Polarforschung 68: 153 - 160, 1998 (erschienen 2000)

Precambrian Evolution of North and North-East Greenland: Crystalline Basement and Sedimentary Basins

By Hans F. Jepsen[1] and Feiko Kalsbeek[1]

THEME 7: Problems of the Caledonian / Ellesmerian Junction

Summary: The crystalline shield of Greenland was formed by amalgamation of Archaean and Palaeoproterozoic terrains around 1750-1850 Ma ago. Most younger rocks occur in sedimentary basins fringing the shield. In North Greenland the oldest sedimentary sequence, the Independence Fjord Group, consists of material eroded from the shield. Deposition had already started around 1740 Ma ago, shortly after the end of Palaeoproterozoic orogenic events. A period of magmatic activity at circa 1250 Ma, perhaps related to the opening of a pre-Grenvillian ocean, resulted in the intrusion of vast amounts of dolerite sheets (the Midsommersø Dolerites) into sandstones of the Independence Fjord Group, and extrusion of tholeiitic basalts (the Zig-Zag Dal Basalt Formation). Little is known from the period between circa 1250 and 850 Ma; no rocks formed during this time are preserved, and there is no evidence of Grenvillian deformation in North- and North-East Greenland. Neoproterozoic shelf sediments of the Hagen Fjord Group, deposited along the north-western margin of the Iapetus Ocean, unconformably overlie the Independence Fjord Group and Zig-Zag Dal Basalt Formation. Neoproterozoic glacial deposits and units of deep-water turbidites are also present. The rock units mentioned above form the foreland to the Caledonian fold belt of East- and North-East Greenland. Within the fold belt equivalent rock units are strongly deformed, and correlations with foreland sequences are not always certain. In eastern North Greenland a sequence of basalts occurs within sandstones correlated with the Independence Fjord Group; they have yielded an age of 1740 Ma, and do not seem to have correlatives in the foreland.

Precambrian rocks make up a large part of the exposed bed rock of North and North-East Greenland (Fig. 1). An old crystalline basement, consisting of strongly deformed Archaean and Palaeoproterozoic granitoid rocks, is overlain by Meso-proterozoic, Neoproterozoic and lower Palaeozoic strata. The latter form part of the Franklinian basin of North Greenland and are described by Henriksen & Higgins (2000, this vol.).

CRYSTALLINE BASEMENT

The >1600 Ma crystalline shield of Greenland consists of Archaean and Palaeoproterozoic orthogneisses and meta-granitoid rocks with intercalated mafic rock units. It is not possible to differentiate Archaean and Proterozoic crystalline rocks on the basis of field observations alone; the subdivision of the shield on the Geological Map of Greenland (ESCHER & PULVERTAFT 1995) is therefore mainly based on isotopic age determinations. Crystalline rocks at the head of Victoria Fjord in North Greenland (Fig. 1) have yielded Archaean zircon U-Pb ages (circa 3000 Ma, HANSEN et al. 1987), but strong disturbance, probably during a Palaeoproterozoic orogenic event, has so far prevented a precise age determination. The crystalline basement here is unconformably overlain by Neoproterozoic and Cambrian formations.

In eastern North Greenland, 500 km further east, Palaeoproterozoic orthogneiss complexes form most of the crystalline basement within the Caledonian fold belt. At one single locality north-east of Dove Bugt (Fig. 1) Archaean rocks have been found (STEIGER et al. 1976), but all other ages obtained from this region range from circa 2000 Ma for orthogneisses to circa 1750 Ma for late meta-granitic intrusions (SHRIMP zircon U-Pb ages; KALSBEEK et al. 1993, 1999, NUTMAN & KALSBEEK 1994). Rocks with similar ages occur in Inglefield Land in North-West Greenland (Fig. 3, DAWES et al. 1988, F. Kalsbeek & A.P. Nutman unpublished SHRIMP data). Large parts of the ice-free area of North-West Greenland south of Inglefield Land are made up of Archaean rocks reworked during the Palaeoproterozoic (DAWES et al. 1988; see KALSBEEK (1994) for an overview of Precambrian basement provinces in Greenland). Unfortunately, it is not possible to correlate basement provinces across the ice sheet that covers the interior of Greenland (the Inland Ice), and the large-scale structure of the Greenland shield is therefore largely unknown.

PLATFORM AND FOLD BELTS

The crystalline basement is overlain by sequences of sedimentary rocks which in North and North-East Greenland occur in two distinct settings. In a platform area centred around Independence Fjord, Hagen Fjord and Danmark Fjord (Fig. 1) the rocks are undeformed. They have north or north-eastward dips of generally not more than 1-3°, and individual strata can often be followed for tens of km along steep fjord walls which may be more than 1 km high. This platform region is bounded to the east by the Caledonian fold belt, and to the north by the slightly later (Franklinian) North Greenland fold belt, which runs across the whole of North Greenland and continues into northern Canada (HIGGINS et al. 2000, this vol.). Most sedimentary sequences in the Caledonian fold belt north of 79 °N can be correlated with those of the Proterozoic platform, whereas the Franklinian belt is mainly built up of lower Palaeozoic strata (HENRIKSEN & HIGGINS 2000, this vol.). The following description of the Precambrian units concentrates on the platform area.

