DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2006/6

Geology and mineral resources in Greenland and northeastern North America

Reports, Abstracts and Presentations, Kangerlussuaq Workshop, October 2005

Henrik Stendal & Bo Møller Stensgaard (eds)

(1 CD-Rom included)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

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With contributions from the Workshop participants

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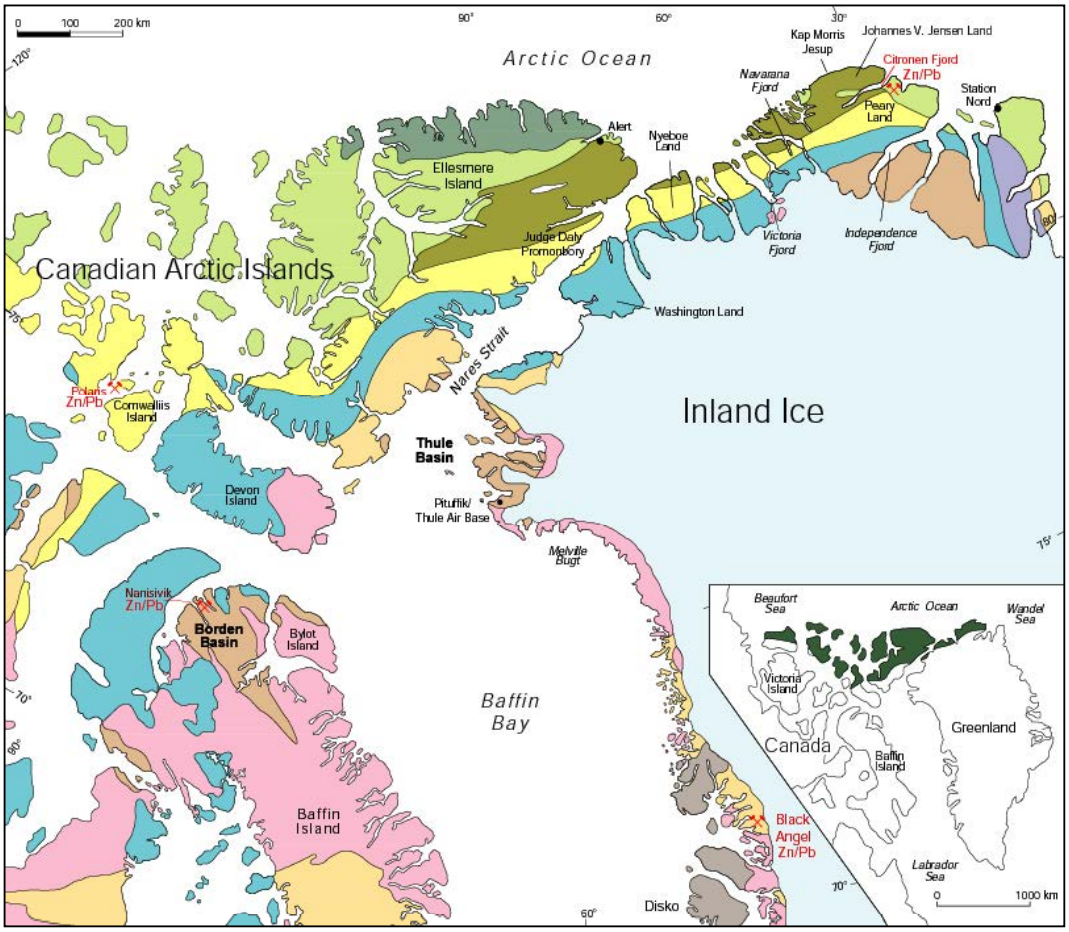

Figure 1. *Geological map of northern Greenland and adjacent parts of the Canadian Arctic Islands and proposed geological. Modified from Dawes (1994) and van der Stijl & Mosher (1998).*

Summary and recommendations

There are many geological similarities between the eastern part of North America and Greenland (e.g. Fig. 1), and over the years co-operation between organisations working here has frequently taken place. The two countries on either side of Baffin Bay have common fields of interest within mineral resource assessment in the polar North Atlantic region and they face many of the same problems. Due to these obvious reasons a Workshop was planned with the ambitious title: 'Geology and mineral resources in Greenland and north-eastern North America'. The Workshop session was held in Kangerlussuaq primo October 2005.

The Workshop was very successful and was fruitful and beneficial for all participants. Excellent presentations followed by constructive discussions of the geology and mineral resources of the region were in focus. Future programs are believed to be launched as a result of these presentations and discussions especially concerning several of the critical issues. Some of the issues discussed and recommendations are summarized below.

- ***Geological correlation and mineral resources***

  An attempt has been made to describe the present knowledge of the geological correlation between Greenland and northern North America – see details in the review (St-Onge *et al.* this report) concerning these geological correlations. The review is a geological, field research-based approach to address the issue of bedrock unit correlations from Canada to Greenland by comparing the salient Archaean to Mesoproterozoic crustal assemblages and features on both sides of Baffin Bay – Davis Strait – Labrador Sea. Similarities in principal crustal assemblages as well as in the timing of magmatic, deformation, and metamorphic events in both western Greenland and northeastern Canada provide the basis for the correlation. The differences in the accessible rock record of northeastern Canada and western Greenland is evaluated in terms of contrasting depths of erosion, primary distribution of tectonostratigraphic units, and along-strike variation within different segments of orogenic belts. The tectonic evolution of the North Atlantic region is compared with the evolution and amalgamation within an Asian plate/Indian plate (Himalayan), accretion/collision context. Recommendations for follow-up themes are listed in the review of St-Onge *et al*. (this report).

  Parallel to the geological correlation a table has been made to illustrate the mineral occurrences/deposits related to the timing of the formation of the mineral deposits. The table gives an overview of the mineral resources in the Arctic Atlantic region divided into uneven time intervals with the oldest known deposits at the bottom and the youngest at the top of the table (Stendal *et al.* this report). Examples of prospective metallogenetic provinces in Greenland and northeastern Canada are related to different commodities. Some examples are: (i) Gold and base metal metallogenetic

provinces are both of Archaean and Palaeoproterozoic ages related to supracrustal rocks (greenstone belts). To evaluate the geological correlation and the mineral potential a much better understanding of the supracrustal belts between the regions is strongly needed. (ii) South Greenland is designated as a metallogenetic gold province related to a certain metallogenetic epoch formed during the Ketilidian Orogen (~1800 Ma). This metallogenetic epoch can be compared with the Makkovik belt in Labrador but the present knowledge of the metallogeny in the two regions is not sufficient. (iii) The North Greenland sedimentary environment (Franklinian basin) is an important metallogenetic province for Zn, Pb and Ba and the sedimentary basin can be continued directly into Arctic Canada. Both areas have already proven base metal deposits of SEDEX and MVT genetic types. (iv) Alkaline magmatic provinces are found both on both sides of Davis Strait and Baffin Bay. The potential for speciality metals in peralkaline rocks is great as well as diamond potential in kimberlites. (v) The Cu-Ni potential looks much better in northeastern Canada than in Greenland.

- ***Exchange of researchers***

  It became apparent during the workshop, that exchange of researchers and possible participations in fieldwork projects on both sides of Baffin Bay, respectively should be encouraged. This would benefit the geological correlation and pursue common goals highly relevant. The participants will be alert for possibilities for such cooperation.

- ***Future workshops on geology and mineral resources in Greenland and north eastern North America***

  It was agreed that similar workshops will be arranged every second year if possible and tentative plans for a meeting in Yellowknife in May 2007 as a separate session at the Geological Association of Canada and Mineralogical Association of Canada conference were discussed.

  After the workshop in Greenland James Donald has initiated that we will join the national meeting of the Geological Association of Canada and the Mineralogical Association of Canada (GAC - MAC), which will be held in Yellowknife, Northwest Territories in May 2007. A theme at the meeting will be on northern geoscience, in part to mark the International Polar Year. J. Donald has proposed to the general chairman of the meeting, Dr. Carolyn Relf, that the meeting includes a special session to follow-up the initiative in Kangerlussuaq. Thus, the 2007 GAC-MAC meeting would include a special session on 'The Geology of Northeast Canada and West Greenland: Correlations, Metallogeny and Hydrocarbon Potential' ... or something like that.

- ***'Global Mineral Resource Assessment Project'***

  This issue was discussed extensively concerning pros and contras in participating in this program. It was agreed that GEUS and BMP should participate in the next European meeting in Orléans at BRGM as observers and as integrated participants in the next meeting in Arizona (Fall 2006), where Greenland is part of the North American block and the first issue is copper.

- ***Circum-Polar Atlas***

  Dave Scott contributed with an orientation about the Circum-Polar Atlas within the heading of the International Polar Year (IPY). D. Scott summarized what was discussed and agreed to in a working group meeting in St. Petersburg in June 2005. A planned coming workshop should allow the group to finalize the structure of the geological legend. This should also allow workers in each participating country to begin the process of migrating their existing geological information into this common structure. The coming workshop in Calgary, December 14-15, 2005 will discuss the current draft of the bedrock legend for the Circum-Polar Atlas. Julie Hollis will represent GEUS at the Calgary meeting.

  Dr. Chris Harrison of the GSC office in Calgary has taken the lead for the technical aspects of the project. D. Scott will pull the logistics together. The proposed structure of the IPY Circum-Arctic Geological Atlas will build upon the recent successes such as the Fenno-Scandian shield 1:2,000,000 map. It is the aim that the new bedrock map will be in digital format, in addition to the printed version. GEUS expressed a strong interest in participating in this international effort incorporate the geological map of Greenland into this context.

  The first task will be to integrate the Geological map of Greenland (1:2,500,000; Escher & Pulvertaft 1995; Henriksen *et al.* 2000) to the proposed bedrock Legend for the Circum-Polar Atlas.

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Dawes, P.R. 1994: Themes in the promotion of Greenland's mineral resource potential. Rapport Grønlands Geologiske Undersøgelse, **160**, 22–27.

Escher, J.C. & Pulvertaft, T.C.R. 1995: Geological map of Greenland, 1:2 500 000., Copenhagen: Geological Survey of Greenland.

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van der Stijl, F.W. & Mosher, G. 1998: The Citronen Fjord massive sulphide deposit, Peary land, North Greenland: discovery, stratigraphy, mineralization and structural setting. Geology of Greenland Survey Bulletin **179**, 40pp.

van Gool, J.A.M., Conelly, J.N., Marker, M. & Mengel, F. 2002: The Nagssugtoqidian orogen of West Greenland: tectonic evolution and regional correlations from a West Greenland perspective. Canadian Journal of Earth Science **39**, 665-686.

Background and objectives

During the last decade, BMP and GEUS have co-financed several projects towards mineral resource assessments of selected regions in Greenland, e.g. Northeast Greenland, South Greenland, and central west Greenland. This is in accordance with Greenland's strategy to make the exploitation of mineral resources an important sector of society to the benefit of the Greenlandic people.

There are many geological similarities between the eastern part of North America and Greenland (Fig. 1), and over the years co-operation between organisations working here has frequently taken place. The two countries on either side of Baffin Bay have common fields of interest within mineral resource assessment in the polar North Atlantic region and they face many of the same problems.

The objectives of this workshop were to develop and extend co-operation and networking between institutions and their researchers in this part of North America and Greenland, which have common fields of interest within mineral resource assessment in the polar North Atlantic region. The workshop addressed issues of common interest on geological correlation, geological environments, and mineral resources. The following topics were presented and discussed in detail during the session:

- Relevant geological environments
- Important geological models for the region
- Comparison of metallogenetic provinces - and the underlying methodology - in Eastern Canada and Greenland
- Development of new projects that will benefit the Davis Strait and Baffin Bay regions in relation to a mineral assessment of the region
- Ideas on how to promote the region and its mineral potential
- Joint discussions of suitable next steps, *e.g.* possible joint activities during the Polar Year 2007-2008
- Involvement in the USGS '*Global Mineral Resource Assessment Project',* which in the near future will focus on the region.

The Bureau of Minerals and Petroleum, Nuuk, Greenland, is acknowledged for the the financiel support and for hosting the workshop "Geology and Mineral Resources in Greenland and Eastern North America" in Kangerlussuaq, Greenland, October 3-7, 2005. Marianne N. Nielsen (Department of Economic Geology, GEUS) is thanked for excellent secretary support and enthusiasm before, during and after the Workshop.

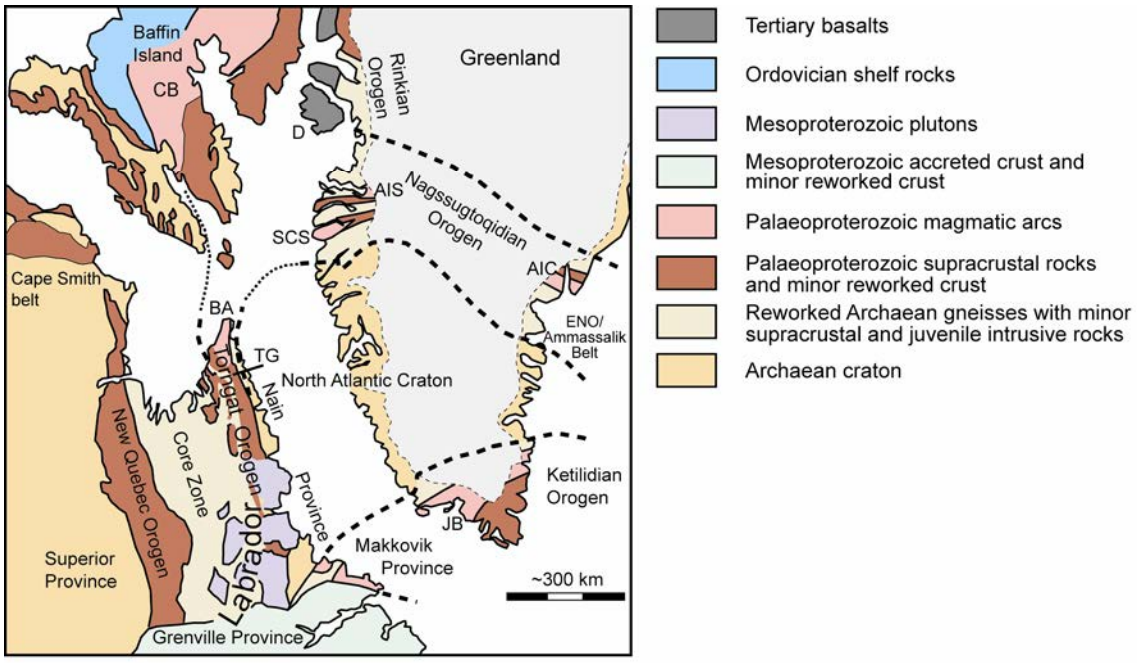

Figure 2. *Simplified proposed geological correlation between north eastern North America and Greenland. Abbreviations: AIC, Ammassalik intrusive complex; AIS, Arfersiorfik intrusive suite; BA, Burwell Arc; CB, Cumberland batholith; D, Disko Island; ENO, Eastern Nagssugtoqidian Orogen; JB, Julianehåbs Batholith; SCS, Sisimiut charnockite suite; TG, Tasiuyak gneiss. Figure after van Gool et al. 2002.*

Participants

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Figure 3. *Participants in the workshop at the margin of the Inland Ice.*

Programme of the workshop

Tuesday, 4 October: Technical session – Chairman L. Thorning

Morning 8.30 – 12.20

H.K. Schønwandt - Opening remarks.

R.J. Wardle – Geology and Metallogeny of Central Labrador: A Review.

D.T. James, M. Young & H. Sandeman – The SE Churchill Province (Labrador/Québec) and the Rae domain (Nunavut), Canada: some thoughts on history and metallogeny.

B. Ryan & A. Kerr – A Review of Bedrock and Economic Geology of Northern Labrador

A.A. Garde, J.A.M. van Gool & J.A. Hollis – Archaean terranes in the North Atlantic Craton, southern West Greenland: lithologies, age components, and problems of correlation at terrane level with the Archaean of Labrador.

Afternoon 13.30 – 17.30

J.A. Hollis, N.M. Kelly[b], J. van Gool[a], D. Frie[a], A.A. Garde[a], M. Persson – Meso- and Neoarchaean supracrustal belts and collisional tectonism in the Nuuk region, southern West Greenland: constraints from U–Pb zircon geochronology.

M.R. St-Onge, M.P. Searle & N. Wodicka – The Trans-Hudson Orogen of North America and the Himalayan-Karakoram-Tibetan Orogen of Asia: Structural and thermal evolution of the lower and upper plates.

J.A.M. van Gool & A.A. Garde – Palaeoproterozoic orogenesis in Greenland, and correlation with Eastern Canada.

D. Utting, E. Little, J. Gosse & O. Brown – Surficial geology and drift prospecting, Northern Baffin Project.

Wednesday, 5 October: Technical session – Chairman R.J. Wardle

Morning 8.30 – 11.45

H.K. Schønwandt – The role of BMP in Greenland.

L. Thorning – The role of GEUS in Greenland.

L.L. Sørensen – Current exploration activities in Greenland.

K.J. Schulz & J.A. Briskey – The Global Mineral Resource Assessment Project: A cooperative international project to assess the World's undiscovered nonfuel mineral resources.

Afternoon

A half day excursion to the Inland Ice and visit to the Kangerlussuaq Museum.

Thursday, 6 October: Technical session and discussions – Chairman L. Thorning

Morning 8.30 – 12.20

H. Stendal, K. Secher, B.M. Stensgaard, H.K. Schønwandt & L. Thorning – Greenland geological environments and mineral resources – an overview.

L.M. Larsen, **J.A.M. van Gool** & A.A. Garde - A pre-mesozoic reconstruction of Greenland and Eastern Canada: closing the Labrador Sea - Davis Strait - Baffin Bay.

B.M. Stensgaard – Former, present and future resource assessments in Greenland.

D. Scott – The Arctic IPY 2007-08 Circumpolar Bedrock Geology Map.

Afternoon 13.30 – 17.30

Summary, discussions, conclusions and recommendations – see section on results of the workshop in this report.

Presentations from the workshop – the CD - ROM

All presentations given by the participants in the workshop (*cf*. also the section with abstracts), are stored on the CD-ROM accompanying this report. The presentations are stored as Microsoft® Office PowerPoint® *.ppt files. This report is also included on the CD-Rom as *.pdf file. The ppt and pdf files are all protected for modifications and for copying by a password.

The presentations

When inserting the CD-ROM in a PC an index of the presentations will automatically open up in Microsoft® Office PowerPoint® as a slide show. By clicking on a presentation in the index, this presentation will open up as a full screen 'Slide Show View'.. When opening the files the user will be asked either to type in a password or open the files as 'Read Only'. Click the 'Read Only' option in order to open the file. Use up and down keys to navigate through the slides.

If the CD-ROM 'autorun' is enabled, it is possible to select and open the presentations manually. The presentations files are stored at the root of the CD-ROM. The files are named according to the authors of the presentations, with a prefix from 02_ to 17_.

If the user prefers to have the slide show opened as thumbnails (in the 'Slide Sorter View' in PowerPoint®) the user must open the presentation manually from the CD-ROM and choose this view option manually.

The presentations are best viewed in Microsoft® Office PowerPoint® 2003.

If the user are having problems in running the presentations via the index, and the user doesn't have Microsoft® Office PowerPoint® 2003 installed, it is possible to run the presentations manually in older versions of PowerPoint®. However, running the presentations in older versions may cause some disturbance in the presentations, and in order to prevent these, the user should install and use the Microsoft® PowerPoint® Viewer 2003. The executable file (named pptview.exe) for the viewer is stored on the CD-ROM. The supported operating systems for the viewer are Windows 2000 Service Pack 3; Windows 98 Second Edition; Windows ME; Windows Server 2003; Windows XP.

The report

The full report of the workshop including the abstracts is also included on the CD-ROM as a *.pdf file. The file can either be opened via the index which opens up automatically or manually from the CD-ROM. The file should open up in the users preferred software for reading pdf files. The Adobe Reader, which can be used for reading pdf files, is available via the link http://www.adobe.com/products/acrobat/readstep2.html.

Reviews of geological correlation and mineral resources in Greenland and eastern Canada based on the workshop contributions

Correlation of Archaean to Mesoproterozoic units and structures across Baffin Bay, Davis Strait, and the Labrador Sea: Kangerlussuaq workshop 2005 report and literature review

M. St-Onge (compiler) with contributions from J.A.M. van Gool, A.A. Garde & D.J. Scott

Introduction

A workshop focused on the "Geology and Mineral Resources in Greenland and Eastern North America" and organized by the Geological Survey of Denmark and Greenland (GEUS) and the Bureau of Minerals and Petroleum of Greenland (BMP) was held in Kangerlussuaq, Greenland during the week of October 3-7, 2005. One of the principal themes during the workshop was the correlation of Precambrian bedrock units and features from western Greenland to eastern Canada across Baffin Bay, Davis Strait and the Labrador Sea. Various geological and tectonic correlations were proposed or revisited during the course of the workshop, and the aim of this report is to review the correlations discussed, utilize an actualistic model to sequence (or order) the periods of amalgamation and growth of northeast Laurentia during the Palaeoproterozoic and Mesoproterozoic, and finally to identify areas requiring further work.

