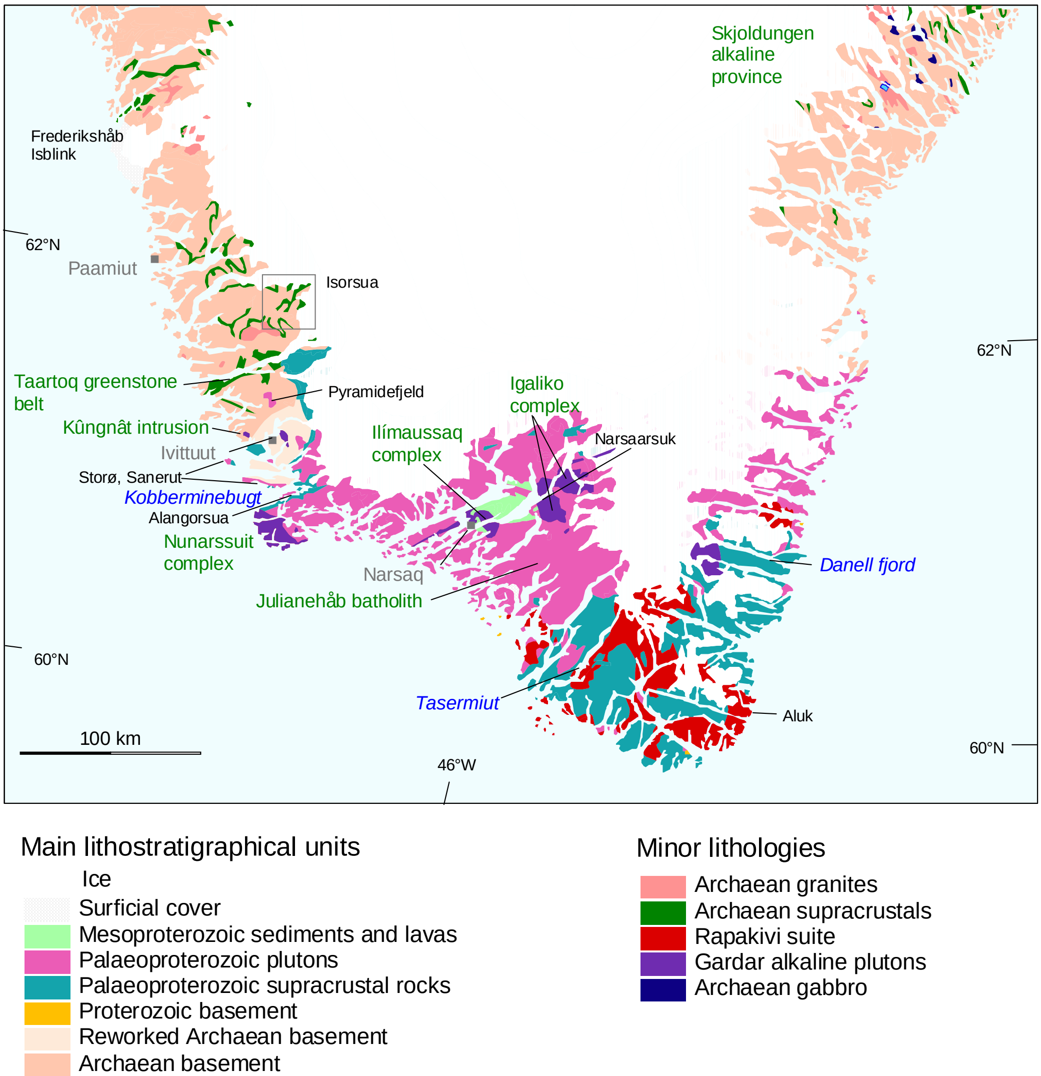

Figure 19. *Geological map of South Greenland with names. Geological formations in green, fjords in blue, settlements in grey, and other place names in black text.*

Kobberminebugt

At Alangorsua in Kobberminebugt an irregular pegmatite lens, 10 x 3 m in size, contains a nest of up to 3 cm long, light green to light blue-green beryl crystals (A. Steenfelt, field notes 1987). The pegmatite is dominated by quartz, whereas feldspar is subordinate and there are only traces of biotite. The host rock is a hornblende-phyric mafic metavolcanic unit of the Kobberminebugt supracrustal rocks.