[1] Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400, Copenhagen NV, Denmark; <hfj@geus.dk>

Manuscript received 12 October 1998, accepted 08 June 19999

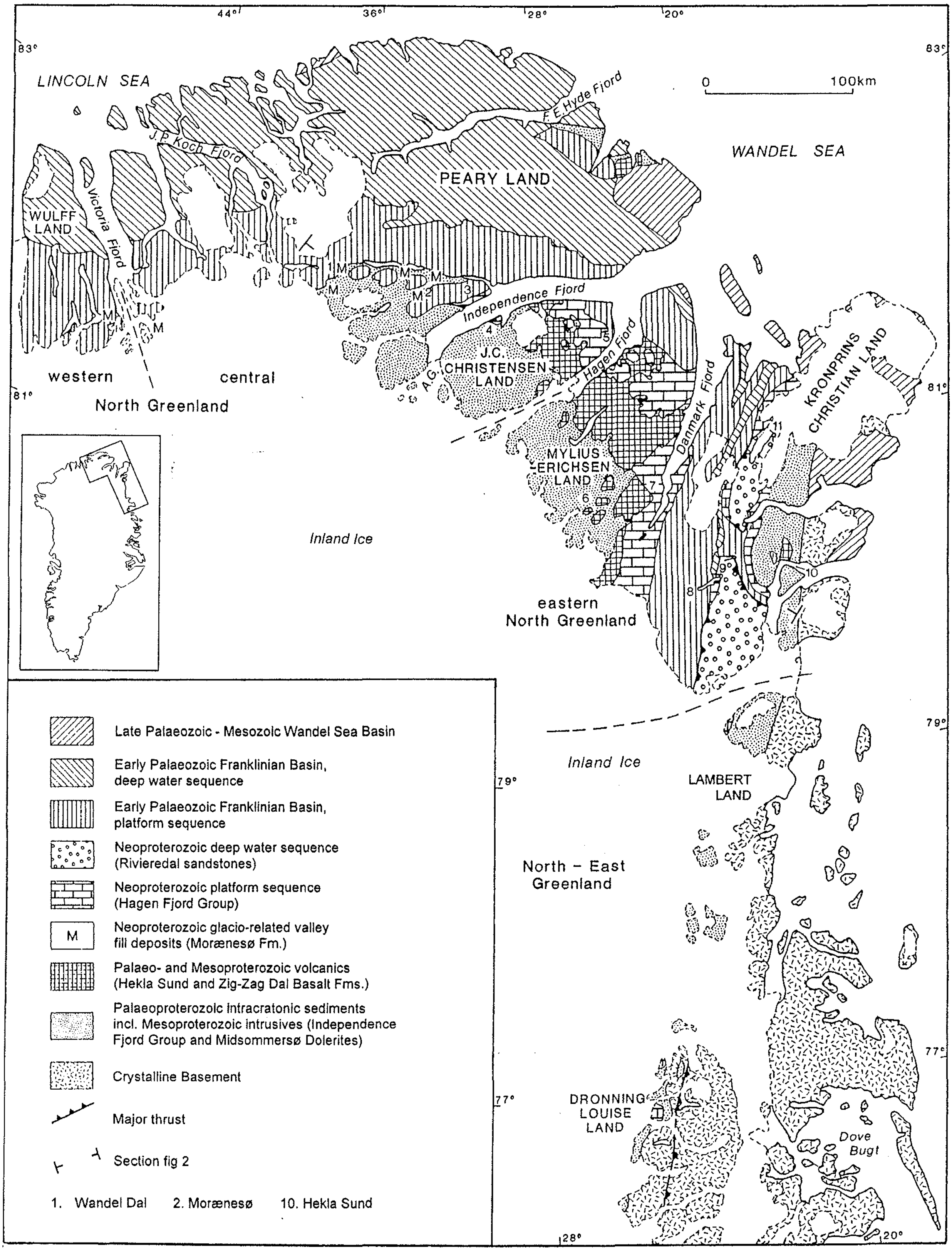

Fig. 1: Geological map of North and North-East Greenland, modified after SØNDERHOLM & JEPSEN (1991).

INDEPENDENCE FJORD GROUP

The oldest sedimentary rocks in North Greenland form a more than 2 km thick sequence of feldspathic sandstones with intercalated siltstone units, referred to as the Independence Fjord Group (COLLINSON 1980, 1983, SØNDERHOLM & JEPSEN 1991). The sandstones are cut by numerous dolerite intrusions, the "Midsommersø Dolerites", described in the next section. The base of the Independence Fjord Group is not exposed, but the group probably overlies crystalline rocks of the Greenland shield underneath the Inland Ice not far from the ice margin, since numerous erratic blocks of granitoid rocks are found in the valleys.

The sandstones are medium- to coarse-grained and quartz-rich, and show trough and tabular cross-bedding indicating fluvial and aeolian sedimentation (COLLINSON 1983). Within the Independence Fjord Group units of red siltstones, up to several tens of metres thick, are present, some of which can be traced for more than 100 km. They probably represent ephemeral lakes which often dried out to form extensive playas, as witnessed by the presence of desiccation polygons and halite pseudomorphs (COLLINSON 1980, 1983).

Sandstones very similar, and probably correlative, to those of the Independence Fjord Group occur some 400 km further south in Dronning Louise Land (Fig. 1). Here a distinct unconformity with the crystalline basement is preserved in the foreland of the Caledonian fold belt (PEACOCK 1956, 1958, STRACHAN et al. 1994). Both the basement and the overlying sedimentary rocks are cut by sheets of dolerite. Sandstones which probably correlate with the Independence Fjord Group, also with common meta-dolerite intrusions, occur within the northernmost parts of the Caledonian fold belt (ESCHER & PULVERTAFT 1995). Here they are tectonically interleaved with crystalline basement rocks which also contain metadolerites.