We take a geological, field research-based approach to address the issue of bedrock unit correlations from Canada to Greenland by: 1) reviewing the salient Archaean to Mesoproterozoic crustal assemblages and features on both sides of Baffin Bay – Davis Strait – Labrador Sea, and 2) considering their tectonic evolution and amalgamation within an Asian plate/Indian plate (Himalayan), accretion/collision context. Our premise is that if one can establish close similarities in principal crustal assemblages as well as in the timing of magmatic, deformation, and metamorphic events in both western Greenland and northeastern Canada, then it provides a basis for correlation. In addition, if this can be done within a southeastern Asian (late Triassic to Miocene) context then it provides a template for considering and applying the principles of actualism to the crustal history documented for northeastern Laurentia during the Palaeoproterozoic and Mesoproterozoic. Remaining differences in the accessible rock record of northeastern Canada and western Greenland can then be evaluated in terms of contrasting depths of erosion, primary distribution of tectonostratigraphic units, and along-strike variation within different segments of orogenic belts.

Tectonic upper plate vs. lower plate context for northeastern Canada and western Greenland during the Palaeoproterozoic

Much of Laurentia (the Precambrian core of North America) was assembled during the late Palaeoproterozoic during a period of global amalgamation of Archaean cratons and crustal slivers, and attendant Palaeoproterozoic cover sequences (Hoffman, 1988; Zhao et al., 2002; Bleeker, 2003). Within the Laurentian assemblage, the Trans-Hudson orogen (Hoffman, 1988; Lewry and Collerson, 1990) is a Himalayan-scale collisional orogenic belt that extends from the south-central part of the North American continent to its northeastern

edge, where it is truncated by the younger Meso- to Neoproterozoic Grenville orogen (Fig. 1). The Trans-Hudson orogen separates the collisional lower-plate (indenting) Archaean Superior craton in the south, from a collisional upper-plate (indented) collage of Archaean crustal blocks that includes the Wyoming craton to the west, the Hearne domain and Rae craton to the north, and the North Atlantic (Nain) craton to the east (Fig. 1). The Manitoba promontory in the west (M, Fig. 1) and the Quebec promontory in the northeast (Q, Fig. 1) mark the corners of the indenting lower plate Superior craton.

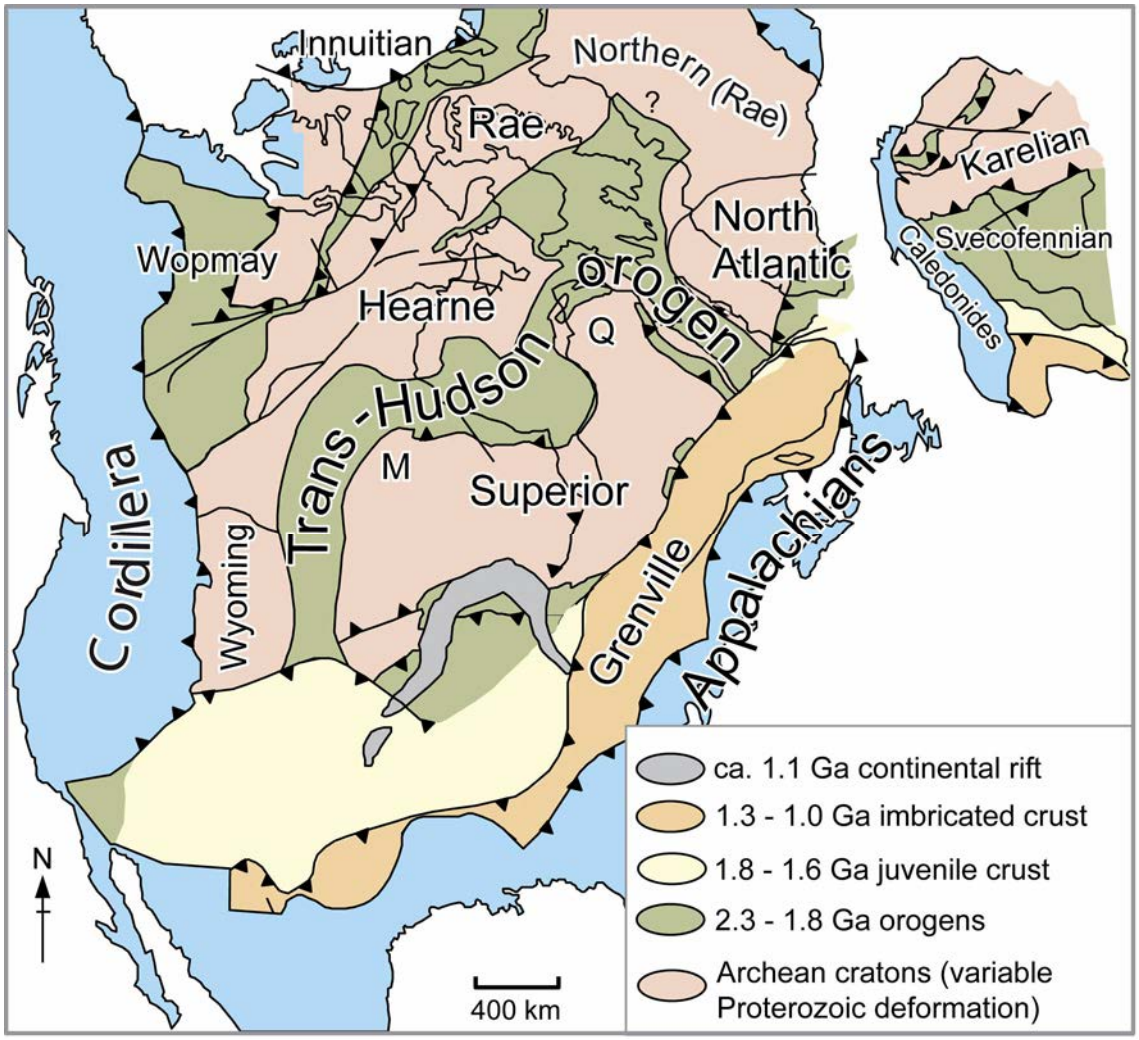

Figure 1. *Summary geological map of North America and western Baltic Shield, modified from Hoffman (1988). Map shows extent of Trans-Hudson orogen and location of bounding Archean crustal blocks and cratons. Abbreviations: M – Manitoba promontory, Q – Quebec promontory.*

Recently, St-Onge et al. (in press a) have argued that the tectonic record of collision and indentation of the Superior craton into the upper plate collage of cratons and terranes (Churchill plate) that made up north-eastern Canada in the late Palaeoproterozoic (ca. 1830–1795 Ma) was similar to the record of collision and indentation of India into the upper plate collage of cratons and terranes that made up central Asia in the Eocene, beginning at ca. 50.6 Ma (Rowley et al., 2004). Using the Asian template, the Archaean to Mesoproterozoic geological record of western Greenland and north-eastern Canada can thus be com-

pared and sequenced (ordered) from north to south in order to document: (1) the amalgamation and growth of a northern (Churchill) composite upper plate, (2) the collision of the Churchill upper plate assemblage with the lower plate Superior craton, and (3) the pre- to syn-collisional accretion of juvenile magmatic arcs along the southern margin of the growing Laurentian craton. Viewed in this context, and as detailed below, the collisional lower plate comprises the Superior craton, which underlies large parts of Quebec, Ontario and Manitoba, plus its surrounding Palaeoproterozoic margin sequences. The collisional upper plate comprises the Churchill domain, which includes: the northern (Rae) craton, the Ellesmere-Devon terrane and Inglefield mobile belt, the Piling Group – Hoare Bay Group – Karrat Group cratonic margin, the North Atlantic craton, the Nagssugtoqidian–Torngat belts, the Makkovik–Ketilidian belts, the Meta Incognita microcontinent, and the Narsajuaq arc. *Within* the composite Churchill collage, individual components were also in relative upper plate vs. lower plate positions during the periods of convergence and accretion that led to the systematic growth of the northern landmass (e.g. the North Atlantic craton was in an upper plate position with respect to the northern (Rae) craton during the period of convergence and collision resulting in the Nagssugtoqidian-Rinkian belt, or the Narsajuaq arc was in a lower plate position with respect to the Meta Incognita microcontinent prior to accretion to the composite Churchill plate, etc.; see below).

Crustal components

An overview of the crustal framework of north-eastern Canada (Ellesmere Island, Devon Island, Baffin Island, northern and central Labrador) and western Greenland is given below from north to south and is based on geological maps, reviews, and descriptions from eastern Canada and western Greenland published by Escher (1971), Allaart (1982), Escher (1985), Frisch (1988), Grocott and Pulvertaft (1990), Hoffman (1990a), Dawes (1991), Garde (1994), Escher and Pulvertaft (1995), Scott and de Kemp (1998), Garde and Steenfelt (1999), Connelly et al. (2000), Culshaw et al. (2000), Dawes et al. (2000), Jackson (2000), Garde et al. (2002), James et al. (2002), Ketchum et al. (2002), St-Onge et al. (2002, in press a, b), van Gool et al. (2002, 2004), Wardle et al. (2000, 2002), Scott et al. (2003), Dawes and Garde (2004), and references therein. Unless otherwise specified, the geological ages quoted in the text below are based on TIMS U-Pb analyses of zircon.

Upper plate Archaean Rae craton

The northern half of Baffin Island (Fig. 2) is underlain by the upper-plate Archaean Rae craton, which comprises banded granodioritic to monzogranitic orthogneisses, overlying metamorphosed siliciclastic sedimentary rocks, iron formation, and mafic to intermediate (minor felsic) meta-volcanic rocks of the Mary River Group, and younger granodioritic to monzogranitic and rare tonalitic plutonic rocks (Scott and de Kemp, 1998; Jackson, 2000; Bethune and Scammell, 2003; Scott et al., 2003). The felsic orthogneisses and plutonic rocks range in age between $2868^{+13/-12}$–$2702^{\pm 3}$ Ma, whereas the felsic meta-volcanic rocks of the Mary River Group cluster between $2732^{+8/-7}$–$2718^{+5/-3}$ Ma (Jackson, 2000; Wodicka et al., 2002b, in preparation; Bethune and Scammell, 2003; Scott, in preparation).

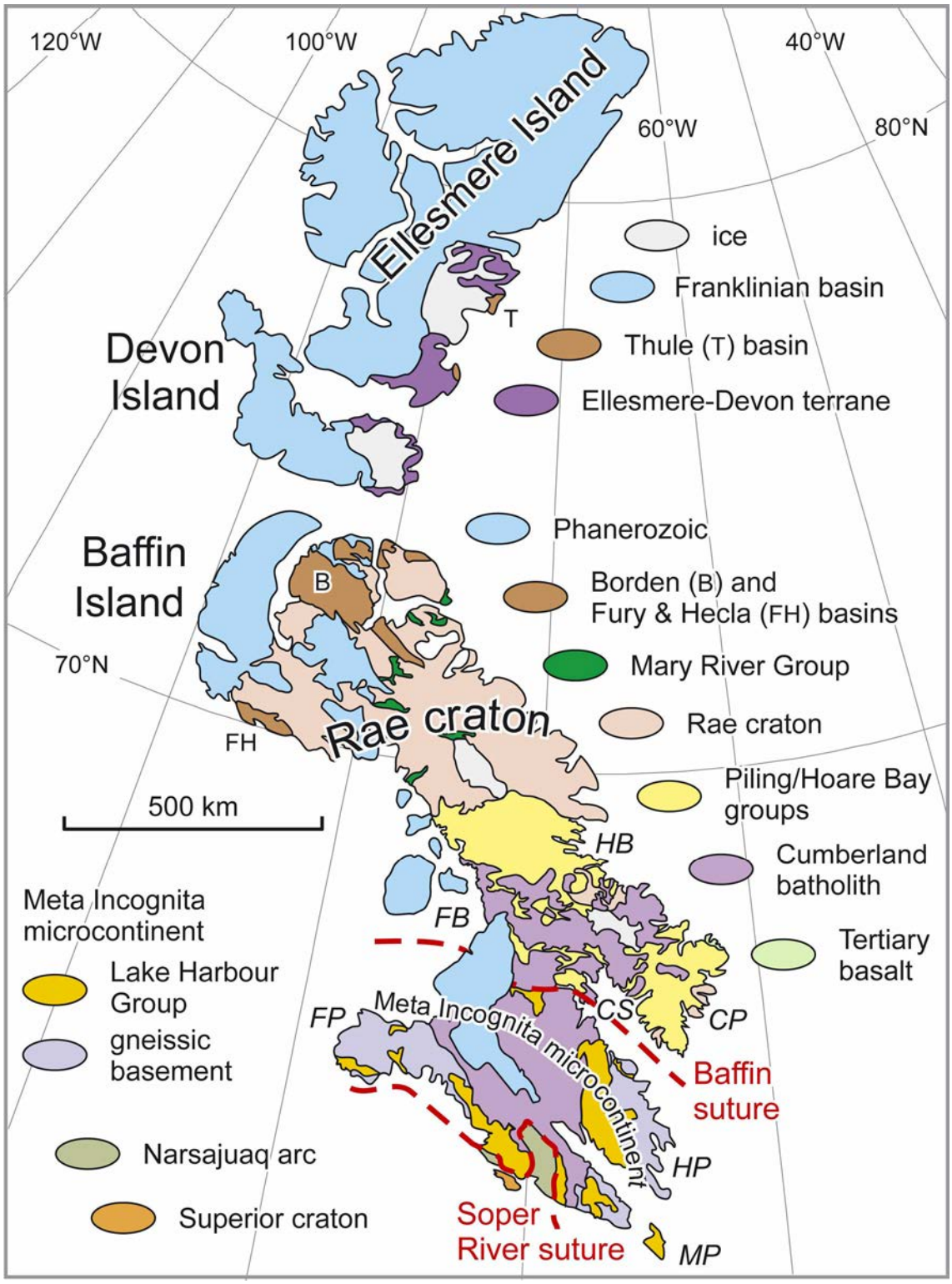

Figure 2. *Simplified geological map of Ellesmere Island, Devon Island, and Baffin Island, modified from Wheeler et al. (1996) showing principal tectonostratigraphic assemblages and structures discussed in the text. Abbreviations: B – Borden basin; CP – Cumberland Peninsula; CS – Cumberland Sound; FB – Foxe Basin; FH – Fury and Hecla basin; FP – Foxe Peninsula; HB – Home Bay; HP – Hall Peninsula; MP – Meta Incognita Peninsula; T – Thule basin.*

In north-western Greenland, the coastal areas of Inglefield Bredning, Kap York, and Melville Bugt (Fig. 3) are underlain by the tonalitic to granitic orthogneisses and quartzofeldspathic paragneisses of the Thule mixed gneiss complex (ca. 2.9 Ga Sm-Nd model age), the gabbro-tonalite-granite units of the Kap York meta-igneous complex (ca. 2.7 Ga Rb-Sr age), and the tonalitic to granitic gneisses and granites of the Melville Bugt orthogneiss complex (ca. 2.7 Ga Rb-Sr age) (Dawes, 1991). Based on lithological characteristics and associations, these Archaean, dominantly felsic, meta-igneous units are correlated with the meta-plutonic units of the upper plate Rae craton of northern Baffin Island. Along the north shore of Melville Bugt, ca. 2.7–2.6 Ga (Rb-Sr and U-Pb ages; Dawes et al., 1988) quartzofeldspathic to pelitic paragneisses and schists (including ironstone), magnetite-bearing quartzites, mafic schists, and amphibolites of the Lauge Koch Kyst supracrustal complex (Dawes, 1991) are similar to the Mary River Group of northern Baffin Island (Jackson, 2000) thus providing an additional basis for the correlation of Archaean Rae craton units between north-western Greenland and northern Baffin Island (Figs 2–3, 5).

Palaeoproterozoic northern margin of the Archaean Rae craton

To the north, the Precambrian basement of southeastern Ellesmere Island and eastern Devon Island comprises highly deformed, granulite facies, meta-sedimentary and meta-igneous rocks of the Ellesmere-Devon terrane (Frisch, 1988), which are overlain by unmetamorphosed strata of the late Mesoproterozoic Thule basin and lower Palaeozoic Franklinian basin (Fig. 2). The meta-sedimentary rocks of the Ellesmere-Devon terrane include quartzofeldspathic gneiss, migmatitic pelitic gneiss, marble and quartzite interpreted to represent a metamorphosed continental margin sequence of shales, greywackes, shallow-water carbonates and volcanogenic rocks (Frisch, 1988). The meta-plutonic rocks comprise pyroxene-bearing tonalite and quartz norite to several varieties of granite, including peraluminous S-type granites. U-Pb age determinations (Frisch and Hunt, 1988) yield $1960^{\pm5}$–$1912^{\pm2}$ Ma for the meta-plutonic rocks, ca. 1930 Ma as a minimum age for the high-T metamorphism, and indicate the presence of Archaean crust on southernmost Devon Island (north margin of Rae craton?). Hoffman (1990a) utilized these ages, similarities in lithotectonic units, and the occurrence of distinctive aeromagnetic anomalies as a basis for correlation with the 2.0–1.9 Ga Taltson-Thelon magmatic zone (north-western boundary of the upper plate Rae craton) exposed south of the Queen Maude Gulf in the north-western Canadian Shield.

In Inglefield Land of northwestern Greenland (Fig. 3), polydeformed and granulite-facies rocks of the Inglefield mobile belt (Frisch and Dawes, 1982; Dawes, 1988; Dawes and Garde, 2004) can be divided into two main groups (Dawes et al., 2000; Dawes, 2004), namely partially melted Palaeoproterozoic meta-sedimentary rocks and paragneisses (Etah Group) and a polyphase igneous suite (Etah meta-igneous complex) that intrudes the former group on all scales. The Etah Group itself comprises pelitic to quartzofeldspathic paragneiss and schist (as well as voluminous S-type granites derived from them), marble and calc-silicate rocks, amphibolite, and ultramafic units. The Etah meta-igneous complex is composed of intermediate to felsic orthogneiss, megacrystic monzogranite, quartz diorite, syenite, and subordinate meta-gabbros and magnetite-rich rocks. The age of the complex and granulite metamorphism have been constrained between ca. 1.95–1.915 Ga, and ca. 1.92 Ga, respectively, by SHRIMP U-Pb ages on zircon (Dawes, 2004). Correlations between the meta-sedimentary rocks of the Ellesmere-Devon terrane and the Etah Group of

the Inglefield mobile belt, as well as between the meta-plutonic rocks of Ellesmere and Devon Islands and those of Inglefield Land were made by Frisch and Dawes (1982) based on similarities in lithology, metamorphic grade, and tectonic history.

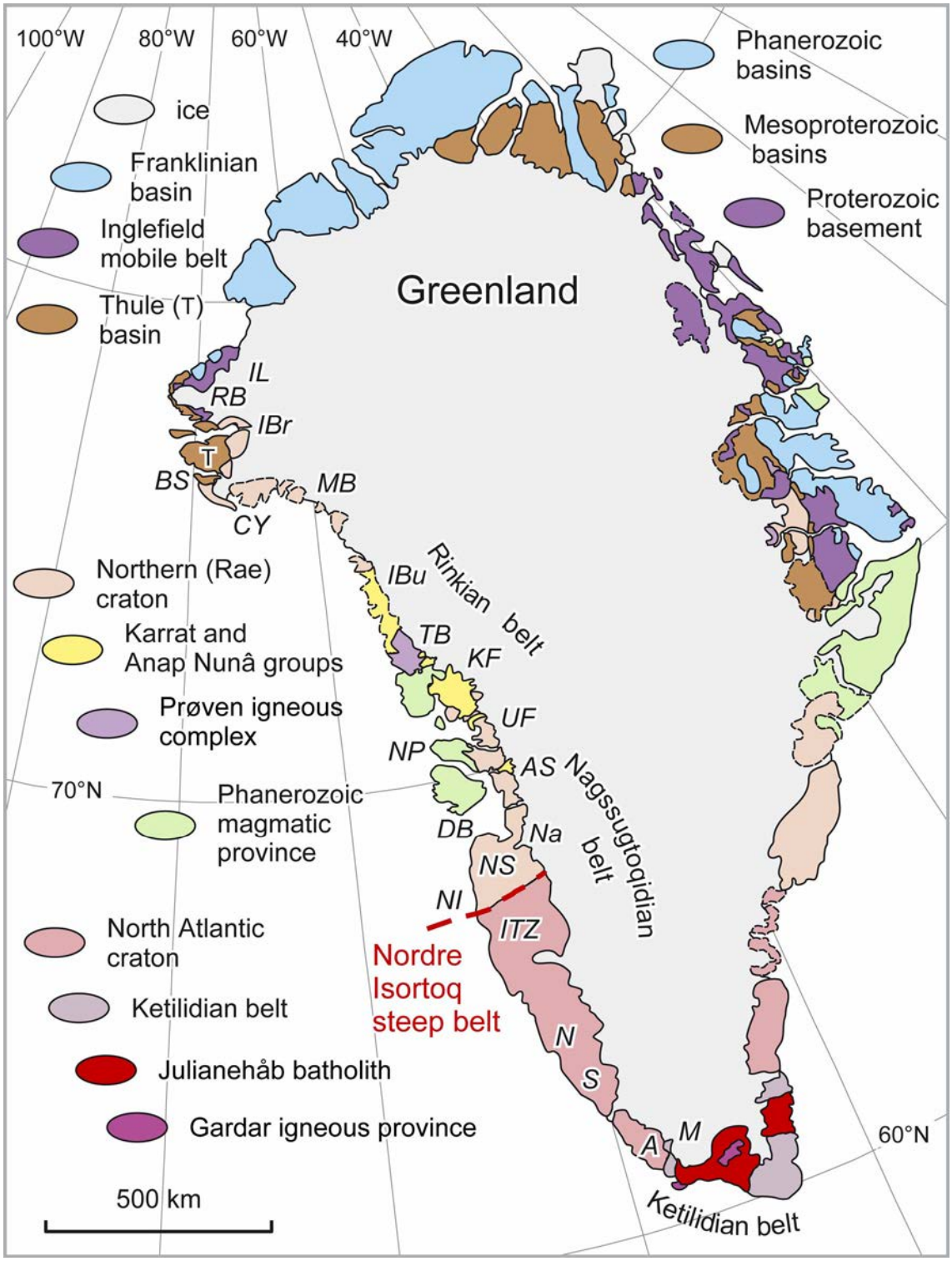

Figure 3. *Simplified geological map of Greenland modified from Escher and Pulvertaft (1995) showing principal tectonostratigraphic assemblages and structures discussed in the text. Abbreviations: A – Arsuk; AS – Ataa Sund; BS – Bylot Sund; CY – Kap York; DB – Disko Bugt; IBr – Inglefield Bredning; IBu – Inussulik Bugt; IL – Inglefield Land; ITZ –*

Ikertôq thrust zone; KF – Karrat Fjord; M – Midternæs; MB – Melville Bugt; N – Nuuk; Na – Naternaq; NI – Nordre Isortoq; NP – Nuussuaq Peninsula; NS – Nordre Strømfjord; RB – Rensselaer Bugt; S – Sermilik; T – Thule basin; TB – Tasiussaq Bugt; UF – Uummannaq Fjord.