Central Ketilidian orogen

The late granitic members of the Julianehåb Batholith are high-level intrusions with associated pegmatites, although there is no special information on these. The 1:100 000 scale geological maps document that pegmatites have been observed. In the central part of the batholith supracrustal units are virtually absent, and pegmatites are likely to be of the simple type.

South-eastern Ketilidian orogen

The two published geological maps covering parts of the deformed and metamorphosed fore-arc basin of the southern and south-eastern Ketilidian orogen illustrate with symbols that migmatites and pegmatites are abundant in the zones of reworked metasedimentary rocks. Partial melting of meta-arkose and quartz-rich sandstone on the Nanortalik Peninsula have formed

Figure 20. *Migmatitic meta-arkose (or acid volcanic rock) carrying radioactive minerals and cut by thin straight quartz-feldspar veins. Tasermiut, South Greenland.*

pegmatitic subconcordant sheets and crosscutting veins up to several metres thick (Nielsen & Tukiainen 1981). The main pegmatite minerals are quartz, feldspar, micas and amphiboles, with accessory pitchblende, chalcopyrite and black tourmaline. Tourmaline- and locally dumortierite-bearing complex pegmatites derived from partial melting of local metasedimentary rocks occur, e.g. north of Danell Fjord (A.A. Garde, field notes 1994,1996).

Garnet- and locally cordierite-bearing S-type granites derived from partial melting of metaarkose and greywacke are common in the eastern and south-eastern parts of the Ketilidian fore arc, and sometimes grade into pegmatites.

The late to post-kinematic Rapakivi intrusive suite of granites and norites also comprises small volumes of granites (microcline granite, biotite granite, Allaart 1973). Pegmatites and aplites associated with the granites are locally enriched in gold, and they have a potential of being enriched in Li as they have high concentrations of the other lithophile elements Rb and Cs (Steenfelt 2000). The type locality for allanite is Aluk in the rapakivi suite (Fig. 19).

Mesoproterozoic Gardar province

Information about pegmatites in the Gardar complexes may be found in Survey publications (especially the Bulletin of the Geological Survey of Greenland) issued at the termination of a regional mapping programme of the 1960s, see references below. A systematic search through maps, publications and field diaries would undoubtedly provide more detailed information. Among the Gardar intrusions the Ilímaussaq intrusive complex described in the following appears to have the best potential for economic use of its pegmatites.

Narsaq

The Ilímaussaq intrusive complex comprises a series of syenites formed by crystallisation of silica-undersaturated, alkaline to peralkaline magmas rich in volatiles, in particular F and Cl (Bailey *et al.* (eds) 1981). As mentioned in the introduction, pegmatites occur within many of the rock units, and a few extend into the country rock. Thus, pegmatites were formed as networks of veins below the roof and along the sides of the chamber of the early naujaite-foyaite stage of felsic nepheline syenites, and as layers within the naujaite. The pegmatites are commonly rich in eudialyte and other minerals containing Nb, Ta and REE, and pegmatites rich in Li and Be minerals occur locally (Sørensen 1962; Sørensen *et al.* 1981; Sørensen 1992). Also in the late magmatic lujavrite (mafic nepheline syenite) stage, facies pegmatites developed as irregular veins and patches, and they are particularly enriched in F, U and Th, Be, Li, Zr, Nb and Ta (Sørensen 1960; Engell *et al.* 1971; Bailey *et al.* 1993; Sørensen 2000).

The Ilímaussaq intrusion has become famous among mineral collectors for its large number of rare mineral species, which are commonly found in its pegmatites (Secher *et al.* 1981; Sørensen *et al.* 1981; Petersen & Secher 1993).