The age of the Independence Fjord Group is not well constrained. Rb-Sr data on clay minerals from a siltstone suggest diagenesis about 1380 Ma ago (LARSEN & GRAFF-PETERSEN 1980). Study of detrital zircons by SHRIMP has shown that most zircons were derived from Archaean rocks, although Palaeoproterozoic zircons are also present (A.P. Nutman personal communication). Within the northernmost part of the Caledonian fold belt sandstones, assumed to belong to the Independence Fjord Group, are interlayered with metabasalts (in part pillow lavas) and metarhyolites, for which an age of 1740 Ma has been obtained. A few 1775 Ma detrital zircons were found in a sandstone sample from this area, indicating that at least some of the sandstones here were deposited between 1775 and 1740 Ma ago, shortly after the end of Palaeoproterozoic orogenic activity (KALSBEEK et al. 1999).

MIDSOMMERSØ DOLERITES

The sandstones of the Independence Fjord Group are cut by numerous sheets and sills of dolerite and associated rocks: the Midsommersø Dolerites (JEPSEN 1971). In some areas they make up 50 % or more of the section in steep fjord walls, and their aggregate thickness may well exceed 1 km. A detailed description of these rocks has been presented by KALSBEEK & JEPSEN (1983). The Midsommersø Dolerites and, probably, also the Zig-Zag Dal basalts are related to a major event of basic magmatism around 1250 Ma ago, and their chemical and isotopic compositions reveal extensive interaction with rocks from the crystalline basement and sandstones of the Independence Fjord Group. Three kinds of intrusive rocks are represented: (1) normal dolerites, (2) granophyric rocks, probably formed from mixtures of basic magma and assimilated country rock at depth, and (3) mobilised sandstones, which we have termed "rheopsammites" (KALSBEEK & JEPSEN 1983). Many of these rocks are strongly affected by hydrothermal alteration, and are red-brown to brick red in colour.

The age of emplacement of the Midsommersø Dolerites is important, since it may coincide with the age of the Zig-Zag Dal Basalt Formation, which has not been dated independently, and which has a key position in the stratigraphy of North Greenland and northern Canada, where similar rocks occur (e.g. JACKSON & IANELLY 1981, LE CHEMINANT & HEAMAN 1989). The age of the dolerites has been determined from Rb-Sr whole-rock isochrons (KALSBEEK & JEPSEN 1983). The most well-defined isochron (1230 ±20 Ma, initial $^{87}Sr/^{86}Sr$ 0.7129 ±0.0006) was obtained for a sheet of strongly altered "red" dolerite; as a result of hydrothermal alteration the analysed samples had a wide range in Rb/Sr ratios, and, strictly speaking, the isochron dates the alteration of the rock. However, for several reasons this was believed to have taken place in relation with the magmatic activity. Accordingly, intrusion of the Midsommersø Dolerites is regarded to have taken place around 1250 Ma ago, but it has to be realised that confirmation of this age by independent means is not yet available. Recently, however, tiny crystals of baddeleyite have been detected in fresh dolerite samples (L. Heaman personal communication, 1998), and hopefully the age of the Midsommersø Dolerites will soon be settled. The high initial $^{87}Sr/^{86}Sr$ ratio (0.7129 ±0.0006) is the result of incorporation into the dolerite of isotopically evolved Sr from basement rocks or from the sandstones during hydrothermal alteration.

Some of the intrusive sheets in the Independence Fjord sandstones consist of very silicic rocks (SiO_2 up to 88 %). These rocks were interpreted as formed from partly molten sandstones by JEPSEN (1971). In these "rheopsammites" quartz occurs as round grains, interpreted as relict sand grains, and as pseudomorphs after tridymite. The sheets of rheopsammite range up to 20 m in width, and invariably have dark borders of normal dolerite a few metres wide (see Fig. 2 in KALSBEEK & JEPSEN 1983). Sandstones of the Independence Fjord Group often contain significant proportions of K-feldspar, and, if fluids are available, they may yield enough granitic melt to make it sufficiently mobile to be intruded. If this odd magma was intruded directly into the sandstones, vapour would be lost, and the melt would crystallise instantly. However, where intruded into the centre of a not fully solidified dolerite sheet, the dolerite

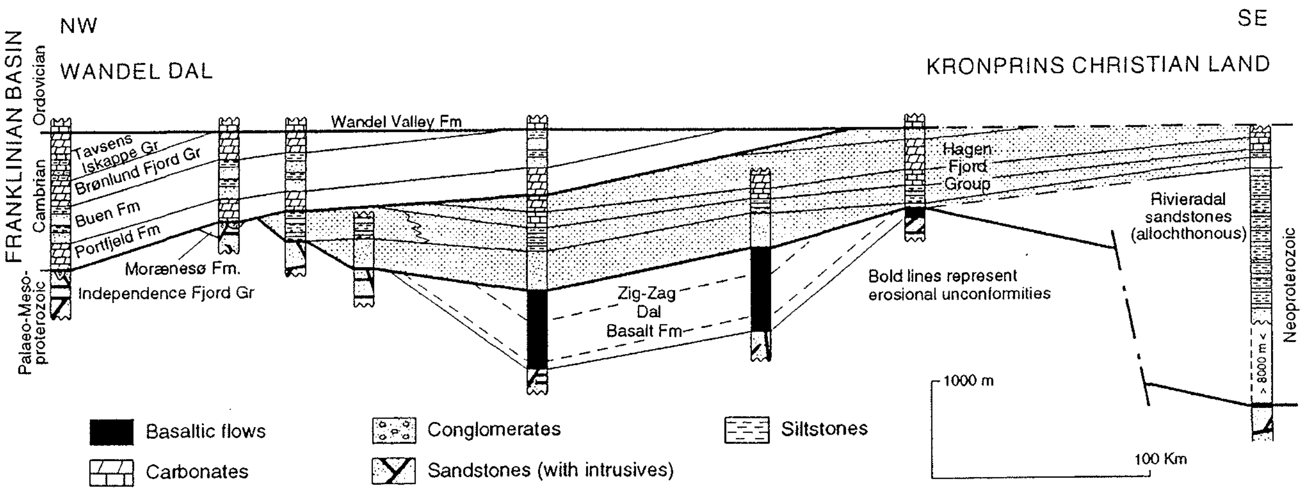

Fig. 2: Schematic stratigraphy of North Greenland, after Clemmensen & Jepsen (1992).