Palaeoproterozoic southern margin of the Archaean Rae craton

On central Baffin Island, the southern margin of the upper plate Rae craton is unconformably overlain by the Palaeoproterozoic Piling Group (Morgan et al., 1975, 1976; Scott et al., 2003) which extends from the Foxe Basin on the western shore of Baffin Island to Home Bay on the east coast, as well as by the stratigraphically correlative Hoare Bay Group to the southeast on Cumberland Peninsula (Jackson and Taylor, 1972; Scott and de Kemp, 1998; Scott et al., 2003; St-Onge et al., in press b; Fig. 2). Within the type Piling Group of west-central Baffin Island, the south-facing continental margin sequence comprises (Scott et al., 2003): shallow marine, continental margin clastic (Dewar Lakes Fm) and carbonate platform (Flint Lake Fm) strata (younger than $2159^{\pm16}$ Ma), mafic intrusive, extrusive, and sedimentary rift (Bravo Lake Fm) units (younger than $1980^{\pm11}$ Ma), rusty-weathering sulphide schist, black shale, and sulphide-facies iron formation (Astarte River Fm), and foredeep turbidites (Longstaff Bluff Fm) (younger than $1915^{\pm8}$ Ma). Analysed sedimentary strata are dominated by 3.60–2.72 Ga detrital zircons (lower Dewar Lakes Fm), 3.02–2.16 Ga detrital zircons (upper Dewar Lakes Fm), 3.32–1.98 Ga detrital zircons (Bravo Lake Fm), and 2.95–1.92 Ga detrital zircons with a preponderance of 2.15–1.92 Ga detritus (Longstaff Bluff Fm). Geochronological constraints on the deposition of the Piling Group are based on SHRIMP U-Pb ages from Wodicka (in preparation). The mafic and sedimentary units of the Bravo Lake Formation occur at the interface between the lower clastic unit (Dewar Lakes Fm) and the overlying black shale and turbidites (Astarte River and Longstaff Bluff Fms), where the marbles of the Flint Lake Formation are missing (Scott et al., 2003). Various felsic plutonic rocks, ranging in age from 1.90-1.85 Ga and including the northernmost components of the dominantly hypersthene-bearing $1865^{+4/-2}$–$1848^{\pm2}$ Ma Cumberland batholith (Jackson et al., 1990; Wodicka and Scott, 1997; Scott and Wodicka, 1998; Scott, 1999), intrude the southern and western strata of the Piling and Hoare Bay groups on Baffin Island.

Palaeoproterozoic units in western and north-western Greenland have traditionally been considered as belonging to two different belts, the Rinkian belt in the north and the Nagssugtoqidian belt farther south, although the two belts are now considered to represent the northern and southern parts of one composite orogenic complex more than 1000 km wide (Garde and Steenfelt, 1999; Connelly et al., 2005; Sidgren et al., in press). In the Inussulik Bugt to Uummannaq Fjord area of north-western Greenland, the ca. 2.71–2.57 Ga (Rb-Sr and U-Pb ages; Kalsbeek, 1981, 1986; Andersen and Pulvertaft, 1985) tonalitic to granodioritic gneisses of the northern (Rae) craton are overlain unconformably by the supracrustal units of the Palaeoproterozoic Karrat Group of the Rinkian belt (Escher, 1971; Garde, 1978; Escher, 1985; Grocott and Pulvertaft, 1990). The Karrat Group in the type Karrat Fjord area (Henderson and Pulvertaft, 1967, 1987) comprises the following units: a lower sequence of shallow marine, shelf-type meta-sedimentary rocks including quartzite, semipelitic to pelitic gneiss and schist (Qeqertarssuaq Fm), and marble (Mârmorilik Fm), overlain by black shales and a thick, uniform, arenaceous turbidite flysch sequence (Nûkavsak Fm) constrained by Kalsbeek et al. (1998) to being younger than $1949^{\pm11}$ Ma. A

sample of meta-greywacke from the Nûkavsak Formation analysed by Kalsbeek et al. (1998) has yielded dominantly 2.10–1.95 Ga detrital zircons. A mafic volcanic member comprising both pillowed lava flows and pyroclastic rocks is found at the interface between the lower clastic and chemical sedimentary units (Qeqertarssuaq and Mârmorilik Fms) and the overlying turbidites (Nûkavsak Fm) (Grocott and Pulvertaft, 1990; Thomassen, 1992). Following Jackson and Taylor (1972), Escher and Pulvertaft (1976), Taylor (1982), and Henderson and Pulvertaft (1987), and based on the similarity in distribution and association of the sedimentary and volcanic lithologies, stratigraphic sequences, unit thickness, overall tectonic context, and recent detrital zircon analytical data, the correlation of the Piling/Hoare Bay groups of central Baffin Island with the Karrat Group of western Greenland is retained (Figs 2–3, 5).

South of the Nuussuaq Peninsula of western Greenland, supracrustal units correlative with the Karrat Group outcrop in the Torsukattak – Ataa Sund area (Anap Nunâ Group of Escher and Burri, 1967; Escher, 1971; see updated description and correlation in Garde and Steenfelt, 1999). The clastic and carbonaceous supracrustal strata unconformably overlie Archaean orthogneisses and supracrustal rocks, with the orthogneisses dated between $2835^{\pm4}$–$2758^{\pm2}$ Ma in the Disko Bugt area (Nutman and Kalsbeek, 1999). Still farther south in the Naternaq, Nordre Strømfjord, and Nordre Isortoq areas of the Nagssugtoqidian belt, psammitic and pelitic schists and gneisses, with banded iron-formation, meta-volcanic rocks, and marble (Naternaq supracrustal belt of Østergaard et al., 2002; Thrane and Connelly, in press; Nordre Strømfjord supracrustal suite of Marker et al., 1999) are dominated by 2.20–1.95 Ga detrital zircons with very little Archaean input (Scott et al., 1998; Nutman et al., 1999). Deposition of the Nordre Strømfjord supracrustal suite is constrained between 1.95–1.92 Ga (van Gool et al., 2002). In spite of overlapping detrital zircon ages of the Naternaq supracrustal belt and the Nordre Strømfjord supracrustal suite with those of the Karrat Group to the north, the lithologies appear to be very different. The former belts are dominated by mafic to ultramafic metavolcanic and pelitic rocks indicative of a rifting or possibly oceanic environment, whereas the Karrat Group largely consists of shelf-type metasedimentary rocks deposited unconformably on the Archaean basement. The correlation of supracrustal units within western Greenland is critical (and needs to be further tested), because it may provide the best method for determining the southern extent of the underlying northern Archaean (Rae) craton. That in turn will further constrain the location of the crustal suture (or sutures), which necessarily separates the northern craton from the North Atlantic craton to the south within the tectonic framework of the Nagssugtoqidian belt (van Gool et al., 2002; Connelly et al., 2005). Based on geometric and structural arguments presented in van Gool et al. (2002) and Connelly et al. (2005, see below), the Rae craton – North Atlantic craton suture is provisionally shown rooting in the Nordre Isortoq steep belt (van Gool et al., 1996) on Fig. 3, as first suggested by Kalsbeek et al. (1987). However, Connelly et al. (2005) have also suggested the presence of a suture in the Disko Bugt area to the north based primarily on the presence of extensive mylonites and a north-to-south change in isotope signatures of the Archaean basement gneisses in this area. Furthermore, the recent discovery of Palaeoproterozoic tholeiitic metavolcanic rocks, pelitic metasedimentary rocks, chert and banded iron formation on islands north of Aasiaat (lithologically similar to the Naternaq supracrustal belt but much better preserved) would corroborate the idea that the transitional area between the Rinkian belt and the northern Nagssugtoqidian belt in the Disko Bugt area may contain one or more microcontinents or an undulating su-

ture (which daylights in more than one locality at the present erosion surface) (A. Garde, personal communication, 2005). The picture is further complicated by geophysical evidence of an unexposed granitic pluton, which is imaged to continue in the subsurface across the proposed suture (Nielsen, 2004).

In the Tasiussaq Bugt to Sullua (Upernavik) area, the meta-sedimentary rocks of the Karrat Group are intruded by the K-feldspar megacrystic, hypersthene-bearing, granite of the Prøven igneous complex, which has a Rb-Sr isochron age of 1860±25 Ma (Kalsbeek, 1981) and has recently been dated more accurately at 1869 ± 9 Ma (Thrane et al., 2005). A-type geochemical signatures and Sm-Nd, Lu-Hf and Rb-Sr isotopic compositions of the Prøven igneous complex suggest that is a crustal melt derived largely from the local Archaean continental crust (Kalsbeek, 1981; Thrane et al., 2005), and the latter authors suggest that it is formed in response to massive underplating related to collisionally-induced delamination of the lithospheric mantle early in the Nagssugtoqidian–Rinkian orogeny.

Similarities in major element geochemistry of the constituent plutonic rock types, the stratigraphy of the encasing host-rocks, and available geochronology might seem to suggest that the Prøven igneous complex can be viewed as an eastern correlative to the Cumberland batholith of Baffin Island (Figs 2–3). However, its geochemical and isotopic compositions prevent it from being a juvenile, arc-type subduction-related pluton formed at a convergent plate boundary as has been suggested for large parts of the Cumberland batholith by St-Onge et al. (in press a).

Mesoproterozoic basins

Both the upper plate Archaean Rae craton of northern Baffin Island and the dominantly Palaeoproterozoic Ellesmere – Devon terrane to the north are unconformably overlain by the siliciclastic rocks, carbonate strata, and basaltic intrusive and extrusive units of the Borden basin (Jackson and Iannelli, 1981; Jackson, 2000) and Thule basin (Frisch and Christie, 1982; Jackson, 1986; Frisch, 1988) of Mesoproterozoic age (Fig. 2). On the Greenland side, from Rensselaer Bugt south to Bylot Sund, the plutonic and supracrustal units of the Palaeoproterozoic Inglefield mobile belt and the Archaean Thule mixed gneiss complex are also unconformably overlain by the clastic strata and basaltic sills of the Thule basin (Dawes, 1997). Early regional correlations involving the Mesoproterozoic strata along the northwestern edge of the Canadian-Greenlandian shield (Figs 2–3, 5) were made by several authors including Blackadar and Fraser (1960), Dawes (1976), Kerr (1979), Young (1979), Fahrig et al. (1981), and Jackson and Iannelli (1981).

Upper plate Palaeoproterozoic Meta Incognita microcontinent

On Baffin Island, the crustal suture separating the northern Archaean Rae craton and its flanking southern continental margin sedimentary and volcanic sequences (Piling and Hoare Bay groups) from accreted tectonic elements to the south has been proposed by St-Onge et al. (in press a) – based on a recent compilation of Palaeoproterozoic tectonostratigraphic units and structures for south-central Baffin Island (St-Onge in press b) – to run from the Foxe Basin to the head of Cumberland Sound (Fig. 2). On the south side of the suture, named Baffin suture by St-Onge et al. (in press a), Archaean and Palaeoproterozoic units of the Meta Incognita microcontinent (St-Onge et al., 2000) are exposed from Foxe Peninsula in the west to Hall and Meta Incognita peninsulas in the east (Fig. 2). The

upper plate Meta Incognita microcontinent comprises: (1) a $1934^{\pm2}$ – ca. 1880 Ma (Scott, 1997, in preparation; Scott et al., 2002) continental margin shelf and rift succession (Lake Harbour Group) and its $3019^{\pm5}$–$1950^{+6/-4}$ Ma (Scott, 1998, 1999; Scott and Wodicka, 1998) crystalline basement (Ramsay River and Hall Peninsula orthogneisses); (2) an overlying foreland basin succession (Blandford Bay assemblage); and (3) an extensive suite of $1865^{+4/-2}$–$1848^{\pm2}$ Ma (Jackson et al., 1990; Wodicka and Scott, 1997; Scott and Wodicka, 1998; Scott, 1999) Andean margin-type quartz diorite to monzogranitic plutons (Cumberland batholith) that intrude both (1) and (2). At this point it remains unclear whether the microcontinent was initially rifted from the lower plate Superior craton (described below) as suggested by St-Onge et al. (2000), whether it constitutes a rifted fragment of the northern upper plate Rae craton, or whether it represents crust exotic with respect to both bounding cratons.

South of Hudson Strait, the siliciclastic and carbonate rocks of the Lake Harbour Group, the underlying Ramsay River and Hall Peninsula orthogneisses, and the crosscutting pyroxene-bearing monzogranites of the Cumberland batholith do not occur in the Ungava Peninsula of northern Quebec (see below). Rather as suggested by Jackson and Taylor (1972) and based on lithological similarities, the supracrustal rocks of the Lake Harbour Group on Baffin Island are correlated with similar supracrustal sequences on the south-eastern side of Ungava Bay (Fig. 4). Recently, St-Onge et al. (2002) utilized residual total magnetic field signatures to further strengthen the correlation and project the boundaries of the Meta Incognita microcontinent assemblage from Baffin Island to the southeast shore of Ungava Bay (Fig. 5). In this correlation, the distinctive aluminous Tasiuyak paragneiss of eastern Labrador (Wardle, 1983) may represent a lateral, deeper water equivalent of the shelf-facies Lake Harbour Group as initially suggested by Goulet and Ciesielski (1990), and the Lac Lomier complex (Ermanovics and Van Kranendonk, 1998; Wardle et al., 2002) may correspond to the southern extension of the Cumberland batholith (R. Wardle, personal communication, 2005). Detrital zircons from both the Lake Harbour Group and the Tasiuyak paragneiss show a similar Palaeoproterozoic-dominated source (2.10–1.94 Ga, Scott and Gauthier, 1996; Scott, 1997; Scott et al., 2002) and distinct REE and Nd-isotopic signature (Thériault et al., 2001) supporting suggestions based on lithological similarities and tectonostratigraphic context that these units, on southern Baffin Island and southeast of Ungava Bay, may have been part of a single depositional system developed along the northeastern and eastern side of the microcontinent. Alternatively, Wardle and Van Kranendonk (1996) utilised the relatively juvenile isotopic character of the Tasiuyak paragneiss to suggest deposition within an accretionary prism environment, associated with the Burwell arc (see below) subduction system (Van Kranendonk and Wardle, 1997). More recently, Wardle et al. (2002) in an attempt to reconcile the juvenile nature of the detrital zircon population and the Archaean input suggested by the Nd-isotopic signature of the Tasiuyak gneiss, proposed accumulation in an oceanic arc setting.

Archaean and Palaeoproterozoic units correlative to those of the upper plate Meta Incognita microcontinent are not thought to occur in western Greenland.

Upper plate Archaean North Atlantic craton

The North Atlantic craton (Bridgwater et al., 1973a) is an upper plate Archaean craton, which is bound to the north and west by segments of Palaeoproterozoic orogenic belts that

are tectonically related to the collisional Trans-Hudson orogen, and include the Nagssugtoqidian/Rinkian belt on the north side and the Torngat orogen on the west side of the craton (Figs 3–4). On its south side the craton is bound by the Palaeoproterozoic, Andean margin-type, Makkovik/Ketilidian belt. Rocks of the North Atlantic craton occur in northeastern Labrador, south-central Greenland, and northwestern Scotland, all of which were likely attached prior to Mesozoic opening of the Labrador Sea and the North Atlantic Ocean (see Sutton et al., 1972; Bridgwater and Schiøtte, 1991; Wasteneys et al., 1996).

In northern Labrador, the upper-plate North Atlantic craton (also known in Labrador as the Nain craton or Nain Province; Stockwell and Williams, 1964; Taylor, 1971, 1972, 1979) comprises the Saglek block in the north and the Hopedale block in the south, on either side of the intervening Mesoproterozoic Nain Plutonic Suite (Fig. 4). The two Archaean blocks in Labrador are characterized predominantly by deeply exhumed, early to late Archaean orthogneisses, greenstone belts, and late granitoid intrusions. The southern Hopedale block contains ca. 3.3 Ga – $3105^{+6/-9}$ Ma (Loveridge et al., 1987; Finn, 1989, James et al., 2002) high-grade tonalite, granodiorite and granite orthogneisses (Maggo Gneiss; Ermanovics, 1993), ca. 3.1–2.98 Ga (James et al., 1998) supracrustal belts dominated by mafic metavolcanic rocks and local occurrences of meta-sedimentary rocks, and ca. 2.89–2.82 Ga (Wasteneys et al., 1994, 1996) tonalitic to granitic plutonic rocks (Kanairiktok plutonic suite). North of the Nain plutonic suite, the Saglek block (Bridgwater et al., 1976; Bridgwater and Schiøtte, 1991) comprises: ca. 3.7–3.3 Ga (Schiøtte et al., 1989a; Collerson et al., 1991; Collerson and Regelous, 1995; Wasteneys et al. 1996) tonalitic to granodioritic metaplutonic rocks (Uivak gneisses), subordinate >3.8 Ga (Schiøtte et al., 1989a) supracrustal and plutonic remnants or inclusions, meta-sedimentary and meta-volcanic rocks (Upernavik supracrustal rocks; Schiøtte et al., 1989b, 1992), and deformed leucograbbroic and anorthositic intrusions and dykes (Saglek dykes). The boundary between the Hopedale and Saglek blocks is assumed to be tectonic, with amalgamation of the two blocks occurring at ca. 2.7 Ga following distinct magmatic and tectonic histories for each block (James et al., 2002 and references therein). Presently the region separating the two blocks is mainly occupied by rocks of the $1343^{\pm3}$ – ca. 1295 Ma (Simmons et al., 1986; Connelly and Ryan, 1994) Nain Plutonic Suite.

In south-western Greenland, recent and ongoing detailed studies of the Archaean magmatic and tectonic evolution of the North Atlantic craton, particularly in the greater Nuuk region (e.g. Friend et al., 1988, 1996; Nutman et al., 1989; Garde et al., 2000; Crowley, 2002; Garde, 2003; Friend and Nutman, 2005) have documented the complex and composite nature of this segment of Archaean crust. The above studies suggest that the North Atlantic craton in Greenland comprises a still unknown number of distinct tectonostratigraphic terranes or microplates, varying in size from tens of kilometres to at least a couple of hundred kilometres, and having independent histories prior to amalgamation in the late Archaean at ca. 2.7 Ga. In the Nuuk region of western Greenland (Fig. 3), several adjacent tectonostratigraphic terranes have been documented (Friend and Nutman, 2005 and references therein). The north-western Akia terrane consists of 3.2–3.0 Ga orthogneisses, which have intruded into older supracrustal rocks and were metamorphosed at up to granulite facies conditions at ca. 2.97 Ga. Several complexly interfolded terranes occur southeast of the Akia terrane. Two of these, the Færingehavn and Isukasia terranes, contain at least two different groups of ca. 3.8–3.5 Ga supracrustal and plutonic rocks including

the well-known Isua supracrustal belt (Nutman et al., 1996, 2000), in addition to ca. 2.8 Ga orthogneisses. The southern Tasiusarsuaq terrane largely comprises ca. 2.8 Ga rocks and does not appear to contain early Archaean components.

The Archaean terranes outside the Nuuk region are not all well defined (van Gool et al., 2004). The southern part of the craton from Sermilik to Arsuk (Fig. 3) comprises several different terranes, which range from ca. 3.0–2.8 Ga in age (Friend and Nutman, 2001), apparently without older components. They mainly comprise orthogneisses, supracrustal amphibolites, and a large anorthosite-gabbro complex with chromitite horizons at Fiskenaesset (Myers, 1985). To the north, the early Archaean Aasivik terrane is located north of the Akia terrane near the southern margin of the Nagssugtoqidian belt and largely consists of ca. 3.78–3.55 Ga orthogneisses (Rosing et al., 2001). The northernmost part of the North Atlantic craton is dominated by ca. 2.85–2.70 Ga orthogneisses (Connelly and Mengel, 2000).