Ivittuut

The intrusion at Ivittuut comprises a stock of alkaline granite (Ivigtût granite) with a pegmatitic facies developed into cryolite-, quartz- and quartz-feldspar pegmatites. The now totally exploited cryolite ore body had the shape of an irregular, flattened dome measuring about 50 x 155 m horizontally and 70 m in depth. The main ore body of cryolite and siderite was followed downwards by a siderite zone mixed with a fluorite shell to the west. At still deeper levels a huge mass of more or less pure quartz with accessory sulphide minerals separated the body from the underlying granite. Late feldspar-quartz pegmatites have been recognised in the upper part of the ore body. Typical complex pegmatite minerals such as topaz, cassiterite, columbite and wolframite occur, together with a suite of rare and unusual fluoride, carbonate and oxide minerals, around 90 different minerals in all. The elements Th and Sr are minor but characteristic constituents of the deposit. The cryolite deposit was mined from 1854–1987, with at total production of 3.7 million t of ore averaging 58% cryolite.

The mode of formation of the cryolite mass adjacent to the Ivigtût granite is still a matter of discussion. One accepted theory considers the cryolite to represent an extreme pegmatitic and/or pneumatolytic phase derived from the crystallising granitic magma. The unusual formation was the result of accumulated fluorine-rich gases trapped in the central upper part of the already solidified granite stock.

The major cryolite, cryolite/siderite and quartz phases of the cryolite deposit are considered to have crystallised in close succession, while subsequent fluorite-cryolite- and fluorite-dominated phases were formed when late fluids reacted with previously crystallised rocks.

Pegmatites from the nearby Kûngnât syenitic intrusion contain ornamental amazonite and iridescent feldspar.

Nunarssuit alkaline complex

This large intrusive complex comprises several intrusive phases of alkaline saturated to oversaturated rocks. Very high Y and Yb concentrations in stream sediment (see high Yb in Fig. 11) suggest that pegmatites with yttrium minerals occur in the intrusive complex. Amazonite occurs in several pegmatites of the complex, see frontispiece.

Igaliko alkaline complex

A pegmatite at a place called Narsaarsuk has been made famous for a large number of new and very rare minerals (Petersen 1989; Petersen & Gault 1993; Petersen & Secher 1993; Petersen *et al.* 1996; Petersen *et al.* 1999).

Palaeoproterozoic basement, Ammassalik/Tasiilaq region

The Precambrian Ammassalik/Tasiilaq region in southern East Greenland (Figs 5 and 12) is supposed to represent the eastern continuation of the Nagssugtoqidian orogen in central West Greenland. Palaeoproterozoic supracrustal rocks are widespread at Tasiilaq (Kalsbeek (ed.)1989). Pegmatites of local origin are common in the gneisses and supracrustal rocks (Chadwick & Vasudev 1989; Dawes *et al.* 1989) and large crystals of amazonite and tourmaline have been observed at the head of Sermilik (Kent Brooks, pers. comm. 2006). The potential for complex pegmatites is considerable.

Neoarchaean Skjoldungen alkaline province

Presently, we have no information on pegmatites from this province (Fig. 19). Some magnetite-apatite segregations are described in Blichert-Toft *et al.* (1995).

Caledonian orogen in East Greenland

Palaeoproterozoic and Archaean basement

The basement to the Caledonian orogen in central East Greenland is dominated by granodioritic to tonalitic orthogneisses of Archaean and Palaeoproterozoic age, respectively, north and south of 73° N. Palaeoproterozoic granites are known, e.g. a *c.* 1850 Ma body of pegmatitic muscovite granite near the margin of the Inland Ice at Charcot Land, 72° N (Hansen *et al.* 1981). The granite/pegmatite body intrudes both basement and supracrustal rocks. The development of migmatites is as widespread as in the Precambrain basement of West Greenland.

Eastern Milne Land

Several metres wide pegmatite with large crystals of tourmaline and beryl (var. aquamarine) hosted by Proterozoic migmatitic gneiss (Bjørn Thomassen, pers. comm. 2007). Caledonian granite intruding in the neighbourhood may have contributed to the formation of the pegmatite.