forms an impermeable margin which permits further intrusion of the rheopsammitic magma. We have been unable to find reference to similar rocks in the literature. If rocks of similar age and origin do occur elsewhere they may be of great help in the correlation of ancient continental blocks.

ZIG-ZAG DAL BASALT FORMATION

The Zig-Zag Dal Basalt Formation (Jepsen & Kalsbeek 1979; for a detailed description see Kalsbeek & Jepsen 1984) conformably overlies the Independence Fjord Group; it consists of tholeiitic flood basalts and is up to 1350 m thick. The chemical composition of the basalts is similar to that of fresh samples of the Midsommersø Dolerites, although crustal contamination is less evident, and a relation to the same igneous event is very likely. Indeed, a palaeomagnetic study has shown that palaeopole positions for the basalts and the Midsommersø Dolerites are indistinguishable (Marcussen & Abrahamsen 1983).

At present the Zig-Zag Dal Basalt Formation covers an area of circa 6000 km^2 between Danmark Fjord and Independence Fjord (Fig. 1), but it probably extended over a much larger area, since outliers of the formation have been found in uplifted fault blocks up to 100 km north of the main outcrop area (Fig. 1). In Mylius Erichsen Land the basalts attain a thickness of circa 1300 m. Here the basalts can be divided into three sequences, locally separated by thin units of sedimentary rocks; in ascending order these are the "basal", "aphyric" and "porphyritic" unit. The basal unit (circa 100 m) consists of many thin flows; pillowed basalts occur locally. The aphyric and porphyritic units (up to circa 450 and 750 m, respectively) consist of much thicker flows, single flows ranging up to more than 100 m. Some of the flows can be traced over large areas and may have had volumes of more than 600 km^3.

Basalts of the basal unit and the lower part of the aphyric unit are strongly affected by spilitic alteration. Most other basalts are relatively fresh, but many have undergone low-grade metamorphism (zeolite to prehnite-pumpellyite facies), especially at sites where water was present (Bevins et al. 1991).

NEOPROTEROZOIC SEDIMENTATION

The Neoproterozoic Hagen Fjord Group (Clemmensen & Jepsen 1992, and references therein) was deposited within a period spanning from Late Riphean to latest Vendian (circa 850-650 Ma ago) along the north-western margin of the Iapetus Ocean (Surlyk 1991). No rocks are known from the interval between eruption of the Zig-Zag Dal Basalt Formation and deposition of the Hagen Fjord Group. During this period block faulting and erosion took place, resulting into a pronounced low-angle unconformity between the two successions. The unconformity is not seen in individual outcrops, but is evident on geological maps, the Zig-Zag Dal Basalt Formation being truncated at very different levels in different parts of the region (Figs. 1, 2).

The Hagen Fjord Group is up to 1000 m thick, and has been subdivided into a number of formations composed of mainly marine, shallow water shelf sediments. Sandstones and siltstones dominate the lower part of the group, grading upward into limestones and dolostones with abundant stromatolites, followed near the top by siliciclastic deposits, mainly siltstone. Skolithos-like burrows are locally present in sandstone layers, suggesting a very late Precambrian age. Deposition of the Hagen Fjord Group took place in low-energy shoreline to shallow marine environments; some fluvial deposits are present near the base of the group. Further south in East Greenland, the Eleonore Bay Supergroup (Sønderholm & Tirsgaard 1993) is broadly similar in age and development with the Hagen Fjord Group. Possible correlations between the two successions have been discussed by Sønderholm & Jepsen (1991), but because they are geographically separated no straightforward correlation is possible.

In eastern North Greenland within the Caledonian fold belt the Hagen Fjord Group conformably overlies a more than 8 km thick east-facing half graben sequence of deep-water turbidites, shales, sandstones and conglomerates collectively termed the "Rivieradal sandstones" (Fig. 2; HURST & MCKERROW 1981, 1985, M. Sønderholm personal communication 1995). The latter only occur within a major Caledonian nappe, displaced westwards by 35-50 km (HIGGINS et al. 2000, this vol.). Based on acritarch studies (VIDAL 1979), the Rivieradal sandstones are believed to be of Upper Riphean to Vendian age.

Evidence of Neoproterozoic glaciation in North Greenland is seen in the Morænesø Formation (JEPSEN 1971), which contains diamictites with striated boulders interptreted by TROELSEN (1956) as tillites. The Morænesø Formation occurs as palaeovalley fills, up to circa 150 m thick, and is unconformably overlain by Lower Cambrian strata; it is not in contact with other Neoproterozoic deposits, and mutual relationships are therefore not known. The formation consists mainly of sandstones, conglomerates and diamictites; most of the deposits appear to be fluvial, and probably formed during post-glacial reworking of tillites (COLLINSON et al. 1989). Near the top of the exposed sections a thin unit of stromatolitic dolomite is present. The age of the Morænesø Formation is not known, but it is believed to be related to the Varangian (circa 650 Ma) glaciation also known from central parts of East Greenland as well as North America, Svalbard, and northern Europe (COLLINSON et al. 1989).