Given an unexposed, pre-drift distance of ca. 300-400 km, sub-cratonic correlations of blocks and terranes between the Canadian and Greenlandic components of the North Atlantic craton are considered highly speculative by van Gool et al. (2004) and are referenced here only for completeness. Friend and Nutman (1994) suggested a correlation between the Akia terrane in Greenland and the Hopedale block in Labrador, based on ca. 3.0 Ga metamorphism and plutonism in both, whereas an unnamed terrane south of Sondre Stromfjord was correlated with the Saglek block, based on a common granulite facies metamorphism at ca. 2.74 Ga. More recently, James et al. (2002) highlighted the significant difference in the timing of metamorphism of the Hopedale block vs. the Akia terrane, and proposed a correlation between the Hopedale block and the Tasiusarsuaq terrane, and the Saglek block with the Færingehavn and Isukasia terranes.

The correlation of the North Atlantic craton from Labrador to western Greenland shown on Fig. 5 follows that of Bridgwater et al. (1973a, 1990), Korstgard et al. (1987), Bridgwater and Shiotte (1991), Garde et al. (2002), and van Gool et al. (2002, 2004). It is consistent with the dating of offshore well cores by Wasteneys et al. (1996), which added additional constraints to correlation of Precambrian bedrock units across the Labrador Sea.

Western and northern margins of the Archaean North Atlantic craton

The Torngat orogen of northwestern Labrador and northeastern Quebec, and the Nagssugtoqidian belt of southwestern Greenland are Palaeoproterozoic collisional orogenic belts that developed respectively along the northern and western margins of the upper plate North Altantic craton (Figs 3–4). The correlation of the two orogenic belts (Fig. 5) is based on a similarity in constituent lithotectonic units, coeval tectonic history including igneous, structural and metamorphic events, and complementary kinematics, as proposed and documented by Bridgwater et al. (1973b, 1990), Korstgård et al. (1987), Hoffman (1990b), Van Kranendonk et al. (1993), Park (1994), Wardle and Van Kranendonk (1996), Connelly et al. (2000), van Gool et al. (2002, 2004), and Wardle et al. (2002).

In northern Labrador, basaltic dykes indicate that rifting along the western margin of the North Atlantic craton occurred at ca. 2.2–2.0 Ga, and was accompanied by the contemporaneous emplacement of anorthosite-granite suites at 2.1–2.0 Ga (Connelly and Ryan,

1994, 1999; Wardle and Van Kranendonk, 1996; Hamilton et al., 1998). Along the eastern coast of Labrador, these rocks are unconformably overlain by Palaeoproterozoic rocks of the Ramah, Mugford, and Snyder groups (Fig. 4), each representing an upward progression from shallow- to deep-water environments (Wardle et al., 2002) and dominated with detritus of Archaean provenance in the lower part of the sequence (Scott and Gauthier, 1996). To the west, the Tasiuyak gneiss (see above) comprises migmatitic pelitic and psammitic rocks, interpreted as meta-turbidites, with minor mafic and ultramafic material, and interpreted either as continental slope deposits off the eastern margin of the orogenic core zone to the west (i.e. deeper-water equivalent to the platformal Lake Harbour Group of Meta Incognita Peninsula) (Goulet and Ciesielski, 1990; Van Kranendonk et al., 1993; Scott, 1998; St-Onge et al., 2002), or as a distal accretionary wedge sequence that accumulated on the western margin of the North Atlantic craton (Van Kranendonk and Wardle, 1997; Wardle et al., 2002).

Palaeoproterozoic crustal deformation within the Torngat orogen is interpreted to result from the collision of the upper plate North Atlantic craton to the east with the Meta Incognita microcontinent (a.k.a. core zone) of to the west. The collision resulted in a narrow, north-south trending, doubly-vergent orogen (Rivers et al., 1996; Wardle and Van Kranendonk, 1996; and references therein), with the crustal suture corresponding to the eastern margin of the Tasuiyak gneiss as shown on Fig. 4. The collision was preceded by emplacement of the continental, calc-alkaline Burwell arc in northernmost Labrador and dated between $1910^{\pm2}$–$1869^{+3/-2}$ Ma (Scott and Machado, 1995). The collision itself is recorded by peak granulite facies metamorphism within the core of the orogen during west-directed thrusting within the Tasiuyak gneisses and east-directed thrusting at the North Atlantic craton margin between ca. 1870–1845 Ma (Scott, 1998; Connelly, 2001). Continued deformation is manifest as sinistral transpressional shear between $1844^{\pm3.6}$–1822 Ma along the north-south trending Abloviak shear zone (Bertrand et al., 1993), which developed mainly in the Tasiuyak gneiss.

The composite Rinkian–Nagssugtoqidian belt is interpreted to result from the upper plate collision of the North Atlantic craton with the northern (Rae) craton. Within the orogen, Archaean dioritic, granodioritic, tonalitic and granitic orthogneisses of the North Atlantic craton predominate, albeit in a reworked state (Kalsbeek et al., 1984, 1987; Kalsbeek and Nutman, 1996; Connelly and Mengel, 2000; van Gool et al, 2002). New data from the southern part of the Rinkian segment (Connelly et al., 2005) yield basement ages of around 3.0 Ga. The orthogneisses in the Nagssugtoqidian segment are generally 2.87–2.81 Ga in age, with the plutonic protoliths deformed and metamorphosed between 2.81–1.72 Ga, immediately after their emplacement (Kalsbeek and Nutman, 1996; Connelly and Mengel, 2000). The Archaean orthogneisses are cut by several sets of mafic dykes, the most voluminous of which is the steeply dipping, north- to north-east trending, Fe-tholeiitic Kangâmiut dyke swarm (Windley, 1970; Escher et al., 1975, 1976; Korstgård, 1979; Bridgwater et al., 1995; Cadman et al., 2001) intruded between ca. 2.05–2.04 Ga (Nutman et al., 1999; Connelly et al., 2000; Mayborn and Lesher, in press). The Kangâmiut dyke swarm becomes progressively reworked towards the centre of the orogen. Continental margin meta-sedimentary rocks with a relatively high proportion of psammite occur in the Ikertôq thrust zone (Fig. 3; Maligiaq supracrustal suite of Marker et al., 1999). The clastic strata have a large proportion of Archaean detrital zircons but also contain a Palaeoproterozoic population (2.85–2.1

Ga), which constrains deposition to after 2.1 Ga (Scott et al., 1998; Marker et al., 1999; Nutman et al., 1999). The Maligiaq supracrustal suite is interpreted to document the northern reaches of the North Atlantic craton (rift basin or continental margin; van Gool et al., 2002) and thus providing an ultimate southern constraint on the position of the northern (Rae) craton – North Atlantic craton suture discussed above (Fig. 3), although it now seems possible that an Archaean microcontinent intervenes between the two main cratons in the Disko Bugt area.

A phase of arc magmatism preceding the Nagssugtoqidian collision (described below) has been documented in the core of the orogen. Here, tectonic slivers and a larger body of quartz diorite (Arfersiorfik intrusive suite; Kalsbeek et al., 1987; Kalsbeek and Nutman, 1996; Whitehouse et al., 1998; Connelly et al., 2000; van Gool et al, 1999, 2002) that were originally intruded into metavolcanic and metasedimentary rocks of the Nordre Strømfjord supracrustal suite are tectonically interleaved with reworked basement rocks, probably of North Atlantic craton parentage. The earliest Palaeoproterozoic, collision-related, deformation documented within the Nagssugtoqidian belt is northwest directed thrusting and imbrication of Archaean and Palaeoproterozoic units at a scale of hundreds of metres to several kilometres between 1885–1837$^{+9/-8}$ Ma (van Gool et al., 1999, 2002; and references therein). Thrust imbrication was followed by isoclinal folding of large-scale tectonic contacts, and subsequent by orogen-parallel thick-skinned folds of basement and cover units at ca. 1825$^{\pm1}$ Ma (Connelly et al., 2000). Late strike-slip deformation in the Nordre Strømfjord shear zone and Nordre Isortoq steep belt occurred ca. 1775 Ma (Connelly et al., 2000). South of the proposed suture rooting in the Nordre Isortoq steep belt (van Gool et al., 2002), calc-alkaline continental arc rocks of the 1912–1873 Ma Sisimiut charnockite suite (Kalsbeek et al., 1987; Kalsbeek and Nutman, 1996; Connelly et al., 2000; Campbell and Bridgwater, 1996; Whitehouse et al., 1998) are emplaced into Archaean ortho- and paragneisses, consistent with the proposed location of the Palaeoproterozoic suture in the Nordre Isortoq area and the interpretation of the North Atlantic craton as the local overriding plate within the Nagssugtoqidian collisional belt. Collision across the Nagssugtoqidian belt is bracketed between ca. 1.86–1.84 Ga (Taylor and Kalsbeek, 1990; Kalsbeek and Nutman, 1996; Connelly et al., 2000; Willigers et al., 2001) based on dating of the granulite-facies thermal peak of metamorphism in the core of the orogen.

South margin of the Archaean North Atlantic craton

The Makkovik belt in central Labrador and the Ketilidian belt of southern Greenland respectively define the southwestern and southeastern boundaries of the upper plate Archaean North Atlantic craton (Figs 3–5). The southern margins of the craton, initiated as passive continental margins at ca. 2.24–2.13 Ga, became the loci of subduction, arc magmatism and juvenile crustal accretion within an Andean-type margin context between 1.89–1.80 Ga (see Culshaw et al., 2000; Garde et al., 2002; Ketchum et al, 2002; and references therein). Thus in contrast to most Palaeoproterozoic suture and deformation zones within the upper Churchill plate (e.g. Baffin suture zone, Torngat orogen, Nagssugtoqidian belt; see above) or those separating the Churchill plate from the Superior plate (e.g. New Quebec orogen, Wardle et al., 2002; Cape Smith belt, see below), all of which dominantly (but not exclusively) involve reworking of Archaean crust, the Makkovik and Ketilidian belts are dominated by Palaeoproterozoic magmatic and tectonic accretion of juvenile magmatic arcs in an overall transpressional environment (Garde et al., 2002). However, in spite of

long being considered along-strike segments of the same orogenic belt (Fig. 5), the correlation of individual Makkovikian and Ketilidian events is complex (Garde et al., 2002; Ketchum et al., 2002; and references therein) and hindered by the 300–400 km wide pre-drift gap between mainland Greenland and Labrador.

Onshore the Makkovik belt, or at least that part sandwiched between the Archaean North Atlantic craton to the north and the Mesoproterozoic to Neoproterozoic Grenville orogen to the south, is much narrower than the Ketilidian belt, which includes a major batholith (Julianehåb batholith; see below). Offshore, the Makkovik belt apparently widens considerably as documented by data from offshore wells and seismic lines (Wasteneys et al., 1996; Kerr et al., 1997; Hall et al., 2002). Overall, the belt records ca. 300–600 Ma of convergent (Andean-type) plate margin activity, including the accretion of several arc- and back-arc units as well as possibly a small Archaean terrane, punctuated with evidence of intra-accretion quiescent periods (Gower et al, 1990; Kerr, 1994; Kerr et al., 1997; Culshaw et al., 2000; Ketchum et al., 2001a, 2001b, 2002). In contrast, in the Ketilidian belt supracrustal and plutonic units record ca. 450 Ma of relatively continuous magmatic and tectonic activity, which does not seem to involve the accretion of allochthonous crustal terranes to the southern margin of the North Atlantic craton (Chadwick and Garde 1996; Garde et al., 1998, 2002).

Rifting of the southern North Atlantic craton in Labrador is pinned by the $2235^{\pm 2}$ Ma age on the Kikkertavak mafic dykes (Cadman et al, 1993; Ermanovics, 1993). Deposition of overlying continental margin sedimentary strata (quartzite, iron formation, shale, dolostone and greywacke) and pillowed mafic volcanic rocks (Moran Lake, Aillik, and Post Hill groups; Ketchum et al., 2002; and references therein) is constrained to post-date $2235^{\pm 2}$ Ma, the age of the Kikkertavak dykes, and to have begun prior to $2178^{\pm 4}$ Ma, the age of an intermediate tuff layer within the Post Hill Group (Culshaw et al., 2000; Ketchum et al., 2001a). Overlying micaceous psammite with minor pelite and graphitic paragneiss (Metasedimentary formation; Marten, 1977) has yielded both Archaean and Palaeoproterozoic detrital zircons and was deposited after $2013^{\pm 3}$ Ma possibly in a foredeep setting (Ketchum et al., 2001a).

In southern Greenland rifting is poorly constrained by an Rb-Sr age of $2130^{\pm 65}$ Ma (Kalsbeek and Taylor, 1985) on doleritic dykes of the Iggavik suite (Berthelsen and Henriksen, 1975) west of Midternæs (Fig. 3). The mafic dykes are emplaced in Archaean quartzofeldspathic orthogneisses, with deposition of continental margin sedimentary rocks (Vallen Group; Bondesen, 1970; Higgins, 1970) loosely constrained by this age. Shallow marine quartz-pebble conglomerate, quartzite, dolomite, mudstone, chert and a banded iron formation characterize the lower part of the group, whereas deeper marine greywackes predominate in the upper part. The Vallen Group is structurally overlain by the possibly laterally equivalent Sortis Group (Bondesen, 1970), which comprises metabasaltic pillow lavas, pillow breccias and sills, intercalated with mudstone and calcareous rocks. Alternatively the Sortis Group may represent an obducted component of a rifted basin to the south of the North Archaean craton (Garde et al., 2002). Unpublished, U-Pb ages of detrital zircons from a Vallen Group quartzite point to a late Archaean basement provenance (Garde et al., 2002). The Vallen and Sortis groups have been generally correlated with, and have appar-

ent tectonostratigraphic equivalents to the Moran Lake and Post Hill groups of Labrador (Wardle and Bailey, 1981).

Early foreland-directed thrusting and dextral transpression in Labrador at ca. 1895–1870 Ma (Culshaw et al., 2000) may be contemporaneous with Ketilidian thrusting of the Sortis Group and dextral transpression along the steep, ENE-trending, Kobberminebugt shear zone in southern Greenland. Deformation along the Kobberminebugt shear zone is constrained by the age of a crosscutting augen granite dated at $1848^{\pm 2}$ Ma (Hamilton et al., 1999).

In the Makkovik belt, early continental calc-alkaline plutonism is manifest by the ca. $1893^{\pm 2}$–1870 Ma Island Harbour Bay plutonic suite (Ryan et al., 1983; Kerr et al., 1992; Culshaw et al., 2000a, 2000b; Barr et al., 2001), and there appears to be no direct plutonic counterpart in the Makkovik belt to the voluminous continental margin arc (Julianehåb batholith) of southern Greenland, which largely comprises 1854–1795 Ma plutons of granodiorite and granite, with minor gabbro, diorite, quartz monzodiorite, tonalite, and rare quartz syenite (Chadwick et al., 1994; Chadwick and Garde, 1996; Garde et al., 2002). The ca. 1860–1807 Ma (Schärer et al., 1988; Ketchum, 1998) felsic volcanic Aillik Group is close in age to the Julianehåb batholith, and like the latter, it contains evidence of synmagmatic sinistral transpression. The Aillik Group has been interpreted as having been erupted in an extensional back-arc setting but it might instead be a high-level equivalent of the Julianehåb batholith (Culshaw et al., 2000a). Finally it is uncertain if onshore, the Makkovik belt preserves sedimentary sequences equivalent to those found in the classic psammite and pelite zones of the Ketilidian belt (Garde et al., 2002; and references therein). Offshore, strongly reflective components of the ECSOOT seismic line (Kerr et al., 1997; Hall et al., 2002) might correspond to a westerly continuation of the psammite-pelite zones as illustrated in fig. 3 of Garde et al. (2002).

Mesoproterozoic rift sequences

The Mesoproterozoic Seal Lake Group and Harp dykes in Labrador are found north of the boundary between the Palaeoproterozoic Makkovik belt (described above) and the Mesoproterozoic to Neoproterozoic Grenville orogen to the south (Fig. 4). The Seal Lake Group is a continental, predominantly clastic succession consisting of red beds, quartzite, shale and basalt flows, intruded by 1.25–1.22 Ga gabbroic sills (Romer et al., 1995). The Harp dykes (Meyers and Emslie, 1977) form a NE-trending swarm of mafic dykes that were emplaced at shallow crustal levels into the Mesoproterozoic Harp Lake pluton and the Archaean gneisses of the southern North Atlantic craton. The Harp dykes have been interpreted as feeders of lava flows and sills within the Seal Lake Group, although that link was questioned by Cadman et al. (1994). Indications of alkaline activity and rifting predating the Seal Lake Group are provided by the peralkaline felsic volcanic rocks and syenites of the Letitia Lake Group – dated at 1.33 Ga, and the alkaline syenites of the Red Wine alkaline suite – dated at 1.29 Ga (Kerr, 1994; R. Wardle, personal communication, 2005). The Gardar igneous province in southern Greenland straddles the boundary between the North Atlantic craton and the Ketilidian belt. A prominent NE-trending rift zone and graben system was active during the period ca. 1350–1140 Ga as described by Upton (1974), Emeleus and Upton (1976), Upton and Emeleus (1987), Kalsbeek et al. (1990), and Upton et al. (2003). Within the rift basin, the Eriksfjord Formation is a ca. 3500 m thick continental suc-

cession of arkosic and quartzitic sandstones interbedded with and overlain by basaltic lava flows. NW- to NE-trending swarms of basaltic to trachytic dykes (and giant dykes) of several age groups occur throughout the province. Intrusive activity gave rise to about 15 intrusive centres with alkaline rocks ranging in composition from gabbro to syenite, nepheline syenite, alkali granite, and carbonatite. The Gardar province is correlated with the Seal Lake Group and Harp dykes of Labrador by van Gool et al. (2004).

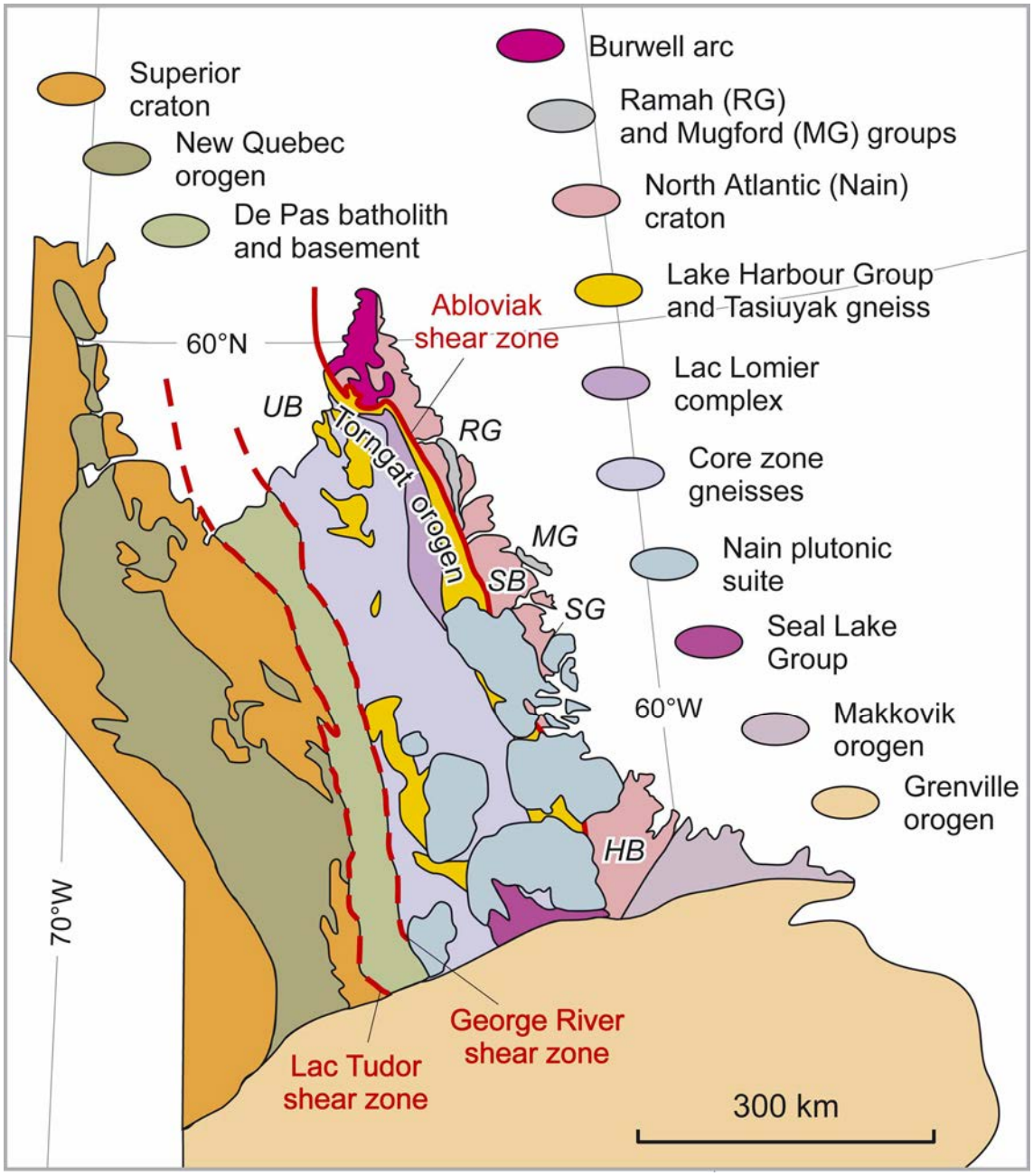

Figure 4. *Simplified geological map of Labrador modified from Wardle et al. (2000) showing principal tectonostratigraphic assemblages and structures discussed in the text. Abbreviations: HB – Hopedale block; MG – Mugford Group; RG – Ramah Group; SB – Saglek block; SG – Snyder Group; UB – Ungava Bay.*

Upper plate Narsajuaq island-arc terrane

South of the upper plate Meta Incognita microcontinent (described above) and in the footwall of a crustal suture exposed along the southern coast of Baffin Island (Soper River suture, Fig. 2), the Narsajuaq arc terrane (Dunphy and Ludden, 1998) is exposed on both sides of Hudson Strait. At ca. 1845 Ma, the arc forms the leading edge of the Churchill plate (St-Onge et al., in press c) and includes: fore-arc siliciclastic rocks (Spartan Group), a dominantly volcanic sequence (Parent Group), and a dominantly plutonic assemblage (Narsajuaq arc). The volcanic and plutonic units of the arc terrane can be grouped into two temporally and petrologically distinct, suites (Dunphy and Ludden, 1998). The older suite includes calc-alkaline layered diorite-tonalite gneiss and tholeiitic to calc-alkaline basaltic andesite to rhyolite, and is dated between $1863^{\pm2}$–$1845^{\pm2}$ Ma (St-Onge et al., 1992; Machado et al., 1993; R. Parrish, personal communication, 1994). It is interpreted as an island-arc assemblage built on Palaeoproterozoic oceanic crust (Watts Group below) and a rifted sliver of Archaean continental crust (Thériault et al., 2001). Accretion of the island-arc assemblage to the composite Churchill upper plate across the Soper River suture is constrained by St-Onge et al. (in press, c) to have occurred at ca. 1845 Ma. The younger suite comprises crosscutting, gneissic to massive, monzodiorite to granite plutons. It is bracketed between $1842^{+5/-3}$–$1820^{+4/-3}$ Ma (Parrish, 1989; Machado et al., 1993; R. Parrish, personal communication, 1994; Scott, 1997; Scott and Wodicka, 1998) and is interpreted as having been emplaced in an Andean-type continental arc setting (Dunphy and Ludden, 1998; Thériault et al., 2001) following accretion of the arc terrane to the northern Churchill plate. St-Onge et al. (2002) have correlated the younger suite of Narsajuaq arc in northern Quebec and Baffin Island with the de 1.84–1.81 Ga de Pas batholith south of Ungava Bay (van der Leeden et al., 1990; Dunphy and Skulski, 1996; James and Dunning, 2000) based on a good correlation between bedrock geology units and residual total magnetic field data, available geochronological constraints, and petrological characteristics.