Mesoproterozoic supracrustal rocks

The Mesoproterozoic Krummedal (meta)sedimentary sequence is exposed intermittently between 70° and 76° N. It comprises basin-type sedimentary rocks including (meta)arkosic and quartz sandstones and greywackes in amphibolite facies (Higgins 1988). During peak metamorphism around 930 Ma, and again at around 435 Ma in the Caledonian orogeny, thermal episodes resulted in partial melting of the metasedimentary rocks, whereby numerous granitic and pegmatitic veins were formed (Kalsbeek *et al.* 2001a; Kalsbeek *et al.* 2001b). Large melt volumes have coalesced to form larger granite bodies that occur in the same areas as the Krummedal sequence. The crystallisation of the granites is considered to have been appropriate for pegmatite formation, although studies of pegmatites in this region are not known to the present authors. The younger granites have partially intruded the Neoproterozoic–Palaeozoic Eleonora Bay Supergroup. Stream sediment samples from areas with exposed rocks of the Krummedal sequence are enriched in Cs, Hf, Th, Ta, and Yb (Figs 8 to11), suggesting a favourable environment for the formation of complex pegmatites.

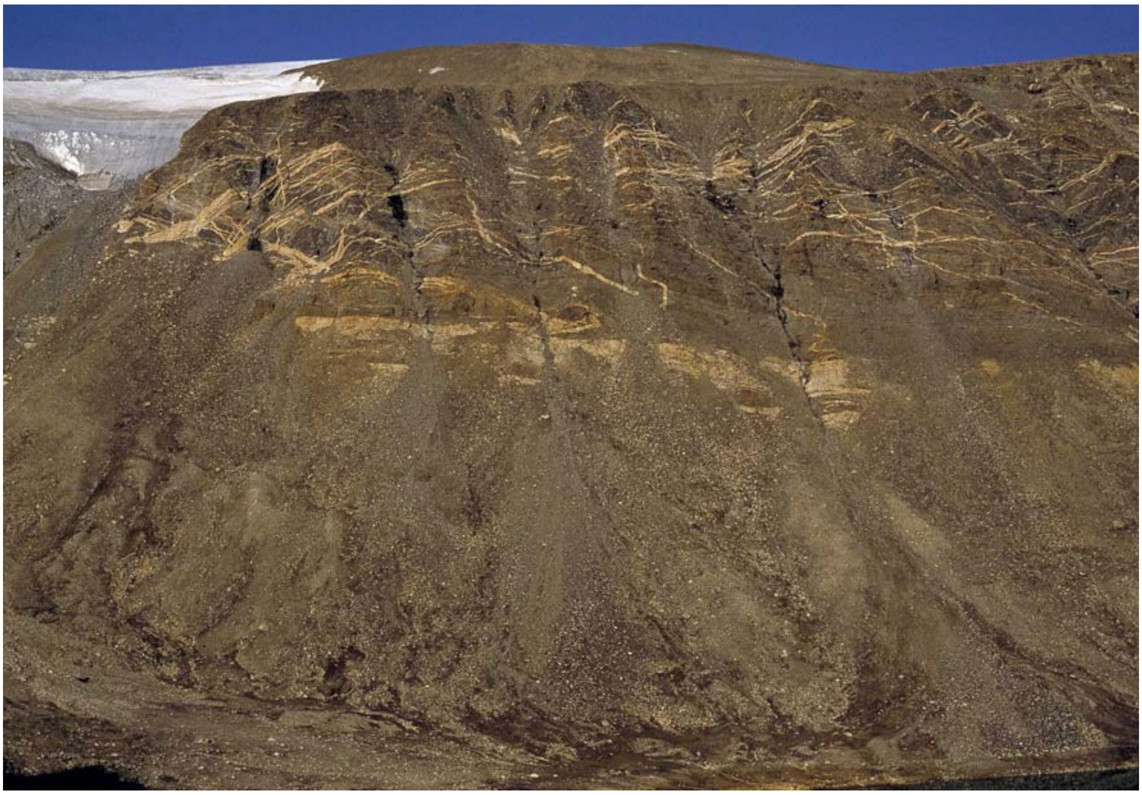

Figure 21. *Migmatitic veins in the Krummedal metasediments at Ardencaple Fjord*

Ardencaple Fjord
Abundant pegmatites occur in the surroundings of the Caledonian granite that has intruded the Krummedal sequence at Ardencaple Fjord, at 75° N (Fig. 21). No detailed study is known to the present authors.

Randenæs
Scheelite and cassiterite with tungsten and tin, respectively, besides fluorite and tourmaline have been recorded in a subconcordant pegmatite presumed to be associated with a Caledonian granite at Randenæs, Forsblad Fjord. Here also Li (200 ppm) and Be (50 ppm) and arsenopyrite with up to 2 ppm Au occur in samples from the contact zone between pegmatite and metasedimentary rocks (Harpøth *et al.* 1986). The finding suggests that pegmatites related to the Caledonian granites have a potential for Li minerals.