The Neoproterozoic deposits of the platform are unconformably overlain by lower Palaeozoic strata (Fig. 2) described by HENRIKSEN & HIGGINS (2000, this vol.).

PRECAMBRIAN ROCKS WITHIN THE CALEDONIAN FOLD BELT

Between 76 and 79 °N the Caledonian fold belt in North-East Greenland is almost exclusively built up of Palaeoproterozoic basement gneisses (Fig. 1). In the foreland areas in Dronning Louise Land they are unconformably overlain by sandstones with basic intrusions, correlated with the Independence Fjord Group, which, in turn, are unconformably overlain by a circa 200 m sequence of quartzitic sandstones, mudstones and dolomitic limestones. Quartzites in the upper sequence contain Skolithos burrows (FRIDERICHSEN et al. 1990) indicating deposition in the latest Precambrian and correlation with the upper part of the Hagen Fjord Group further north.

In Dronning Louise Land these rocks are increasingly affected by Caledonian deformation eastward; farther east within the Caledonian fold belt proper equivalents of the metasedimentary cover rocks have not been documented. Further north within the fold belt, however, metasandstones with meta-basic intrusions become more common, and in Lambert Land and Kronprins Christian Land they occupy major areas (Fig. 1). The sandstones have traditionally been correlated with the Independence Fjord Group of the foreland (e.g., ESCHER & PULVERTAFT 1995), and the meta-dolerites with the Midsommersø Dolerites. The sandstones are tectonically interleaved with basement gneisses. Convincing depositional contacts against crystalline basement have not been observed, but this may be due to strong deformation.

In Kronprins Christian Land units of basic volcanic rocks occur within the sandstones. Basalts at Hekla Sund (Fig. 1) form a circa 1200 m thick unit which interfingers with conglomerates and sandstones of the surrounding metasedimentary rocks. Both pillow lavas and massive volcanic rocks, as well as agglomerates and pillow breccias are present, and in the lower part of the sequence a brown rhyolitic flow is found. The basalts are interpreted as formed within a water-filled basin during synvolcanic rifting (S.A.S. Pedersen personal communication, 1998).

On the Geological Map of Greenland (ESCHER & PULVERTAFT 1995) these rocks are correlated with the Zig-Zag Dal Basalt Formation of the foreland. However, SHRIMP U-Pb data on zircons from two samples of the rhyolite flow have yielded a reliable age of 1740 ±10 Ma, showing (1) that deposition of the surrounding sandstones must have taken place at about that time, and (2) that the basalts at Hekla Sund cannot be correlatives of the Zig-Zag Dal Basalt Formation; that is, if the assumed age of circa 1250 Ma for the Zig-Zag Dal basalts is correct. Non-correlation of the Hekla Sund and Zig-Zag Dal basalts is supported by very different chemical signatures of the two sequences, the Zig-Zag Dal basalts being much more Mg-rich (B.G.J. Upton personal communication, 1988). Confirmation of the circa 1250 Ma age of the Zig-Zag Dal Basalt Formation in the foreland would settle this point definitively.

CORRELATIONS

Sedimentary basins, with rocks similar to those described above, occur at several places along the northern border of Laurentia, as well as in East Greenland and Spitsbergen (YOUNG 1979, CLEMMENSEN & JEPSEN 1992). It is not possible within the scope of this review to discuss possible correlations in detail, but a few main points will be touched upon in the following.

Within the Thule Basin which straddles parts of North-West Greenland and north-eastern Canada (Fig. 3; see DAWES 1997 for detailed description), the Lower Thule Supergroup contains sandstones with dolerite intrusions. These rocks are reminiscent of the Independence Fjord Group and Midsommersø Dolerites. However, the sandstones also contain beds of siltstone, shale and carbonates, which are not seen in the Independence Fjord Group. Dawes suggests that the Thule Supergroup was deposited after circa 1270 Ma (DAWES 1997, p. 29), but this is mainly based on K-Ar dating of basic intrusions which could be misleading. One of the intrusions has yielded a $^{207}Pb/^{206}Pb$ baddeleyite age of 1268 Ma (LECHEMINANT & HEAMAN 1991), very similar to the Rb-Sr ages obtained for Midsommersø Dolerites. Major units of basic volcanic rocks are also present within the Thule Supergroup. We suggest that, although a direct correlation between the Independence Fjord Group and the Lower Thule Supergroup is not possible because they were deposited in dif-