Plutonic, volcanic and sedimentary units correlative with those of the Narsajuaq arc terrane are not thought to occur in western and southern Greenland.

Lower plate Superior craton and northern margin

In northern and northeastern Quebec, and in western Labrador, the exposed lower-plate Archaean Superior craton (Figs 4–5) comprises dominantly felsic orthogneisses and plutonic units ranging in age between $3220^{+32/-23}$–$2654^{\pm5}$ Ma (Machado et al., 1989; Mortensen and Percival, 1989; Parrish, 1989; St-Onge et al., 1992; R. Parrish, personal communication, 1994; Scott and St-Onge, 1995; James and Dunning, 2000). In the Cape Smith belt of northern Quebec (Fig. 5), a suite of parautochthonous basal clastic sedimentary units, carbonatitic volcaniclastic rocks, and continental tholeiitic flood basalt and rhyolite (Povungnituk Group) associated with initial Paleoproterozoic rifting of the northern Superior craton unconformably overlies the felsic basement. These units have yielded ages between $2038^{+4/-2}$ –$1958.6^{+3.1/-2.7}$ Ma (Parrish, 1989; Machado et al., 1993). Stratigraphically overlying the initial-rift sedimentary and volcanic rocks is a younger succession of predominantly komatiitic to tholeiitic basalts (Chukotat Group) accumulated during renewed rifting along the northern continental margin and dated between $1887^{+37/-11}$–$1870^{\pm4}$ Ma (R. Parrish, personal communication, 1994; Wodicka et al., 2002a). The ages of the younger volcanic succession indicate that ca. 150 Ma elapsed between the onset of initial continental rifting and the subsequent rifting event (St-Onge et al., 2000).

Along the eastern margin of the Superior craton within the New Quebec orogen (Fig. 5), the tectonostratigraphic record (Hoffman, 1990a; Rohon et al., 1993; Skulski et al., 1993; and references therein) includes a parautochthonous succession of: (1) basal fluvial redbeds and mildly alkalic mafic lavas (Seward Subgroup) that are associated with initial Palaeoproterozoic rifting of the craton, (2) marine-shelf quartzite and dolostone (Pistolet Subgroup) that mark the establishment of a platform-type continental margin, (3) interstratified black shale and turbidites (Swampy Bay Subgroup) that interfinger eastward with tholeiitic basalts, gabbro sills, and rhyolites (Bacchus Formation) and are interpreted as a foredeep sequence, and (4) a regressive peritidal carbonate reef complex (Denault and Abner formations). Age constraints range between $2169^{\pm 2}$–$2142^{+4/-2}$ Ma (Clark, 1984; Rohon et al., 1993). The initial rifting assemblage is overlain by a succession of transgressive quartzite (Wishart Formation), which is in turn overlain by shale (Ruth Formation), banded iron formation (Sokoman Formation), coeval alkalic mafic to felsic volcanic rocks, tholeiitic sills, basalts, and turbidites (Menihek Formation), which are intruded by layered peridotite-gabbro-diorite sills and which collectively accumulated in pull-apart basins during renewed rifting along the established continental margin (Skulski et al., 1993). Age dates range between ca. $1884^{\pm 1.6}$–1870 Ma (Findlay et al., 1995; Machado et al., 1997). Thus ca. 292 m. y. separate the older and younger successions (cf. Skulski et al., 1993), and the establishment and subsequent rifting of the eastern margin of the lower plate Superior craton.

A south-verging tectonic boundary or crustal suture (Bergeron suture) separates the northern Superior margin strata from allochthonous crustal elements of the composite Churchill plate to the north (Fig. 5; St-Onge et al., 1999, 2001). Associated with and sitting in the hanging wall of the Bergeron suture are the crustal components of an obducted Paleoproterozoic ophiolite (Watts Group) dated as $1998^{\pm 2}$ Ma (Parrish, 1989), as well as the plutonic, volcanic and sedimentary components of the Narsajuaq arc (described above). Preservation of the ophiolite and the higher structural levels it represents within the Paleoproterozoic orogen is entirely a function of the late to post-collisional, crustal-scale, orogen-parallel folding and orogen-perpendicular cross-folding which characterizes the southern, lower plate margin of THO in northern Quebec (Lucas and Byrne, 1992). Closure of the Bergeron suture, and collision of the composite Churchill plate with the lower plate Superior craton is bracketed between $1820^{+4/-3}$ Ma (youngest component of Narsajuaq arc) and 1795±2 Ma (the age of an undeformed crosscutting syenogranite pegmatite dyke) (St-Onge et al., in press a).

Plutonic, volcanic and sedimentary units correlative with those of the lower plate Superior craton are not thought to occur in western and southern Greenland.

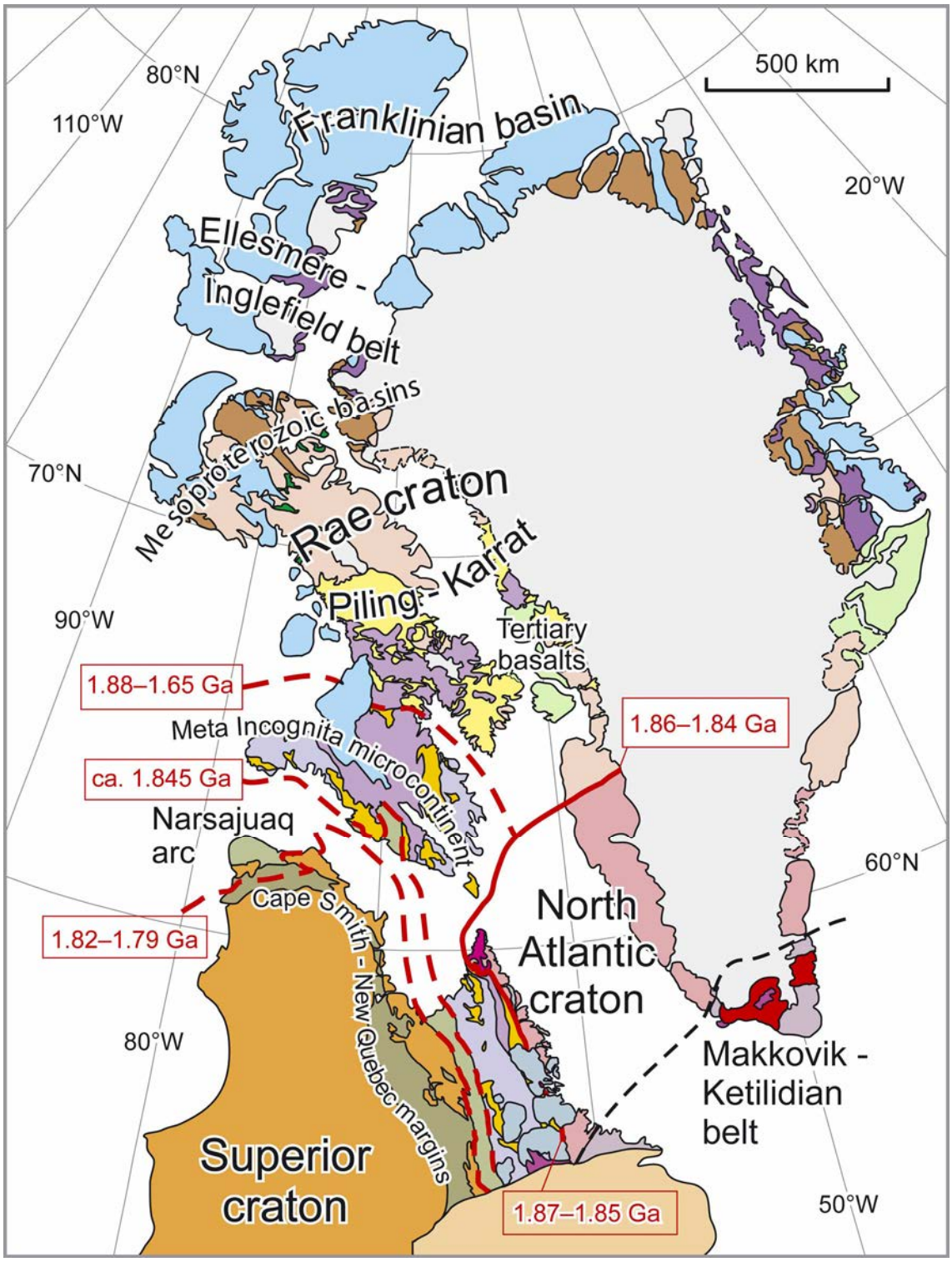

Figure 5. *Composite geological map highlighting the principal cratonic, supracrustal and tectonic entities that can be correlated from eastern Nunavut, Quebec, and Labrador to western Greenland (see text for explanation and references). Greenland is shown in a pre-drift (i.e. pre-Cretaceous) position with respect to northeastern Canada, following the re-construction of van Gool et al. (2004) and based on the geophysical data of Chalmers and Pulvertaft (2001). Lines of latitude and longitude are pertinent to the Canadian side. Palaeoproterozoic sutures are shown in red with known age constraints, and include the 1.82–1.79 Ga Bergeron suture described in the text. Note that the figure documents a systematic*

79 Ga Bergeron suture described in the text. Note that the figure documents a systematic north-to-south decrease in the age of suturing from the upper plate Rae craton to the lower plate Superior craton, and that with the alignment of the Tertiary basalts on either side of Davis Strait, all other units and structures of Palaeozoic, Mesoproterozoic, Palaeoproterozoic, and Archaean age in western Greenland and northeastern Canada follow suite. Colour scheme follows that of Figs 2–4.

Tectonic evolution of northeast Laurentia

The correlation of Archaean, Paleoproterozoic, and Mesoproterozoic bedrock units and structures between the eastern Canadian Shield and western Greenland as presented in this workshop report, allows the identification of an internally-consistent, north-to-south sequence of accretion and collision events. These tectonic events (itemized below) first resulted in the growth of the composite Churchill plate around the crustal nucleus provided by the Rae craton, which maintained an upper plate position for approximately 200 Ma. Initial assembly of the Churchill plate was then followed by collision with the lower plate Superior craton, which resulted in the Himalayan-scale Trans-Hudson orogen and consequently significantly added to the landmass of the emerging Laurentian craton.

Based on available tectonostratigraphic, structural, and geochronological data in eastern Canada and western Greenland, the sequence of tectonic events (and supporting tectonostratigraphic correlations – references provided in the text above) which characterize the tectonic evolution of northeast Laurentia are as follows:

1. Cratonization of the upper plate Rae craton by the late Archaean (2.7–2.6 Ga). *Tectonostratigraphic correlations include:* Thule mixed gneiss complex, Kap York meta-igneous complex, and Melville Bugt orthogneiss complex of northwest Greenland with the meta-plutonic units of the Rae craton of Baffin Island; Lauge Koch Kyst supracrustal complex of Melville Bugt with the Mary River Group of northern Baffin Island.
2. Deformation and magmatism along the northern margin of the upper plate Rae craton at ca. 1.96–1.91 Ga. *Tectonostratigraphic correlations include*: meta-sedimentary rocks of the Ellesmere-Devon terrane in Canada with the Etah Group of the Inglefield mobile belt in Greenland; meta-plutonic rocks of Ellesmere and Devon Islands with the Etah meta-igneous complex of Inglefield Land (NW Greenland).
3. Accumulation of a south-facing continental margin sequence along the southern margin of the upper plate Rae craton between ca. 2.16–1.88 Ga. *Tectonostratigraphic correlations include*: the Piling Group of central Baffin Island and the Hoare Bay Group of Cumberland Peninsula with the Karrat Group and Anap Nunâ Group of north-western Greenland; Naternaq supracrustal belt and Nordre Strømfjord supracrustal suite of central-western Greenland; specifically the following correlations can be made between the Piling Group and the Karrat Group: Dewar Lakes Fm – Qeqertarssuaq Fm; Flint Lake Fm – Mârmorilik Fm; Longstaff Bluff Fm – Nûkavsak Fm; Bravo Lake Fm – mafic volcanic member of Karrat Group.
4. North-south convergence and accretion of the Meta Incognita microcontinent to the southern margin of the upper plate Rae craton across the Baffin suture between ca. 1.88–1.87 Ga. *Tectonostratigraphic correlations include*: the Cumberland batholith of Baffin Island with the Prøven igneous complex of western Greenland, although it seems doubtful that the two plutonic complexes were generated precisely in the same way.

5. Collision of the upper plate North Atlantic craton with the southern margin of the Rae craton in Greenland between ca. 1.86–1.84 Ga (Nagssugtoqidian belt), and with the eastern margin of the Meta Incognita microcontinent in western Labrador and eastern Quebec between ca. 1.87–1.85 Ga (Torngat orogen). Complexities are identified in central West Greenland, where a microcontinent may separate the contiguous Rae and North Atlantic cratons. *Tectonostratigraphic correlations include*: the Archaean orthogneisses and supracrustal units of the Nain craton in Labrador with those of the North Atlantic craton of southwestern Greenland; the Paleoproterozoic Ramah, Mugford, and Snyder groups of northern Labrador with the Maligiaq supracrustal suite of western Greenland; the Burwell arc of northern Labrador with the Sisimiut charnockite suite of western Greenland.
6. Establishment of an active (Andean-type) margin along the southern margin of the upper plate North Atlantic craton in Labrador (Makkovik belt) and southern Greenland (Ketilidian belt) between ca. 1.89–1.80 Ga. *Tectonostratigraphic correlations include*: the Moran Lake and Post Hill groups of Labrador with the Vallen and Sortis groups of southwestern Greenland; possibly the Aillik Group of Labrador with the Julianehåb batholith of southern Greenland.
7. Accretion of Narsajuaq arc terrane to the southern margin of the upper plate composite Churchill domain at ca. 1.845 Ga. Plutonic, volcanic and sedimentary units correlative with those of the Narsajuaq arc terrane are not thought to occur in western and southern Greenland.
8. Collision of the lower plate Superior craton with the upper plate Churchill domain between ca. 1.82–1.795 Ga. Plutonic, volcanic and sedimentary units correlative to those of the lower plate Superior craton are not thought to occur in western and southern Greenland.
9. Accumulation of Mesoproterozoic rift sequences and emplacement ca. 1.3 Ga plutonic suites. *Tectonostratigraphic correlations include*: Borden basin of Baffin Island and Thule basin of Ellesmere Island, Devon Island, and north-western Greenland; Gardar Igneous Province of southern Greenland with the Seal Lake Group and Harp dykes of central Labrador; no counterparts of a similar scale to the Nain Plutonic Suite are identified in Greenland.

Future work

Based on the present state of knowledge, published geological map coverage, available geochronological constraints, and documented tectonostratigraphic/structural/petrological context, we have drawn below a partial list of areas and geological issues/questions in northeastern Canada and western Greenland that would benefit from modern field-based research and mapping in order to test/strengthen the correlations reviewed and presented here (ordered from north to south):

1. Hoare Bay Group of Baffin Island: whereas the Piling and Karrat groups can be correlated on a formation level, field-based mapping and research on Cumberland Peninsula is required to fully integrate the Hoare Bay group into this correlation;
2. Area between Foxe Basin and Cumberland Sound on Baffin Island: field-based mapping and research is required to test/document the proposed location of the Baffin suture;
3. Karrat Group, Anap Nunâ Group, Naternaq supracrustal belt, and Nordre Strømfjord supracrustal suite of western Greenland: detailed stratigraphic and detrital geochro-

nological work is required to test the proposed correlations between the Karrat and Anap Nunâ groups, and between the Naternaq and Nordre Strømfjord supracrustal belt/suite, and contrast with other sequences such as the Maligiaq supracrustal suite to further constrain the location of the Rae craton – North Atlantic craton suture; investigations of the Au potential of the upper Qeqertarssuaq Fm (in areas with the mafic member of the Karrat Group present) may be warranted given the proven gold potential of the upper Dewar Lakes/Bravo Lake Fm sequence on Baffin Island; of interest, gold has previously been reported from the volcanic member of the Karrat Group by Thomassen (1992) and Thomassen and Lind (1998); see also Steenfelt et al. (1998);

4. Rinkian and Nagssugtoqidian belts of western Greenland: completion of field-based structural work is required to further establish/test the kinematic and tectonic foreland–hinterland equivalence of these two (segments of) orogens; the crustal architecture in the transitional Disko Bugt area needs to be better understood before the location of the suture zone(s) can be further constrained.
5. Cenozoic evolution of Baffin Bay – Davis Strait – Labrador Sea: as outlined in van Gool et al. (2004) and discussed during the workshop, the correlation of the geology across Baffin Bay, Davis Strait and the Labrador Sea is hampered by the significant separation and offset of eastern Canada and western Greenland as a combined result of stretching of the continental crust, potential creation of ocean floor and transcurrent movements during the Cenozoic. Quantitative pre-Cenozoic plate reconstructions for this area, which are beyond the scope of this paper, are required to enhance/further the Precambrian tectonostratigraphic correlations presented here.

Acknowledgements

We are grateful to the Bureau of Minerals and Petroleum, Nuuk, Greenland, for hosting the workshop “Geology and Mineral Resources in Greenland and Eastern North America” in Kangerlussuaq, Greenland, October 3-7, 2005.The workshop provided a stimulating forum for discussing some of the ideas presented in this report, and for this we would like to sincerely thank all workshop participants for their contributions. Special thanks go to Hans Kristian Schønwandt (Bureau of Minerals and Petroleum, Greenland), Henrik Stendal and Marianne N. Nielsen (Department of Economic Geology, GEUS) for devising the idea behind the workshop and putting it into effect. Dick Wardle (Geological Survey, Newfoundland and Labrador) is thanked for reviewing and improving a first version of this report.

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Review of mineral resources in Greenland and eastern Canada - based on the workshop contributions

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An attempt to give an overview of the mineral resources in the Arctic Atlantic region is compiled in the Table 1. A despription of the dominating geological events and mineral occurrences of these time intervals are given below. The table is divided into uneven time intervals with the oldest known deposits at the bottom and the youngest deposits at the top of the table.

3800 – 3200 Ma

The Early Archaean is domininated by microcontinents, which is assembled to the Archaean North Atlantic Craton. Enclaves of supracrustal rocks (e.g. greenstone belts) are found within a mixed lithology of gneisses and granites. Banded iron formations are found in many places within the Archaean and reworked Archaean craton in Greenland e.g. in the Isua area, in the Disko Bugt area, in the Melville bugt area (Stendal *et al.* 2005). The age of the latter BIF is unknown. The Isukasia (Isua) iron deposit, northeast of Nuuk is a banded iron formation and probably the oldest banded iron formation (~3.7 Ga) in the world. Equivalent deposits in Labrador might be the banded iron formation (Nulliak) consisting of several belts of magnetite iron formation in gneisses at Saglek Fjord, Labrador (Ryan & Kerr, Abstract this report).