Palaeozoic supracrustal rocks and granites

Exploration by Nordisk Mineselskab A/S in the years 1952–1984 led to the discovery of many mineral occurrences within the Neoproterozoic–Palaeozoic Eleonora Bay Supergroup surrounding Caledonian granites of Silurian age. However, most of these are hydrothermal types of mineralisation rather than pegmatites, and no economically interesting pegmatites were noted by Harpøth et al. (1986). Drainage samples collected near small intrusions of Devonian granites have yielded elevated concentrations of Sn and Mo that are likely to have been derived from pegmatite or greisen (Harpøth *et al.* 1986).

Palaeogene alkaline intrusions in East Greenland

Mineral exploration related to the Palaeogene alkaline intrusions in central East Greenland has been attracted by the hydrothermal alteration that is very pronounced within and around preserved roof zones of several large intrusions, and previous investigations summarised in Nielsen (2005) do not account for exploration of pegmatites. Many pegmatites have however been observed, and in general terms they have a potential for rare minerals enriched in Li, Be, Zr, Hf, Nb, Ta, REE and Y, U and Th.

The summary information presented here is mainly based on personal communication with Troels Nielsen, GEUS, and Kent Brooks, Geocenter Copenhagen, 2006. The Gardiner intrusion comprises many pegmatites. Pegmatites occur in the Kangerlussuaq intrusion (Kempe & Deer 1970). The large Werner Bjerge intrusive complex with nefeline-syenitic, syenitic and granite members hosts a porphyry-type Mo mineralisation, see Harpøth *et al.* (1986) for description and references. Li-amphibole has been observed in pegmatites.
An undersaturated alkaline pegmatite occurs at Bagnæsset. At Kræmer Ø, a quartz vein contains large crystals of aegirine, arfvedsonite, astrophyllite, and abundant small zircon crystals and amazonite. The Caledonian alkaline intrusion at Batbjerg contains large pegmatites with crystals of Cr-diopside, phlogopite and ‘moonstone’ feldspar.

Caledonian rocks in northern East Greenland and the Franklinian Basin, North Greenland

Geological maps do not indicate pegmatites. No occurrences are known to the authors at this time.

Known and expected pegmatite minerals in Greenland

Table 3 contains a selection of common pegmatite minerals known or expected to occur within pegmatites in Greenland. The minerals are arranged alphabetically with notes on their use, classification, and appearance in Greenland (if any). The table is meant to provide an easy way of checking for knowledge about a particular mineral in Greenland.

Mineral	Commodity	Remarks on setting and use	Greenland locality
Allanite	-	Typical pegmatite mineral; crystals usually poorly developed and metamict due to uranium and thorium content	Nordre Strømfjord Nuuk region Fiskenæsset Aluk
Apatite	P	Common accessory mineral in pegmatites, often developed as large and clean crystals	Gardiner alkaline complex
Bastnaesite	Ce	In alkaline pegmatites	Narsaarsuk
Beryl	Gemstone, Be	Commonly as crystals up to a few cm large, gigantic crystals not uncommon; gemstone varieties are emerald and aquamarine	Nuuk region Kobberminebugt
Betafite	U, Nb	Pyrochlore group mineral; often together with columbite, euxenite and beryl	To be expected in Greenland
Biotite	Mica	Very common in both simple and complex pegmatites	Nuuk region Tasiilaq
Cassiterite	Sn	Principal tin ore, in some cases together with tantalite	Ivittuut
Columbite	Nb, Ta	Often in granitic pegmatites; commonly the primary resource for Nb exploitation	Ivittuut
Corundum	Gemstone	In simple secretion pegmatites with feldspars	Nuuk region
Davidite	U	In simple pegmatites; uranium ore	To be expected in Greenland
Epidote	Gemstone	Accessory constituent in simple pegmatites	Nordre Strømfjord Nuuk region
Euxenite	Y	Often together with monazite, mica, garnet, beryl in granite pegmatites	To be expected in Greenland Nuuk region
Fluorite	F	Sometimes an important constituent in pegmatites; accessory in allanite pegmatites	Ivittuut