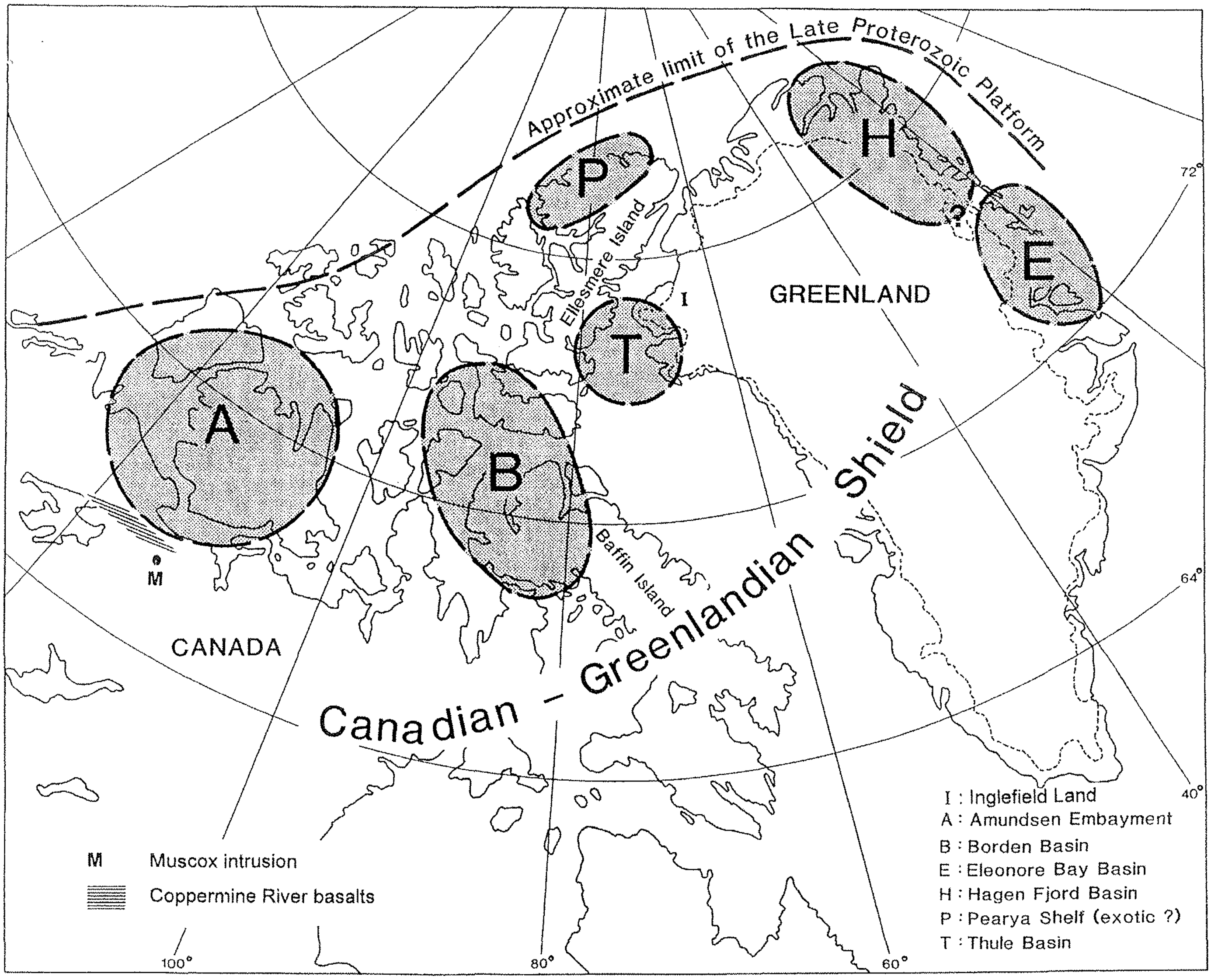

Fig. 3: Location of sedimentary basins in northern Greenland and Canada mentioned in the text, after CLEMMENSEN & JEPSEN (1992).

ferent basins, they may be closely similar in age and geological setting.

In northern Canada a major event of basic magmatic activity, the Mackenzie igneous event, took place 1270-1267 Ma ago (LECHEMINANT & HEAMAN 1989). It resulted in emplacement of the Muscox intrusion and major swarms of mafic dykes as well as extrusion of extensive continental flood basalts, the Coppermine River basalts (IRVINE & BARAGAR 1972). Given the inherent uncertainties of Rb-Sr whole rock dates on mafic rocks, emplacement of the Midsommersø Dolerites (dated at circa 1230 Ma) may well be related to the same event. The Coppermine River basalts comprise thin subaquous flows in the lower parts and very thick flows, up to >100 m, higher up in the sequence, a situation very similar to that seen in the Zig-Zag Dal Basalt Formation.

The Mackenzie magmatic event has been interpreted as being related to the opening of the pre-Grenvillian Poseidon ocean (FAHRIG 1987, JACKSON & IANELLI 1981). Closure of this ocean resulted in Grenvillian orogenesis in northern Canada (TRETTIN 1987, COOK 1988). In North Greenland there is no evidence of Grenvillian orogenic activity (JEPSEN & KALSBEEK 1985); this is surprising, since widespread high-grade metamorphism and granite formation took place further south in East Greenland, between latitudes 70 and 76 °N, around 950 Ma ago (e.g. STEIGER et al. 1979). It is possible that this Grenvillian belt runs north-eastward, offshore, east of the area shown in Figure 1, where a several hundred kilometres wide area is underlain by continental crust (ESCHER & PULVERTAFT 1995), to link up with the area affected by Grenvillian activity on Svalbard (e.g. OHTAH 1994). In North Greenland Grenvillian activity may have influenced variations in uplift and erosion prior to deposition of the Neoproterozoic strata (see Fig. 2).

Neoproterozoic sedimentary sequences similar to the Hagen Fjord Group occur in central parts of East Greenland (the Eleonore Bay Supergroup, SØNDERHOLM & TIRSGAARD 1993, FREDERIKSEN 2000, this vol.), in the upper part of the Thule Supergroup of the Thule basin, North-West Greenland (DAWES

1997), in the Borden Basin of north-eastern Canada (STEWART 1987), in the Amundsen Embayment, North Canada (YOUNG 1981), and in the Pearya terrain, North Canada (TRETTIN 1987). All these successions are characterised by fine- to medium-grained sandstones, mudstones, and stromatolitic dolostones, deposited in marginal basins along the northern margin of Laurentia. Detailed correlation is not possible, however, since deposition took place in geographically separated basins. In several of these basins diamictites or glacial deposits are present, which plausibly can be related to the Varangian glaciation.