3200 – 2800 Ma

This period is dominated by rifting, active continental margins and magmatic intrusions. The lithologies are supracrustal sequences comprising felsic and mafic volcanics intercalated with siliciclastic rocks. These rocks include greenstone belts with gold and exhalative VMS occurrences both in Greenland and Labrador. A Greenland equivalent of the Hunt River and Florence Lake metavolcanic belt may be the Tartoq Group of southern part of the North Atlantic Craton (Wardle, Abstract this report). Layered intrusions having ultramafic to anothositic rocks are also common for both regions but only the Fiskenæsset region has the chromite-bearing intrusions. Both regions are carrying rubies.

2800 – 2500

In this period, a lot of granite intrusions occured in West Greenland especially between 2650 – 2500 Ma. Late Archaean greenstone belts, which are well represented on the North American side, are not known or absent (?) on the Greenlandic side. The greenstone belts worldwide at this age are known for both gold, iron formations and base metal deposits.

The greenstone belts are especially abundant in the Nunavut region (e.g. Baffin Island and western part of Nunavut). All the mineral deposits in the westernmost part of Nunavut are not listed in Table 1 (e.g. Lupin, Muskox, Coppermine). The gold occurrence hosted in the Archaean Woodburn Lake Greenstone belt, Meadowbank, Nunavut, is probably deposited in Palaeoproterozoic time (James *et al.*, Abstract this report).

The Attu gold occurrence lies within the southern part of the Northern Nagssugtoqidian Orogen related to a shear/mylonite zone striking along the contact between brown gneisses and Meso-Archaean (~3.1 Ga) layered amphibolites. The timing of gold mineralisation is interpreted as ~2650 Ma based on Pb-Pb isotopes, which corresponds to one of the granite intrusion episodes.

2500 – 2000 Ma

This period is geological diverse with extensive sedimentation (Karrat Group, West Greenland and Piling Group, Baffin Island), rifting (Kangâmiut dikes (~2040 Ma) and intrusions of granite, anorthosite and minor lamprophyre dikes in West Greenland. The mineral deposit potential is gold in the supracrustal rocks and SEDEX style Pb-Zn deposits in carbonates (e.g. Black Angel mine, West Greenland), copper-nickel known from pyroxenite and anorthosite intrusions (Labrador), and also possible diamond potential on Baffin Island and Labrador.

2000 – 1500 Ma

During this period the Nagssugtoqidian, Rinkian and Torngat orogeneses starts with rift-drift supracrustal sequences around the border to the North Atlantic Craton. Mineral occurrences comprise VMS, SEDEX and MVT style base metals (e.g. Moran Lake Group, Makkovik Province and Lersletten, West Greenland) and graphite deposits (e.g. Nordre Strømfjord supracrustal rocks, West Greenland and Tasiuyak gneiss, Labrador). During subduction and formation of calc-alkaline magmatism and volcaniclastic sediments minor occurrences of Fe-Ti-V, Cu-Ni-PGE and Au are known. During the main Nagssugtoqidian/Torngat metamorphism and deformation pegmatite formation is common in West Greenland. Contemporaneously on Baffin Island sapphires from Kimmirut are formed.

In South Greenland and in the Makkovik province, southern Labrador the juvenile Ketilidian/Makkovikian Orogeny with subduction calc-alkaline magmatism and sedimentation took place (~1860 – 1750 Ma). Both places are known principally for their uranium mineralization, but examples of molybdenum and base metals also occur. Recently the Ketilidian Orogen of South Greenland is discovered as a gold province (Stendal & Frei 2000) and contains also the only active gold mine in Greenland (Nalunaq Gold Mine). The gold bearing vein system is related the Julianehåb batholith formation. Emplacement of the various gold occurrences is considered to take place at the late stage of the batholith formation (1800-1770 Ma) before the intrusion of rapakivi granites (~1740 Ma). After the peak of the Palaeoproterozoic orogeneses only minor mineral occurrences are known such as uranium-molybdenum (see Table 1).

1500 – 1000 Ma

The main geological processes in this period are rifting and formation of sedimentary basins several places in Greenland (e.g. Thule Basin) and the equivalent in Nunavut is the Bylot Supergroup (~1200 Ma). The latter sequence hosts the Nanisivik Zn-Pb-Ag deposit, but the mineralization age is Ordovician (Sherlock *et al.* 2004). The peralkaline intrusions

occur both in eastern Canada (Labrador) and South Greenland (Gardar Province 1300 – 1120 Ma). Also the mafic intrusions in Labrador are important from an economic point of view. The latter contains the famous Ni-Cu troctolitic Voiseys Bay deposit (~1333 Ma). The alkaline rocks comprise special metals such as Zr-Y-Nb-Ta-REE-Be, U-Th and the Industrial mineral cryolite, Iviittut, SW Greenland.

1000 – 540 Ma

This period is dominated by rifting and deposition in sedimentary basins such as Eleonore Bay Supergroup in East Greenland. Sedimentary copper occurrences are common in sandstones and shales. Magmatic events comprises granites, carbonatites and kimberlite/lamproite dikes. Sarfartoq carbonatite, West Greenland carries Nb-Ta and phosphor. The kimberlite suite (~575 Ma) is highly potential for diamonds and contains both macro- and micro-diamonds both in West Greenland and Labrador. Epigenetic gold is known from Avalonian rocks within the Appalachian Orogeny e.g. Hope Brook, Newfoundland (~575 Ma).

540 – 150 Ma

Sedimentary basins of different ages occur in East Greenland and in North Greenland the Franklinian basin strikes through to Nunavut (Fig. 1). The carbonate rocks in the basins host MVT type Pb-Zn occurrences e.g. Polaris, Nunavut and minor occurrence in the Jameson Land basin, East Greenland. Sandstone hosts red-bed Cu in the Jameson Land basin and Pb-Zn occur in Lower Permian sandstone e.g. Blyklippen Mine, East Greenland. VMS occurrences are known from the island volcanic and sedimentary rocks (Dunnage zone of the Appalachian) from Newfoundland e.g. Buchans.
S-type granite intrusions in East Greenland (~425 Ma) have associated W-Sb-Au occurrences. Kimberlitic rocks ±diamonds occur both in eastern Canada and West Greenland. The Jurassic Qaqqaarsuk carbonatite (~170 Ma) with phosphor and REE mineralisation occur in the Maniitsoq region, West Greenland.

150 Ma – present

Sedimentary basins occur both on the east- and west-side of Greenland. In the same region extensive flood basalt are poured out in Tertiary times with possibility for Norilsk type Cu-Ni and PGE mineralisation. Intrusions are common but especially East Greenland is mentioned with the Skaergaard gabbro intrusion holding Pd-Pt-Au mineralisation (~55 Ma) and the alkali granite intrusions with porphyry Mo deposits e.g. Malmbjerget (~26 Ma). Nunavut has kimberlites with the potential for diamonds but the age of these kimberlites are uncertain.

Future work

Examples of prospective metallogenetic provinces in Greenland and northeastern Canada are related to different commodities. Some mineral deposits are straight forward to correlate between the regions but others are uncertain and need a lot of research to prove the correlation (see a few examples below). Further investigations of the mineral resource potential of the Arctic Atlantic region should be based on a combination of available geoscientific data, geo-statistical approach and modern field-based research to improve the correlation between Greenland and northeastern Canada.

- Gold and base metal metallogenetic provinces are both of Archaean and Palaeoproterozoic ages related to supracrustal rocks (greenstone belts). The Archaean gold-bearing regions in Greenland e.g. Disko Bugt, Nuuk and Sermiligaarsuk (Tartoq Group) regions needs a lot more field-based studies to do the right correlation to northeastern Canada. A much better understanding of the correlation of the Palaeprorterozoic supracrustal belts between the regions is strongly needed for evaluation of the mineral potential e.g. the Palaeoproterozoic supracrustal Karrat Group (West Greenland) and the Piling Group (Baffin Island) have both the potential for gold occurrences but much more detailed work is needed to verify the potential.
- South Greenland is designated as a metallogenetic gold province related to a certain metallogenetic epoch formed during the Ketilidian Orogen (~1800 Ma). This metallogenetic epoch can be compared with the Makkovik belt in Labrador but the present knowledge of the metallogeny in the two regions is not sufficient. Thus, more detailed work for a better understanding of the metallogenetic evolution (especially orogenic gold) in the two regions is recommended.
- The North Greenland sedimentary environment (Franklinian basin) is an important metallogenetic province for Zn, Pb and Ba and the sedimentary basin can be continued directly into Arctic Canada (Fig. 1). Both areas have already proven base metal deposits of SEDEX and MVT genetic types. The potential for more Zn, Pb and Ba deposits are favourable for these northernmost regions.
- Alkaline magmatic provinces are found both on both sides of Davis Strait and Baffin Bay. The potential for speciality metals in peralkaline rocks is great e.g. Gardar Province (South Greenland), Flowers River, Strange Lake and Letitia Lake Group (Labrador). Alkaline rocks such as kimberlites have positive indications for diamond potential in the whole Arctic Atlantic region. More age dating is needed to deduce which alkaline suites are the most favourable for diamonds.
- The Cu-Ni potential looks much better in northeastern Canada than in Greenland. In Greenland we still look for the counterpart to the Ni-Cu-Co Voisey's Bay Deposit in Labrador.

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Age (Ma)	Geological setting	Greenland (East = EG, North = NG, South = SG, West = WG)	Canada (NF = Newfoundland)
150 - present	Sedimentary basins, granitic and mafic in- and extrusions.	• Palaeogene magma provinces in the Disko Bugt region (WG) – flood basalts (Ni-PGE) • Porphyry Mo (Malmberget, EG ~26 Ma) • PGE-Au (Skaergaarden mafic intrusion, EG ~55 Ma)	• Kimberlite-hosted diamonds (age unknown), Nunavut
540 - 150	Sedimentary basins of different ages, granite intrusions (~425 Ma; EG). Island arc and platform sediments in Newfoundland (NF).	• Franklianian basin, Ellesmerian Orogeny, NG (~400 Ma) - SEDEX and MVT Zn-Pb • Caledonian Orogeny, EG (~425 Ma) – W-Sb-Au • Qaqqaarsuk carbonatite, WG (~170 Ma) – phosphor, REE. • Jameson Land Basin, EG - sedimentary deposits of Cu-Zn-Pb-Ba • Blyklippen, Pb-Zn veins in sandstone, EG • Kimberlites, Maniitsoq region, WG	• VMS Cu-Zn-Pb±Au in the Dunnage zone (e.g. Buchans), NF • MVT Pb-Zn in the Humber zone (e.g. Daniel's Harbour), NF • Polaris MVT Pb-Zn, Arctic Archipelago, Nunavut • Nanisivik Zn-Pb-Ag hosted in Bylot Supergroup (~1200 Ma) but mineralization is mid-Ordovician, Nunavut • Kimberlite-hosted diamonds (age unknown), Nunavut
1000 - 540	Rifting and sedimentary basins and intrusive granite ~900 Ma; carbonatite ~600 Ma and kimberlite ~570 Ma)	• Eleonore Bay Supergroup, EG - sedimentary Cu • Sarfartoq carbonatite, WG - Nb-Ta, phosphor • Kangerlussuaq/Maniitsoq kimberlite suite, WG - diamond	• Epigenetic Au in the Appalachian Avalonian rocks e.g. Hope Brook, NF (~575 Ma) • Diamonds, ultramafic lamprophyres/kimberlites (584-550), Makkovik and northern Labrador-Quebec
1500 - 1000	Rifting, sedimentary basins, magmatic alkaline intrusions. Grenville Orogen (Labrador).	• Thule Supergroup, NG; Krummedal Group EG, Independence Fjord Group, NG, Eriksfjord Formation,(SG - all with only minor mineral occurrences (e.g. Cu). • Gardar province, SG (1300-1120 Ma) – cryolite, Nb-Ta, Zr, REE and U-Th	• Zr-Y-Nb-REE-Be, Strange Lake peralkaline granite, Labrador (1240 Ma) • Seal Lake Group (1250 Ma) Cu of Redbed type and later veining, Labrador • Zr, Mo, Zn, Nuiklavik volcanics and Flowers River peralkaline intrusions (1292-1270 Ma), Labrador • Peralkaline syenites Be-Nb-Y, Letitia

			Lake Group (1327 Ma), Labrador • Voisey's Bay Deposit Ni-Cu-Co (1333 Ma), Labrador • Ni-Cu, Pants Lake intrusion, southern NPS (1333 Ma) Labrador • Magmatic-hosted Ni-Cu, Harp Lake (1460 Ma), Labrador • U remobilized (Bruce River Group), Labrador
1775 – 1500	Post orogenic cooling of the Nagsoqtoqidian Orogen from c. 600 to 400ºC. Rapakivi intrusion (SG). Post-orogenic granites (1760-1740 Ma), Labrador. Labradorian plutonism and volcanism (1710-1655 Ma) Labrador.	• Hydrothermal activity in the region from 66º to 71ºN. Albitisation in Disko Bugt area, WG - mainly minor sulphide showings with minor base metal contents but elevated gold contents	• Intrusion/volcanism-related U-Mo (1665-1650 Ma), Central Mineral belt (Makkovik, Bruce River), Labrador • Urananium occurrences in Palaeoproterozoic Thelon Formation (sandstone), Nunavut
1870 – 1775	Main Nagssugtoqidian metamorphism and deformation. Pegmatite formation ~1800 Ma. Ketilidian-Makkovikian Orogeny with subduction and calc-alkaline magmatism. Torngat orogenesis.	• Remobilization of metals during metamorphism and deformation in the whole region. Monazite and allanite in pegmatite, WG. • Orogenic Au in the Ketilidian, SG • Magmatic Ti-V-Cu-Ni, EG • graphite in supracrustal rocks,SG • Strata-bound and epigenetic U, SG	• Sapphires from Kimmirut, Baffin Island • Strata-bound and epigenetic U (1860 – 1810 Ma); Makkovik, Labrador • Orogenic Au, Makkovik, Labrador • Au in Archaean Woodburn Lake Greenstone belt, Nunavut (e.g. Meadowbank (deposition of Au probably Palaeoproterozoic in age)
1920 – 1870	Subduction and calc-	• Arfersiorfik diorite and Sisimiut charnockite,	• Cu-Ni-PGE, Lake Harbour Group, Baffin

	alkaline magmatism (Nagssugtoqidian Orogen). Volcaniclastic sediments (Torngat Orogen).	WG – Hydrothermal activity with minor oxide occurrences (Fe-Ti-V)	Island (~1880 Ma) • Graphite in Tasiuyak gneiss, Labrador • Au in Tasiuyak gneiss, Labrador
2000 – 1920	Drifting and sedimentation (Nagsoqtoqidian Orogen) Rift-drift supracrustal sequences around border of Nain province (North Atlantic craton).	• Supracrustal rocks with exhalative volcanic massive sulphides (IF, Cu-Zn, Au), Nordre Strømfjord, Lersletten and Ataneq, WG • Graphite in mica schist/gneiss associated with sulphides, WG	• Epigenetic Pb-Zn, Moran Lake Group • SEDEX-style Zn, Moran Lake Group, Makkovik Province • U, MVT Pb-Zn, and SEDEX?, Ramah, Mugford and Snyder groups, Labrador
2500 - 2000	Rifting, epicontinental marginal basin and carbonate shelf; mafic dyke swarms, granite, anorthosite, and minor lamprophyre intrusions in Labrador.	• Kangâmiut dykes, WG (~2040 Ma) (Cu) • SEDEX Zn-Pb Black Angel Mine, WG • Minor Au in the Karrat Group, WG	• Cu-Ni in pyroxenite and anorthosite, e.g. Okak Bay area, Labrador • Cu-Ni in Churchill Province gneisses, Labrador • Au in Piling Group, Baffin Island • Diamond, Baffin Island • Diamond potential?, Nain area, Labrador
2800 - 2500	Granite intrusion into gneiss.	• Intrusive related Au (~2650 Ma), Rifkol granite, WG	• Banded iron formation, Mary River Group, Baffin Island • Au potential in sulphide-facies iron Formation, Mary River Group, Baffin Island • Au in Archaean Woodburn Lake Greenstone belt, Nunavut e.g. Meadowbank (deposition og Au probably Palaeoproterozoic in age)
3200 - 2800	Rifting or active continental margin and magmatic intrusion.	• Disko Bugt Craton, WG - Exhalative VMS and hydrothermal activity (Cu, Zn, Pb, Au, BIF) • North Atlantic Craton, WG - greenstones with Au in Nuuk region	• Florence Lake metavolcanic belt (Baikie Sub-belt), komatiite-hosted ‘Kambalda’ Ni-Cu (Labrador) • Florence Lake metavolcanic belt (Knee

		• North Atlantic Craton, WG - greenstones with Au and exhalative VMS (Tartoq Group) • Norite Belt with Cu-Ni-PGE (Maniitsoq, WG) • Fiskenæsset anorthosite complex, WG with Cr and Sinarsuk gabbro with Fe-Ti-V • Rubies, Fiskenæsset and Nuuk regions, WG	Lake area), greenstone-hosted VMS-style Zn-Cu-Pb-Au-Ag (Labrador) • Cr, PGE, Cu-Ni, layered mafic intrusions of the Nain Province, Labrador • Corundum (rubies), paragneisses of the Nain area, Labrador
3800 - 3200	Rifting, ocean floor basalts and sedimentation and/or continental rift/active continental margin.	• Melville Bugt, WG - BIF • Isua supracrustal rocks, Nuuk region, WG - BIF; Au	• Banded iron formation (Nulliak) at Saglek Fjord, Labrador

Table: Review of mineral deposits in the Arctic North Atlantic region.

Workshop Abstracts

Archaean terranes in the North Atlantic Craton, southern West Greenland: lithologies, age components, and problems of correlation at terrane level with the Archaean of Labrador

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The Archaean North Atlantic craton (NAC) in Greenland was contiguous with the Nain Province in Labrador prior to the opening of the Labrador Sea, and in some reconstructions the two blocks have been placed directly adjacent to each other. However, the most recent reconstruction prior to the opening of the Labrador Sea points to a wide gap of unexposed continental crust under the present Labrador Sea about 400 km wide. This gap effectively prevents a direct correlation of individual geological units between the NAC and Nain Province, despite known examples of parallel crustal evolution within the two blocks.

The most intensely studied and best known part of the North Atlantic craton is the Nuuk region, which consists of a complex, mid-crustal collage of different, early to late Archaean tectono-stratigraphic terranes with individual crustal components and geological evolutions, outlined by Garde (2003). Seven terranes have so far been identified in the Nuuk region (Fig. 1), although several of their boundaries are still poorly known or need revision. The crustal architecture to the north and south of this region has only been established at reconnaissance level.

Early Archaean crust (3.86–3.6 Ga in age) occurs in the Færingehavn and Isukasia terranes south-east and north-east of Nuuk, and in the Aasivik terrane with poorly known extent c. 200 km north-north-east of Nuuk (Fig. 1). The oldest rocks in West Greenland are 3860 Ma orthogneisses of the Færingehavn terrane (formerly called Amîtsoq gneisses), which also contains small enclaves of supracrustal rocks. The geographically separate Isukasia terrane is somewhat younger but contains the famous, c. 3.8 Ma Isua greenstone/supracrustal belt which remains the largest coherent piece of early Archaean rocks formed at the surface of the Earth. Both terranes contain fragments of mid-Archaean Ameralik dykes. The Aasivik terrane south of Kangerlussuaq only comprises c. 3.7 Ga orthogneisses.

The mid-Archaean Akia terrane north-west of Nuuk contains a c. 3.2 Ga core in granulite facies surrounded by supracrustal rocks and younger orthogneisses c. 3.05–2.97 Ga in age including members formerly called Nûk gneiss, besides slightly younger granitic rocks remobilised from the orthogneisses. An andesitic island-arc component of a large supracrustal belt near Nuuk has recently been dated at 3.07 Ga. The northern boundary of the Akia terrane is poorly known, and another terrane of late Archaean age may be present south of Kangerlussuaq. The c. 3.07–2.96 Ga Kapisillik terrane east of Nuuk was estab-

lished in 2005 (Friend & Nutman 2005). As it contains similar components and lithologies as the younger parts of the Akia terrane, it may be a rifted part of the latter.

The Tre Brødre and Tasiusarsuaq terranes east and south-east of Nuuk are composed of late Archaean rocks. The main components of the amphibolite facies Tre Brødre terrane are 2.82 Ga Ikkattoq orthogneisses and disrupted layers of a large anorthosite complex. The Tasiusarsuaq terrane tectonically overlies the Tre Brødre terrane and extends at least 100 km to the south. the bulk of the Tasiusarsuaq terrane comprises c. 2.92–2.86 Ga orthogneisses (in part retrogressed from 2.795 Ga granulite facies metamorphism), a major body of granodiorite emplaced under granulite facies conditions, and the large Fiskenæsset anorthosite complex with layered chromitites and occurrences of ruby. Large supracrustal belts dominated by metavolcanic amphibolite in amphibolite facies occur at Bjørnesund and Ravn Storø (Fig. 1). Two or three additional terranes are present to the south between the Tasiusarsuaq terrane and the northern front of the Palaeoproterozoic Ketilidian orogen. One of these contains the >3.0 Ga Târtoq Group composed of metavolcanic greenstones with low-grade gold mineralisation.

It will be apparent from the foregoing descriptions that despite their individual ages and characters each terrane of the NAC typically comprises four main components: a) orthogneisses which form the bulk of the crust, b) enclaves of older, predominantly mafic crust and oceanic arcs, c) granitic rocks mobilised from the orthogneisses, and d) basic dykes in variable states of preservation witnessing episodes of rifting within each terrane. Most terranes are exposed at upper amphibolite to granulite facies corresponding to relatively deep crustal levels. Accordingly, their supracrustal components are not greenstones s.s. although they have been termed so in some publications in order to emphasise lithological similarities with low-grade greenstones in other Archaean cratons.