Gadolinite	Be, Y	Often together with allanite and fluorite	To be expected in Greenland
K-Feldspar species	Feldspar	Main pegmatite constituent, especially microcline, and previously mined for the ceramic industry; the green coloured variety amazonite is a well-known gemstone	Fiskenæsset Ivittuut Nunarssuit
Lepidolite	Li	An important Li ore known from the pegmatite environment; also host for Rb	To be expected in Greenland
Magnetite	Fe	Accessory in some simple pegmatites; alkaline rocks can produce gigantic crystals	Gardiner intrusion
Muscovite	Mica	Very common in complex pegmatites	Nuuk region
Molybdenite	Mo		Fiskenæsset
Monazite	Ce	Accessory and major constituent in a variety of pegmatites	Nordre Strømfjord
Plagioclase	Feldspar, Al	A main constituent of many pegmatites (albite), and previously mined for the ceramic industry	Fiskenæsset
Prehnite	Gem		Gardiner intrusion
Pyrite	Fe	Accessory constituent in many pegmatites	Ivittuut
Quartz	Glass	A main constituents of almost all pegmatites; traditionally quarried for use as flux in metal smelters or for glass production	Nuuk region Fiskenæsset Ivittuut
Rutile	Ti	Important Ti ore	To be expected in Greenland
Spessartite	Gemstone	Typical complex pegmatite mineral (garnet group)	Tasiilaq
Spodumen	Li	Important Li mineral	To be expected in Greenland
Tantalite	Ta	Often associated with columbite and in many places the primary resource for Ta mining	To be expected in Greenland
Titanite	Ti	In pegmatites of alkaline affinity	Gardiner intrusion
Topaz	Gem	Often associated with mica, tourmaline and beryl.	Ivittuut
Tourmaline	Gem, B	As typical boron mineral in pegmatites, often in large well shaped crystals.	Nuuk region Fiskenæsset
Uraninite	U	Accessory in granitic pegmatites.	Nuuk region

Uranophane	U	Alteration of uraninite.	Nuuk region
Wolframite	W		Malmbjerg
Xenotime	Y	Accessory constituent in simple pegmatites.	To be expected in Greenland
Zircon	Zr	Accessory in pegmatites	Ivittuut

Table 3. *Pegmatite minerals and examples of known occurrences in Greenland. The location of the places are shown in Figs 12 and 19.*

Conclusions and recommendations

Favourable areas for complex pegmatites of granitic composition with economic potential occur where partial melting of metasedimentary sequences has taken place. Published geological maps at scale 1:100 000 show the distribution of supracrustal rocks and pegmatites, but these maps still have limited coverage in Greenland. Additional information is provided by stream sediment geochemistry maps, which can be used to outline favourable areas for complex pegmatites. Such areas occur as combined high concentrations of Cs and U reflecting the granitic component, and Hf, Mo, or Th reflecting components in clastic (meta)sedimentary rocks.

Favourable units with this potential are the Palaeoproterozoic Karrat Group in the Rinkian fold belt of West Greenland and the fore-arc basin of the Ketilidian orogen in South Greenland, and the Mesoproterozoic Krummedal sequence in the central Caledonian orogen in East Greenland. Other units considered favourable are underlain by Archaean supracrustal rocks at Nuuk, Taartoq and Isorsua in the Archaean craton.

Alkaline pegmatites occur abundantly within the Gardar alkaline province in South Greenland and the intrusions of the Palaeogene igneous province in East Greenland. However, the commodities of interest hosted by alkaline rocks are not confined to pegmatites, so that the entire complexes are target areas for detailed exploration for specific elements or minerals.

In order to provide more evidence for the existence of pegmatites with economic potential, the following activities are recommended:

- Analysis of selected stream sediment samples for Li.
- Examination of selected stream sediment samples for certain minerals such as spodumene, cassiterite, tantalite, molybdenite. GEUS already possesses facilities for semi-automatic mineral identification using scanning electron microscopy.
- Systematic screening of published geological maps and literature, as well as company reports, for information on pegmatites within the areas considered in this report to have a potential for complex pegmatites.
- Further interviewing of field geologists and screening of field diaries.

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