ACKNOWLEGMENT

This paper is published with the permission of the Geological Survey of Denmark and Greenland.

References

Bevins, R.E., Rowbotham, G. & Robinson, D. (1991): Zeolite to prehnite-pumpellyite facies metamorphism of the late Proterozoic Zig-Zag Dal Basalt Formation, eastern North Greenland.- Lithos 27: 155-165.

Clemmensen, L.B. & Jepsen, H.F. (1992): Lithostratigraphy and geological setting of Upper Proterozoic shoreline-shelf deposits, Hagen Fjord Group, eastern North Greenland.- Rapport Grønlands Geologiske Undersøgelse 157: 1-27.

Collinson, J.D. (1980): Stratigraphy of the Independence Fjord Group (Proterozoic) of eastern North Greenland.- Rapport Grønlands Geologiske Undersøgelse 99: 7-23.

Collinson, J.D. (1983): Sedimentology of unconformities within a fluvio-lacustrine sequence; Middle Proterozoic of eastern North Greenland.- Sedimentary Geology 34: 145-166.

Collinson, J.D., Bevins, R.E. & Clemmensen, L.B. (1989): Post-glacial mass flow and associated deposits preserved in palaeovalleys: The Upper Precambrian Morænesø Formation, North Greenland.- Meddelelser Grønland Geosci. 21: 1- 26.

Cook, F.A. (1988): Middle Proterozoic compressional orogen in northwestern Canada. J. Geophys. Res. 93: 8985-9005.

Dawes, P.R. (1997): The Proterozoic Thule Supergroup, Greenland and Canada: history, lithostratigraphy and development.- Geology Greenland Survey Bull. 174: 1-150.

Dawes, P.R., Larsen, O. & Kalsbeek, F. (1988): Archaean and Proterozoic crust in North-West Greenland: evidence from Rb-Sr whole-rock age determinations.- Canadian J. Earth Sci. 25: 1365-1373.

Escher, J.C. & Pulvertaft, T.C.R. (1995): Geological map of Greenland, 1:2,500,000.- Geol. Surv. Greenland, Copenhagen.

Fahrig, W.F. (1987): The tectonic settings of continental mafic dyke swarms: failed arm and early passive margin.- In: H.C. HALLS & W.F. FAHRIG (eds.): Mafic Dyke Swarms. Geol. Assoc. Canada Spec. Paper 34: 331-348.

Frederiksen, K.S. (2000): Evolution of a late Proterozoic carbonate ramp (Ymer Ø and Andrée Land Groups, Eleonore Bay Supergroup, East Greenland): response to relative sea-level rise.- Polarforschung 68.

Friderichsen, J.D., Holdsworth, R.E., Jepsen, H.F. & Strachan, R.A. (1990): Caledonian and pre-Caledonian geology of Dronning Louise Land, North-East Greenland.- Rapport Grønlands Geologiske Undersøgelse 149: 133-141.

Hansen, B.T., Kalsbeek, F. & Holm, P.M. (1987): Archaean age and Proterozoic metamorphic overprinting of the crystalline basement at Victoria Fjord, North Greenland.- Rapport Grønlands Geologiske Undersøgelse 133: 159-168.

Henriksen, N. & Higgins, A.K. (2000): Early Palaeozoic basin development of North Greenland – part of the Franklinian basin.- Polarforschung 68.

Higgins, A.K., Soper, N.J. & Leslie, A.G. (2000): The Ellesmerian and Caledonian fold belts of North and North-East Greenland – a brief review.- Polarforschung 68.

Hurst, J.M. & McKerrow, W.S. (1981): The Caledonian nappes of Kronprins Christian Land, eastern North Greenland.- Rapport Grønlands geologiske Undersøgelse 106: 15-19.

Hurst, J.M. & McKerrow, W.S. (1985): Origin of the Caledonian nappes of eastern North Greenland.- In: D.G. GEE & B.A. STURT (eds.): The Caledonide Orogen: Scandinavia and related areas. London: Wiley & Sons, 1065-1069.

Irvine, T.N. & Baragar, W.R.A. (1972). Muscox intrusion and Coppermine River lavas, Northwest Territories, Canada.- XXIV Internat. Geol. Congress (Montreal), Excursion A29, 70 pp.

Jackson, G.D. & Ianelli, T.R. (1981). Rift-related cyclic sedimentation in the Neohelikian Borden Basin, northern Baffin Island.- In: F.H.A. CAMPBELL (ed.): Proterozoic basins of Canada. Geol. Surv. Canada Paper 81-10: 269-302.

Jepsen, H.F. (1971): The Precambrian, Eocambrian and Early Palaeozoic stratigraphy of the Jørgen Brønlund Fjord area, Peary Land, North Greenland.- Meddelelser om Grønland 192(2): 1-42.

Jepsen, H.F. & Kalsbeek, F. (1979): Igneous rocks in the Proterozoic platform of eastern North Greenland.- Rapport Grønlands Geologiske Undersøgelse 88: 11-14.

Jepsen, H.F. & Kalsbeek, F. (1985): Evidence for non-existence of a Carolinidian fold belt in eastern North Greenland.- In: D.G. GEE & B.A. STURT (eds.): The Caledonide Orogen: Scandinavia and related areas. London: Wiley & Sons, 1071-1076.