The orthogneisses are largely of tonalite-trondhjemite-granodiorite (TTG) type and are believed to have formed by partial melting of wet oceanic crust in plate-tectonic subduction environments. It has recently been shown that the orthogneisses also comprise dioritic members, which contain components of mantle wedge material which has been variably contaminated by carbonatite (Steenfelt et al. 2005).

The supracrustal components have probably largely been derived from mafic oceanic or back-arc crust, and mainly consist of amphibolite to granulite facies tholeiitic metavolcanic rocks and associated layered mafic-ultramafic intrusions and anorthosite complexes. Andesitic amphibolite has previously been described from the Bjørnesund area in the southern Tasiusarsuaq terrane 100–150 km south of Nuuk, and another relict andesitic arc has recently been discovered in the eastern Akia terrane 50 km north of Nuuk. These relics point directly to subduction-related primary arc environments which may be more prospective for gold and VMS deposits than the tholeiitic metavolcanic and metagabbroic components of the supracrustal rocks. Gold mineralisation at Storø near Nuuk has previously been interpreted as epigenetic and shear-zone related, but ongoing studies may lead to a reinterpretation. PGE and chromite mineralisation (although not yet identified in economic quantities) is known from mafic igneous rocks in both the Akia and Tasiusarsuaq terranes, and an olivine mine for industrial use was opened in 2005 in a basal cumulate member of a large layered intrusion.

Besides metavolcanic and intrusive mafic and anorthositic complexes, the youngest terranes also comprise metasedimentary units derived from contemporaneous continental crustal terranes and/or from andesitic arcs that no longer exist. Such rocks are also typically trapped at the boundaries of the individual terranes.

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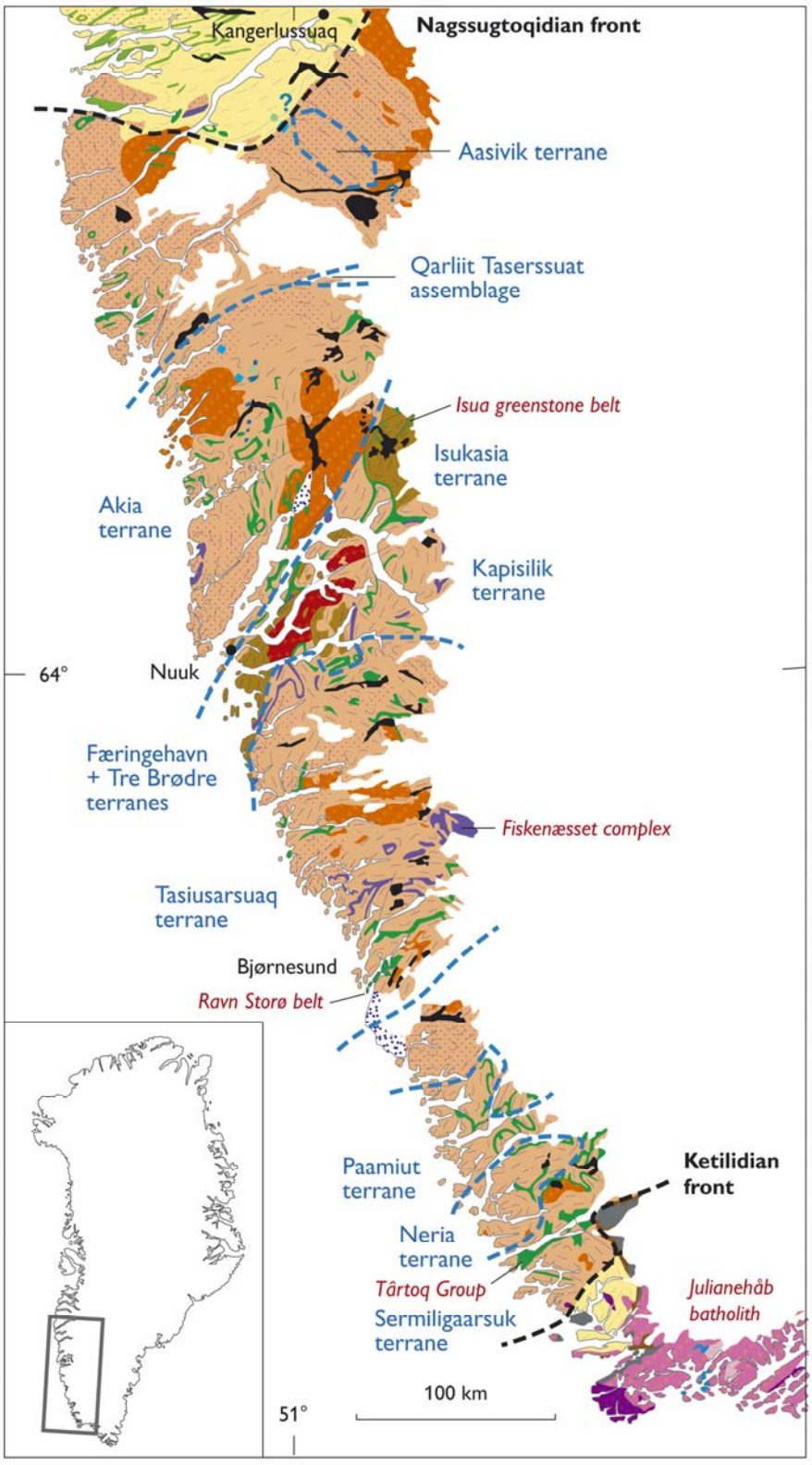

Figure. 1. *Tectono-stratigraphic terrances of Archaean age and simplified terrane boundaries (shown in blue) in the North Archaean Craton of southern West Greenland. Modified from Geological Map of Greenland, scale 1:2 500 000 (Escher & Pulvertaft 1995, with information from Nutman et al. 2004 (Precambrian Research 135, 281-314).*

Meso- and Neoarchaean supracrustal belts and collisional tectonism in the Nuuk region, southern West Greenland: constraints from U–Pb zircon geochronology

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The Archaean Craton in the Nuuk region of southern West Greenland has previously been divided into several crustal terranes, which were amalgamated in the period 2980–2700 Ma. Each of these experienced distinct tectonometamorphic histories prior to their amalgamation. We present new laser ablation ICPMS U–Pb zircon geochronology data for Archaean crustal components in the Nuuk region. This study was carried out to place timing constraints on the formation of gold-bearing supracrustal belts in this region, and on the development of major structures controlling their present distribution. The data also constrain some of the major sources of the dominant Meso- and Neoarchaean supracrustal rocks, and thus the proximity of different crustal components during their deposition. These data and the tectonic mechanisms invoked here may also have implications for understanding the Meso- and Neoarchaean tectonic evolution of the Saglek block, Labrador.

We present new evidence for Neoarchaean collisional tectonism that involved tectonic interleaving of distinct Archaean crustal components, first by major thrusting and then by folding and shear zone formation. Our data build on evidence for a c. 3070–3050 Ma (now dismembered) island arc complex formed synchronous with crustal growth via emplacement of tonalitic to granodioritic magmas in a subduction-related setting. Metamorphic zircon growth indicates that the arc and related magmatic rocks experienced granulite to amphibolite facies conditions at c. 2980–2960 Ma, possibly a consequence of emplacement of the voluminous Tasersuaq felsic pluton. Widespread Neoarchaean arc volcanism and deposition of volcanoclastic sediments occurred during and shortly after crustal growth via accretion of tonalitic magmas at c. 2840–2825 Ma. Dating of detrital zircon populations reveals that the Neoarchaean sedimentary and volcanoclastic rocks were dominantly derived from a c. 2900 Ma source – probably the Tasiusarsuaq tonalitic gneiss suite, which is now also recognised in a thin tectonic panel in the central Nuuk region. Meso- and Neoarchaean supracrustal rocks and orthogneisses were then tectonically interleaved along thrusts in the period 2800–2700 Ma. The Neoarchaean metasedimentary and metavolcanoclastic rocks show evidence of c. 2700 Ma amphibolite facies metamorphism, synchronous with widespread granitoid emplacement during collisional amalgamation of the different Palaeo-, Meso-, and Neoarchaean crustal blocks. Subsequent NW-directed thrust

shear zones and associated folds were probably predominantly formed at c. 2630 Ma during continued convergent tectonism. The widespread c. 2830 Ma magmatism and volcanism, sedimentation at < 2800 Ma, and subsequent punctuated thermal activity from c. 2740 to 2630 Ma indicates a cycle of Neoarchaean subduction-related magmatism and subsequent collisional tectonism at a time when Palaeo-, Meso-, and Neoarchaean sources were in close proximity.

The SE Churchill Province (Labrador/Québec) and the Rae domain (Nunavut), Canada: some thoughts on history and metallogeny

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When first defined, the Churchill Province was thought of as that vast region of the Precambrian Canadian Shield remaining after better defined older and younger structural provinces had been delineated. Today, we recognize the Churchill Province as a composite of Paleoproterozoic collisional orogens and intervening lithotectonic domains, including Archean and Paleoproterozoic components, formed and assembled between intact Slave, Superior and North Atlantic (Nain) cratons. This presentation will examine two components of the Churchill Province in eastern and northern Canada: the Southeast Churchill Province on the Labrador - Québec peninsula, and the Rae domain in central Nunavut. In addition, we will discuss some aspects of the late Paleoproterozoic (1.8-1.6 Ga) geology of southern Labrador.

The Southeast Churchill Province

The Southeast Churchill Province represents one segment of the circum-Superior system of Paleoproterozoic orogens assembled between obliquely colliding Superior and North Atlantic cratons between ca. 1.86 and 1.80 Ga. This segment has a broadly tripartite architecture consisting of (from west to east): 1) a west-verging fold-and-thrust belt (New Québec Orogen) developed in 2.17-1.86 Ga sedimentary and volcanic cover rocks, and involving pervasively reworked Superior craton basement, 2) a medial hinterland that is a composite terrane having Archean and Paleoproterozoic components, and 3) a doubly-verging, fan-shaped wedge (Torngat Orogen) developed primarily in juvenile (<1.95 Ga) Paleoproterozoic sediments and minor amounts of reworked North Atlantic craton crust, and interpreted as an accretionary complex along the suture between the medial hinterland and the North Atlantic craton. Steeply-dipping dextral (west) and sinistral (east) transcurrent shear zones, that are synchronous- to post-tectonic with respect to thrusting in the New Québec and Torngat orogens, respectively, separate the bordering 'foreland' orogens from the medial hinterland, which is informally defined as the Core Zone.

The southern Core Zone is a mosaic of variably reworked Archean crustal blocks, metamorphosed Paleoproterozoic supracrustal rocks, and plutons of 1.84 to 1.81 Ga megacrystic granite and charnockite belonging to the De Pas batholith. Intrusion of De Pas batholith rocks pre-dates and overlaps with ca. 1.82 to 1.78 Ga high-grade metamorphism and attendant deformation in the southwestern Core Zone. Assembly of constituent blocks that

make up the southwestern Core Zone by 1.81 Ga is predicted to coincide with the onset of thrusting in the New Québec Orogen.

Affinity of Archean crust in the Core Zone is a critical problem having significant implications for developing Paleoproterozoic tectonic models for the region. Archean rocks in the southern Core Zone, including intrusive and supracrustal components, have broadly similar ages as rocks in the northeast Superior craton, although the geochronological data provide only circumstantial (and probably misleading) evidence of their parentage. However, their origin notwithstanding, Archean crustal blocks are interpreted to have acted as independent tectonic units relative to the bounding Archean cratons during Paleoproterozoic assembly.

Paleoproterozoic sedimentary rocks of the New Québec Orogen contain a significant iron ore resource for Canada. In addition, widespread showings of sulphide mineralization suggest the New Québec Orogen also has potential for SEDEX and Besshi-type mineralization, Ni-Cu-PGE mineralization in gabbro, and structurally controlled Au mineralization.

The Core Zone has not been a traditional target for mineral exploration, although occurrences of Archean and Paleoproterozoic metavolcanic rocks may have some potential for hosting volcanic associated base- and precious-metal mineralization. Paleoproterozoic mafic intrusions in the western part of the Core Zone may have potential for Ni-Cu-PGE sulphide mineralization.

Composite Mesoproterozoic (ca. 1.46 Ga) anorthosite-gabbro bodies (e.g., Michikamau and Harp Lake intrusions) that intrude the Core Zone have potential for Ni-Cu-Co-PGE mineralization. These bodies received a significant amount of exploration interest prior to and following discovery of the Voisey's Bay Ni-Cu-Co deposit hosted by the Mesoproterozoic Nain Plutonic Suite.

The Southeast Churchill Province may have some potential for hosting diamond-bearing kimberlitic rocks. The Archean crust in the Core Zone has been variably reworked by Paleoproterozoic metamorphism and deformation, although the affects of this reworking on the lithosphere and potential 'diamond reservoir' are uncertain. Multiple occurrences of diamondiferous kimberlites, which intrude reworked Archean rocks in the Rae domain, suggest the Southeast Churchill Province should not be casually dismissed as an exploration target for diamonds.

In marked contrast to pre-1.8 Ga growth of Laurentia, which is effectively accomplished by assembly from Archean components, the late Paleoproterozoic from ca. 1.8 to 1.6 Ga is characterized by a significant addition of juvenile continental crust to the southern margin of Laurentia, forming a belt that truncates the system of Paleoproterozoic circum-Superior orogens, including the Southeast Churchill Province. In detail, the new crust includes an extensive belt of pre-1.7 Ga metasedimentary rocks having psammitic and pelitic protoliths, ca. 1.65 Ga plutonic rocks belonging to the >500-km-long Trans-Labrador batholith, and 1.65-1.62 Ga mafic intrusive complexes. In addition, this period included formation of 1.65 Ga volcanic and related sedimentary rocks (e.g., Bruce River and Blueberry Lake groups) that were deposited unconformably along the southern margin of pre-1.65 Ga Laurentia. These rocks are overprinted by the ca. 1.7-1.6 Ga Labradorian Orogeny. This episode of

continental growth, recognized sporadically from the southwestern United States to western Norway and southern Sweden, marks a fundamental shift in the construction of Laurentia after 1.8 Ga.

The Rae Domain

Similar to the Southeast Churchill Province, the northwest Churchill Province of north-central Canada, has a broadly tripartite, Paleoproterozoic architecture including (from northwest to southeast): 1) the 2.0-1.9 Ga Thelon-Taltson Orogen, 2) a composite internal zone, and 3) the 1.9-1.8 Ga Trans-Hudson orogen. The internal zone, which forms the 'upper plate' to the bounding orogens, is subdivided into Rae and Hearne domains. The Rae domain, which is featured in this discussion, is a northeast-striking division that is exposed for almost 2000 km from central Canada to northeast Baffin Island.

The Rae domain consists of reworked Archean crust and Paleoproterozoic supracrustal rocks. The Archean crust mainly includes 2.72-2.68 Ga greenschist- to amphibolite-facies supracrustal belts intruded by ca. 2.7-2.57 Ga felsic plutons, although local evidence for >2.8 Ga crust is preserved. In addition, Nd/Sm isotopic evidence from the northeast Rae domain suggests cryptic internal divisions of the Rae consisting of fundamentally different Archean blocks. The supracrustal belts, including rocks of the Woodburn, Prince Albert and Mary River groups, are locally characterized by basalt, komatiite and associated quartzite. Locally, iron formation represents a significant component of Mary River Group rocks on Baffin Island, and is of significant economic interest. The Archean rocks are locally overlain by deformed and metamorphosed, >1.9 Ga Paleoproterozoic sedimentary rocks (e.g., Amer, Chantrey, Penrhyn and Piling groups) including sequences of quartzite, marble, iron formation, and pelitic rocks, and younger, <1.8 Ga rocks of the Baker Lake, Thelon and Athabasca groups.

The Rae domain is variably overprinted by ca. 2.35 and 1.85 Ga tectonothermal events (Berman et al., 2005, Canadian Mineralogist, V. 43, p. 409-442) inferred to be related to 'far-field' reworking of the internal zone. The younger metamorphism is most easily associated with the temporally equivalent Trans-Hudson orogeny, although the 2.35 Ga event is somewhat enigmatic. The regional extent and significance of Paleoproterozoic reworking is undefined, although occurrences of deformed, high-grade Paleoproterozoic supracrustal rocks in several areas indicate at least local, pervasive reworking of the Archean Rae rocks.

The Archean supracrustal rocks, particularly in the central part of the Rae domain, have significant potential for Paleoproterozoic and Archean gold mineralization. In particular, the Meadowbank gold deposits, occurring in Woodburn Lake Group rocks, represent one of the largest undeveloped gold reserves in Canada, containing approximately 3.2 million ounces (measured and indicated). Northwest and north of the Meadowbank deposits, ongoing exploration in the 300-km long Committee Bay greenstone belt has resulted in more than 50 new gold discoveries. Paleoproterozoic supracrustal rocks also have promising potential for gold mineralization in association with silicate-facies iron formation (e.g., Piling Group, Bravo Lake Formation) and are the focus of exploration on Baffin Island.

The recent discovery of diamond-bearing kimberlites, which intrude Rae domain crust and local Paleozoic cover, has generated a significant exploration rush in Nunavut. To date, the most promising occurrences of diamondiferous kimberlite bodies are on the Melville Peninsula in central Nunavut. The degree of Paleoproterozoic reworking of Archean Rae crust and subcontinental lithosphere is uncertain, although the unequivocal occurrence of diamonds indicates a cool mantle root, providing a ‘diamond reservoir’, was preserved under parts of the Rae domain.

A pre-Mesozoic reconstruction of Greenland and eastern Canada: closing the Labrador Sea - Davis Strait - Baffin Bay

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Correlation of the geology across the Labrador Sea and Davis Strait is hampered by the separation as a combined result of stretching of the continental crust, creation of ocean floor, and transcurrent movements. Furthermore, hundreds of kilometres of continental crust are presently submerged which further complicates the correlation.

The Labrador Sea was formed during a series of events, of which the most important ones are the following:

1. Mesozoic (mainly Cretaceous) to early Palaeocene: stretching and thinning of the lithosphere. The direction was approximately NE–SW, and stretching factors (width after stretching/width before stretching) are in the order of 2–3.
2. Palaeocene, 61–55 Ma, geomagnetic chron 27n–24r (sea floor linear magnetic anomaly 27 normal to 24 reversed). Continental break-up, drift, and formation of ocean floor; direction approximately NE–SW.
3. Eocene, 55–33 Ma, geomagnetic chron 24r–13. Continued continental drift and formation of ocean floor, but with the direction changed to NNE–SSW to almost N–S. Strong transcurrent movements along the Ungava transform fault zone. Spreading between Canada and Greenland stopped around geomagnetic chron 13, c. 33 Ma.

Many aspects of these events are well constrained, but others are not. In particular, accurate rotation poles for the movements of the continental plates are not agreed on, mainly because of plate deformations in the northern areas, and this has prevented agreement on quantitative plate reconstructions back in time. Moreover, the Baffin Bay area remains relatively poorly known.

We have based our reconstruction on the latest geophysical data from GEUS and Canadian co-workers (Chalmers & Pulvertaft 2001). The present configuration of the sea floor is as shown in Fig. 1. We have then simply gone mechanically through the steps 3–2–1 mentioned above and successively removed the sea floor, then overlapped the thinned continental margins to adjust for the stretching during phase 1. Constraints from the Labrador Sea and Davis Strait were used, whereas the areas around Baffin Bay passively followed suit.

The resulting pre-Mesozoic reconstruction is shown in Fig. 2. The net movement of the two coast lines is nearly 600 km in SSW–NNE direction, and they end up being nearly parallel with 300–400 km separation. This leaves a considerable gap, underlain by the presently submerged and stretched continental crust, which is twice the presently exposed width on land in Greenland, and across which the geology has to be correlated.

At first inspection, it is only the Ketilidian and Makkovikian fronts of similar Palaeoproterozoic age that align in this reconstruction. The Mesoproterozoic Gardar dykes in South Greenland and the contemporaneous Harp dykes in Labrador straddle the northern Makkovik/Ketilidian front, but occur on opposite sides of it. The eastern continuation of the Grenville front runs south of Greenland. The Palaeoproterozoic Torngat and Nagssugtoqidian orogens are almost at right angles and their correlation is not significantly enhanced by this geometric reconstruction; however, a strong correlation can me made based on geochronology and tectono-stratigraphy. The geometries of Archaean terranes in the North Atlantic craton and Nain Province are not as well defined and often of much smaller dimensions. None of these terranes can be traced across the gap, but an overall correlation of Archaean geology is definitely possible.