Kalsbeek, F. (1994): Archaean and early Proterozoic basement provinces in Greenland.- Rapport Grønlands Geologiske Undersøgelse 160: 37-40.

Kalsbeek, F. & Jepsen, H.F. (1983): The Midsommersø Dolerites and associated intrusions in the Proterozoic platform of eastern North Greenland – a study of the interaction between intrusive basic magma and sialic crust.- J. Petrol. 24: 605-634.

Kalsbeek, F. & Jepsen, H.F. (1984): The late Proterozoic Zig-Zag Dal Basalt Formation of eastern North Greenland.- J. Petrol. 25: 644-664.

Kalsbeek, F., Nutman, A.P. & Taylor, P.N. (1993): Palaeoproterozoic basement province in the Caledonian fold belt of North-East Greenland.- Precambrian Res. 63: 163-178.

Kalsbeek, F., Nutman, A.P., Escher, J.C., Friderichsen, J.D., Hull, J.M., Jones, K.A. & Pedersen, S.A.S. (1999): Geochronology of granitic and supracrustal rocks from the northern part of the East Greenland Caledonides: ion microprobe U-Pb zircon ages.- Geol. Greenland Surv. Bull. 184:31-48.

Larsen, O. & Graff-Petersen, P. (1980): Sr-isotopic studies and mineral composition of the Hagen Bræ Member in the Proterozoic clastic sediments at Hagen Bræ, eastern North Greenland.- Rapport Grønlands Geologiske Undersøgelse 99: 111-118.

Le Cheminant, A.N. & Heaman, L.M. (1989): Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening.- Earth Planet. Sci. Lett. 96: 38-48.

LeCheminant, A.N. & Heaman, L.M. (1991): U-Pb ages for the 1.27 Ga Mackenzie igneous events, Canada: support for the plume initiation model.- Joint Annual Meeting Geol. Assoc. Canada and Minaral. Assoc. Canada and Soc. Econ. Geol., Toronto, 1991. Program Abstracts 16: A73.

Marcussen, C. & Abrahamsen, N. (1983): Palaeomagnetism of the Proterozoic Zig-Zag Dal Basalt and the Midsommersø Dolerites, eastern North Greenland.- Geophys. J. Royal Astronom. Soc. 73: 367-387.

Nutman, A.P. & Kalsbeek, F. (1994): Search for Archaean basement in the Caledonian fold belt of North-East Greenland.- Rapport Grønlands Geologiske Undersøgelse 162: 129-133.

Ohta, Y. (1994): Caledonian and Precambrian history in Svalbard; a review, and an implication of escape tectonics.- Tectonophysics 231: 183-194.

Peacock, J.D. (1956): The geology of Dronning Louise Land, N.E. Greenland.- Meddelelser om Grønland 137(7): 1-38.

Peacock, J.D. (1958): Some investigations into the geology and petrography of Dronning Louise Land, N.E. Greenland.- Meddelelser om Grønland 157(4): 1-139.

Sønderholm, M. & Jepsen, H.F. (1991): Proterozoic basins of North Greenland.- Bulletin Grønlands Geologiske Undersøgelse 160: 49-69.

Sønderholm, M. & Tirsgaard, H. (1993): Lithostratigraphic framework of the Upper Proterozoic Eleonore Bay Supergroup of East and North-East Greenland.- Bulletin Grønlands Geologiske Undersøgelse 167: 1-38.

Stewart, W.D. (1987): Late Proterozoic to Early Tertiary stratigraphy of Sommerset Island and northern Boothia Peninsula, District of Franklin, N.W.T.- Geol. Surv. Canada Paper 83-26: 1-43.

Strachan, R.A., Friderichsen, J.D., Holdsworth, R.E. & Jepsen, H.F. (1994): Regional geology and Caledonian structure, Dronning Louise Land, North-East Greenland.- Rapport Grønlands Geologiske Undersøgelse 162: 71-76.

Steiger, R.H., Harnik-Šoptrajanova, G., Zimmermann, E. & Henriksen, N. (1976): Isotopic age and metamorphic history of the banded gneiss at Danmarkshavn, East Greenland.- Contr. Mineral. Petrol. 57: 1-24.

Steiger, R.H., Hansen, B.T., Schuler, C., Bär, M.T. & Henriksen, N. (1979): Polyorogenic nature of the southern Caledonian fold belt in East Greenland: an isotopic age study.- J. Geol. 87: 475-495.

Surlyk, F. (1991): Tectonostratigraphy of North Greenland.- Bulletin Grønlands Geologiske Undersøgelse 160: 25-47.

Trettin, H.P. (1987): Pearya: a composite terrane with caledonian affinities in northern Ellesmere Island.- Canadian J. Earth Sci. 24: 224-245.

Troelsen, J.C. (1956): Groenland – Greenland.- Lexique stratigraphique international. Vol. 1. Europe, fasc. 1a, 116 pp. Paris, C.N.R.S.

Vidal, G. (1979): Acritarchs from the Upper Proterozoic and Lower Cambrian of East Greenland.- Bulletin Grønlands Geologiske Undersøgelse 134: 1-40.

Young, G.M. (1979): Correlation of middle and upper Proterozoic strata of the northern rim of the North Atlantic craton.- Transact. Royal Soc. Edinburgh 70: 323-336.

Young, G.M. (1981). The Amundsen embayment, Northwest Territories; relevance to the Upper Proterozoic evolution of North Americ.- In F.H.A. CAMPBELL (ed.), Proterozoic basins of Canada. Geol. Surv. Canada Paper 81-10: 203-218.