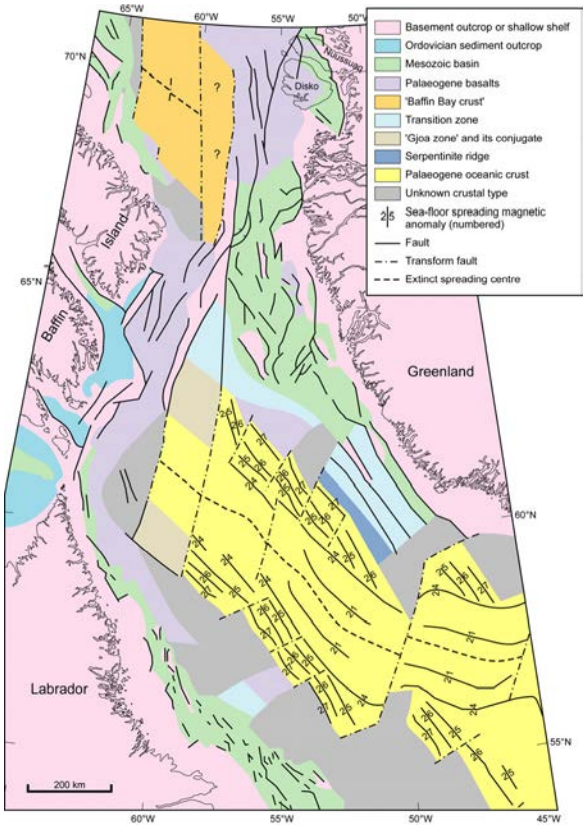

Figure 1. *Present configuration of the Labrador Sea–Davis Strait region, from Chalmers & Pulvertaft (2001). The data in this figure were used for the geo- metric reconstruction of Labrador and Greenland prior to rifting.*

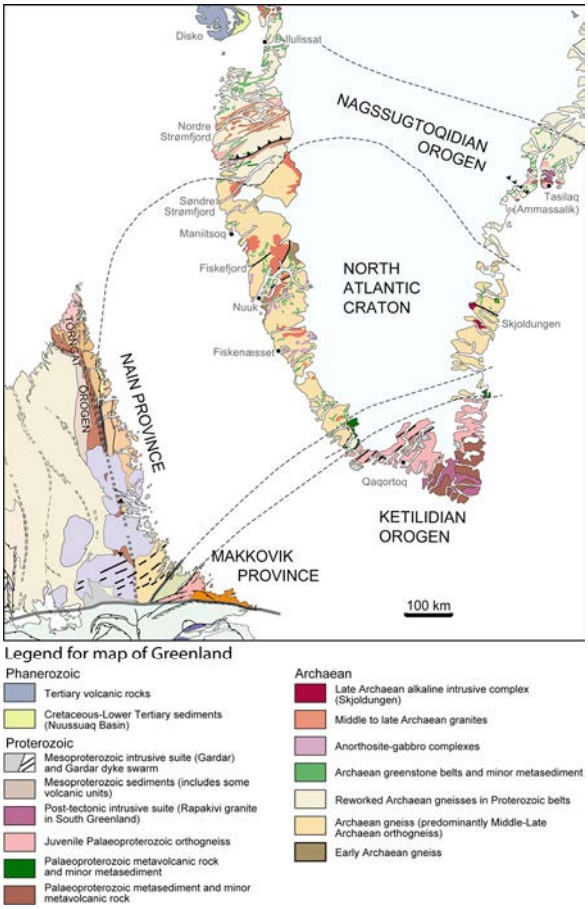

Figure 2. *Reconstruction to pre-Mesozoic time of the southern West Greenland – north-eastern Labrador region.*

Reference

Chalmers, J.A. & Pulvertaft, T.C.R. 2001: Development of the continental margins of the Labrador Sea: a review. In: Wilson, R.C.L. et al. (eds.): Non-volcanic rifting of continental margins: a comparison of evidence from land and sea. Special Publication, Geological Society, London 187, 77–105.

A review of bedrock and economic geology of northern Labrador

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Introduction

Northern Labrador comprises rocks ranging from the Early Archean (>3700 Ma) to the Mesoproterozoic (ca. 1240 Ma). Represented in these rocks is a spectrum of Earth processes, including granulite-facies gneisses related to continental collision, bi-modal plutons related to incipient crustal rifting, and ignimbrite blankets from subaerial volcanism. The compositional spectrum encompassed by the rocks runs the gamut from ultrabasic to peralkaline. The economic geology of the region reflects these diverse tectonic settings and rock compositions. A synopsis of the geological framework, the inferred tectonic settings of the major subdivisions, and the mineral commodities of northern Labrador is provided below. The information synthesized here has been extracted from numerous published and unpublished sources.

Archean rocks of the coastal region – the Nain Province:

General Geology: The Archean rocks of northern Labrador, forming the Nain Province, are a westward extension of those found along the west coast of south-central Greenland, representing the westernmost remnant of the fragmented North Atlantic Craton. Like most of the Greenland Archean block, the Labrador rocks are polydeformed, amphibolite- to granulite-facies gneisses that reflect a diversity of environments and geological processes. By far the largest component comprises quartzofeldspathic gneisses derived from plutonic protoliths. Interlayered with these felsic orthogneisses are other gneisses derived from layered basic intrusions, from sedimentary rocks, and from volcanic rocks. Unlike the Greenland part of the North Atlantic Craton, amalgamation of differing lithological "packages" along discrete tectonic boundaries has not yet been demonstrated in Labrador, but no serious effort to systematically investigate the Nain Province from this perspective has been undertaken. From a regional perspective, the Nain Province has been subdivided into a southern half referred to as the Hopedale block and a northern half referred to as the Saglek block. Only the latter is discussed here, the Hopedale block being addressed by R. Wardle in a separate contribution.

Based on investigations between 1975 and 1990 the oldest-documented components (>3700 Ma) of the Saglek block of Nain Province occur in the northern part of it; younger (accreted?) rocks occur southwards. The oldest, widely recognized components are the metasedimentary, metavolcanic and meta-plutonic rocks of the Nulliak assemblage, which form inclusions and discrete belts within polyphase migmatitic gneisses of overall tonalitic composition referred to generally as Uivak gneiss (ca. 3700 - 3400 Ma). Other metasedimentary and metavolcanic gneisses are considered to be post-Uivak, and are collectively referred to as the Upernavik supracrustals. Outside the Saglek Fiord "type area" for these rocks, there has been no definitive breakdown nor stratigraphic correlation attempted, so geological continuity between distant regions is uncertain. Layered basic intrusions, including significant components of meta-anorthosite, are found in that part of the Saglek block south of Saglek Fiord, but their emplacement niche vis-à-vis the remnants of smaller layered intrusions to the north is not well established.

Tectonic Setting: The intercalation of Archean metaplutonic and supracrustal rocks was produced by combinations of magma injection, perhaps in a subduction type of environment, and subhorizontal tectonics under conditions of high-grade metamorphism and concomitant partial meting that may have been the result of continental collisions. With the benefit of results of recent work in Greenland, the current "stratigraphy" outlined for the Labrador Archean rocks is, in all probability, far too simplistic. This conclusion is borne out by geochronological studies, and therefore the attempts to regionally correlate units may be erroneous because they likely represent a tectonic collage of superficially identical rocks. There are limited geological and geochronological data from the Nain area to conclude that such mega-scale tectonic juxtaposition of differing parts of the Nain Province - the northern Saglek block and the southern Hopedale block - did occur at ca. 2550 Ma, but this collisional(?) event has not been defined regionally.

Economic Geology: The high-grade, tonalitic to granitic gneisses that constitute the bulk of the Nain Province have never been traditionally considered to have high mineral potential, and thus have not been prime targets for exploration. Some of the supracrustal rocks have fared better from this perspective. The earliest "explorationists" were the prehistoric peoples of the coast, who exploited and utilized soapstone from supracrustal-hosted and isolated tectonic slivers of altered ultrabasic rocks; local soapstone is still used by today's Inuit carvers in Labrador. Prospecting companies became aware in the mid-1950s of several belts of magnetite iron formation in gneisses at Saglek Fiord. This iron formation is now known to be part of the Nulliak assemblage, and it is confined to several isolated and restricted belts of quartz- and clinopyroxene-rich rocks that are interpreted to be dismembered units of cherty iron formation. By comparison with Archean iron formation at Isua, the Labrador occurrences are minor, and are certainly not economically viable sources of iron. Some ultrabasic rocks within the supracrustal sequences seem to be remnants of komatiites, but no nickel mineralization is known from such settings. Several, kilometre-scale layered intrusions having ultramafic to anorthositic rocks, and overall similar to the deformed chromite-bearing intrusions of the Fiskenaesset region, occur in the Nain Province, but neither has been systematically prospected for base metals nor platinum group minerals.

Paleoproterozoic intrustions marking break-up of the Archean Craton

General Geology: A well-preserved terrane of Paleoproterozoic anorthositic and granitic rocks, the Arnanunat Plutonic Suite (APS), has been recently identified in the southern part of the Saglek block of the Nain Province. Among this group of aggregated plutons are anorthosite, leucogabbro, syenite and rapakivi granite. Until 1996 this plutonic assemblage had been considered part of the Mesoproterozoic Nain Plutonic Suite (see below), but field characteristics, corroborated by U-Pb geochronology, indicate the APS is Paleoproterozoic, having been formed between 2130 Ma and 2110 Ma. The plutons and surrounding gneisses were invaded by a swarm of gabbroic dykes at ca. 2044 Ma. Even younger silicic plutons, ca. 2050 Ma to ca. 2025 Ma, occur southeastwards. The whole APS constitutes a linear array up to 150 km long and 20 km wide, with the anorthositic rocks apparently confined to its northern half.

Tectonic Setting: The general compositional characteristics of the APS, along with the linear distribution within the Nain Province, are consistent with its development within a discrete southeast-trending zone of crustal extension. The progressively southwards-younging, linear shift, in the locus of intrusion is interpreted to reflect the track of migrating magmatism and rift propagation. The continental rift is inferred to mark the initiation of a Wilson Cycle and the foundering of the western margin of the North Atlantic Craton. This crustal fragmentation led to the growth of an ocean farther west, an ocean that eventually closed and culminated in the collisional Torngat “orogeny” between 1860 Ma and 1745 Ma (see below).

Economic Geology: The rocks represented within the APS are so similar to the much younger Nain Plutonic Suite that when a major Ni-Cu discovery was made in the younger rocks in 1993 (see below) the APS was also subsequently scrutinized for base metals. There was some exploration success, with several, small, previously unknown prospects being systematically investigated and drilled. The most actively explored area was located near Okak Bay, where pyroxenite dykes intruded into anorthosite are hosts to sulphides. Minor sulphide concentrations were also discovered 20 km to the south, within olivine-magnetite-bearing rocks that are interpreted to be dioritic dykes intruded into anorthosite. None of the sulphide discoveries in the APS has proven to be significant storehouses of Ni-Cu minerals, and none has been the locus of dedicated study since the late 1990s. Apart from the sulphide minerals, the APS is reported to host one small occurrence of gold- and silver-bearing quartz veins.

Paleoproterozoic supracrustal rocks resting on cratonic peneplain

General Geology: Several sequences of Paleoproterozoic sedimentary and volcanic rocks rest unconformably on the Archean - Paleoproterozoic peneplain of gneisses and basic dykes of the Nain Province. From north to south these are the Ramah Group, the Mugford Group and the combined Snyder and Falls Brook groups. The Ramah Group of the Nachvak-Saglek area comprises mostly clastic sedimentary rocks - quartzite, siltstone, shale/slate, greywacke turbidites - and lesser dolomitic carbonates, the whole injected by gabbroic sills. In a graben-like structure 100 km to the southeast, the Mugford Group is

mostly submarine to subaerial basalts, overlying a lower division of siliciclastic sedimentary rocks that may be temporal distal equivalents of the Ramah Group. The less-extensive Snyder and overlying Falls Brook groups comprise, respectively, predominantly clastic sedimentary rocks and a sequence of basic volcanic or intrusive rocks separated by sedimentary screens. In the relative scheme of comparative geology, these supracrustals have a setting similar to the Moran Lake Group of the southern Nain Province and the Sortis and Vallen groups of west Greenland.

Tectonic Setting: All three belts of supracrustal rocks overlie gneissic basement, and are considered to represent the vestiges of continental-margin cover on a rifted and subsided Nain craton. Ramah Group shows the effects of later deformational events, having been located proximal to the collisional suture of Torngat orogen (see below), and is now disposed as an open, asymmetric, easterly-overturned syncline in its type area, but is recognized as ductile-slide-bounded, amphibolite-facies, slivers intersliced with reworked basement for some 100 km farther south. The Mugford Group is located inboard from the main Torngat collisional front and is relatively pristine, being largely flat-lying, showing few thrust faults, and a greenschist facies overprint. The Snyder Group and overlying Falls Brook Group were also distal from the blanket of Torngat metamorphism and deformation, but both groups fall in the contact aureole of the ca. 1305 Ma Kiglapait troctolitic layered intrusion and have been subjected to thermal metamorphism up to pyroxene-hornfels facies. The groups were folded at the time the Kiglapait was emplaced, but the Snyder Group has retained its unconformable contact with Archean gneisses.

Economic Geology: The Ramah Group provided the prehistoric peoples with a quarry stone of immeasurable value, for a chert bed in the Paleoproterozoic sequence proved to be an ideal stone for implement making. Associated with the chert is a bed of massive pyrite, which in the early 20th century was investigated and had limited mining as a possible source of iron and sulphur. The Ramah Group pyrite bed was also targeted in the 1980s as a possible environment for synsedimentary exhalative (sedex) base metals, but results were discouraging. Small showings of Pb and Zn, having characteristics of “Mississippi Valley type”, are known from the carbonates of the Ramah Group, but reconnaissance examination points to overall low volumes of the metals. The Mugford Group hosts several minor base metal showings, in both the sedimentary and volcanic rocks, and one small occurrence of radioactive minerals is located in the basal clastic rocks proximal to the unconformity with the Archean basement. Massive pyrrhotite has been identified within the Snyder Group, but there is an absence of significant Cu. The Falls Brook Group, having sedimentary rocks sandwiched between mafic rocks that may be sills from the troctolitic Kiglapait intrusion, provides an environment in which Ni-Cu sulphides may have been generated by the interaction of basic magma and sulphur-bearing sediments, but no such mineralization has yet been documented.

Reworked Archean and juvenile Paleoproterozoic rocks of the Labrador interior - Torngat orogen and Churchill province

General Geology: The Churchill Province in Labrador refers to the geographically central composite region of amphibolite to granulite facies gneisses and associated foliated plu-

tonic rocks generated during development of the Paleoproterozoic Torngat Orogen. The core of the Churchill Province encompasses both re-worked Archean crust (ca. 2800 - 2600 Ma) and juvenile Paleoproterozoic rocks, largely of tonalitic to granodioritic composition, having intercalated belts of paragneiss and mafic gneiss. Archean-age gneisses are generally differentiated from superficially-similar Paleoproterozoic rocks by the presence of variably deformed basic dykes. Among the Archean rocks are dismembered layered intrusions that include Fiskenaesset-type meta-leucogabbro and meta-anorthosite. A 40 km-wide belt of Paleoproterozoic garnetiferous paragneiss, termed Tasiuyak gneiss, derived from psammitic to pelitic precursors, dominates the eastern part of the Churchill Province adjacent to the collisional suture, and is a prominent feature on both geological and aeromagnetic maps of Labrador. Rocks of similar supracrustal parentage constitute distinct units in the Nagssugtoqidian of Greenland.

Tectonic Setting: The Torngat Orogen of the eastern Churchill Province is a product of oblique collision between the Nain Province and a western continental block of uncertain prior affinity, and records events accompanying the obliteration of an ocean that had originally separated the two blocks. Metamorphism and deformation displayed across Torngat Orogen and the adjacent Archean and Paleoproterozoic rocks of the Churchill Province attest to the oblique docking of the two blocks and the transpression that marked the ultimate formation of a single continental mass. Folding of the Paleoproterozoic Ramah Group is a consequence of these events, as is a broad zone of sinistral-shear granulite-facies mylonite referred to as the Abloviak zone. U-Pb ages indicate the current architecture of the Churchill Province and the Torngat Orogen in northern Labrador was progressively developed through intrusion, metamorphism, and deformation between ca. 1900 Ma and 1750 Ma.

Economic Geology: The supracrustal gneisses of the Churchill Province are regionally characterized by gossan zones in both metasedimentary and mafic gneisses, which in the former setting locally reflect distinct layers of massive sulphide. Some of the largest such gossans were investigated by exploration companies in the mid-1990s, but no such mineralized zones have proven to signify the presence of exploitable base metals because the predominant sulphide is pyrrhotite. Pods of graphite were discovered in the Tasiuyak gneiss in the late 1930s, but attempts at mining and marketing it were unsuccessful. More recently, gold was discovered within an “iron formation” part of Tasiuyak gneiss near Nain, but it appears to have restricted distribution. Garnet sands in northern Labrador, derived from Tasiuyak gneiss by glacial pulverization, weathering, meltwater dispersal, and subsequent coastal reworking, are currently in the market-testing stages as a source of industrial abrasives.

Mesoproterozoic bi-modal batholih (Nain Plutonic suite) – incipient rifting

General Geology: The central coastal region of Labrador is home to a Mesoproterozoic, batholith-scale, plutonic welt of coalesced anorthositic, granitic, troctolitic and dioritic (gabronoritic) intrusions. This batholith, the Nain Plutonic Suite (NPS), was constructed over approximately 60 million years, between ca. 1350 Ma and 1290 Ma. On its eastern side, it was emplaced into the Archean gneisses of the Nain Province; on its western side,

it intrudes the Archean and Paleoproterozoic gneisses of the Churchill Province. The areally predominant rocks of the NPS are a bimodal group of anorthositic (leuconoritic, leucotroctolitic) and granitic (monzonitic, quartz-monzonitic) plutons. Subordinate to these are troctolitic (gabbroic, olivine-gabbroic) and dioritic (gabbronoritic, monzonoritic) intrusions. This batholith has no direct analogue in Greenland, but some Garder intrusions of south Greenland contain feldspar and anorthosite xenoliths possibly derived from subterranean anorthositic intrusions equivalent to the NPS.

Tectonic Setting: The NPS constitutes a "stitching batholith" that straddles and seals the north-south collisional boundary between the Nain and Churchill provinces. Mineral assemblages in contact aureoles indicate most plutons crystallized at mid- to upper-crustal levels. Models for the generation of the NPS favour an intracontinental "anorogenic" setting, the result of plume induced magmatism and of crustal extension that failed to evolve to a complete sundering. Current geochronological data imply that magmatism migrated from west to east.

Economic Geology: The largely anorthositic-granitic terrane of the NPS was essentially ignored by most explorationists until late 1994 when a major discovery of magmatic Ni-Cu-Co sulphides in a mafic intrusion near Voisey's Bay was announced. The sulphide mineralization is located within the feeder system to, and near the base of, the troctolitic Voisey's Bay intrusion, emplaced ca. 1333 Ma. The formation of a Ni-Cu sulphide liquid within the troctolitic magma was triggered by passage through, and the assimilation of, sulphur-bearing Tasiuyak gneiss by several pulses of magma feeding into one or more chambers. The Voisey's Bay deposit has just been advanced to the mining stage, producing the first concentrate on September 16th, 2005. The Voisey's Bay Nickel Company indicates the following nickel resources for the site: the "Ovoid deposit", the first to be exploited, contains estimated proven and probable resources of 32 million tonnes, but other deposits within the Voisey's Bay troctolite are reported to have an additional 50 million tonnes of indicated resource and 12 million tonnes of inferred resource. The initial announcement of the Voisey's Bay discovery initiated a frenzy of exploration in the NPS, and over the next few years numerous sulphide prospects were discovered and variably examined. None proved to be nearly as significant as the Voisey's Bay deposits, and none progressed beyond the drilling stage. The settings of these numerous discoveries are quite varied, both from the perspective of the hosting rocks and the timing of mineralization relative to crystallization of the host. Though base metal exploration has received most of the attention vis-à-vis the NPS in recent years, a small but successful dimension stone industry has also grown. Two textural types of labradorite-bearing anorthosite have been introduced to the world-wide architectural community, and have fared well in application to a wide market of "high end" users. In addition, the labradorite-bearing anorthosite is becoming a carving medium, commanding premium prices from buyers, and large labradorite crystals are used extensively and imaginatively by local lapidaries.

Mesoproterozoic peralkaline rocks – last signatures of failed rifting??

General Geology: The youngest rocks of regional geological significance in northern Labrador are the Flowers River - Nuiklavik assemblage of granite and subaerial volcanic rocks

and the Strange Lake granite. The Flowers River intrusions and the Nuiklavik volcanic rocks are located along the southeastern edge of the Nain Plutonic Suite. The Flowers River - Nuiklavik association constitutes a ring complex of, respectively, A-type, arfvedsonite-bearing peralkaline granite and trachytic to pantellelleritic, quartz-feldspar ash-flow tuffs. The volcanic caldera complex developed ca. 1290 Ma, and the granites were intruded between 1288 Ma and 1270 Ma. The Strange Lake granite, 100 km west of the NPS, was intruded into Churchill Province gneisses at 1240 Ma. This unique multi-phase, intrusion comprises arfedsonite-aegirine peralkaline granite that is characterized by exotic rare-earth bearing minerals. The magmatism represented by these “young” plutons and volcanic rocks is conceivably a Labrador expression of Gardar activity.

Tectonic Setting: The Flowers River granite and its carapace of peralkaline volcanic rocks mark the southern edge of the Nain Plutonic Suite. These rocks clearly carry the signatures of extensional tectonics, and document the high-level emplacement and effusion of magmas unlike the “normal” NPS assemblage. Although a strict stratigraphic assignment to the NPS is questionable, their geographic location ties them to the NPS, and their temporal niche places them as being a probable continuation of NPS magmatism. Consequently, they may represent the last magmatic event prior to the cessation of the mantle-crust interaction that produced the earlier anorthosite, granite and associated rocks. The Strange Lake granite seems to record a singular event in this region, and its localized distribution indicates it may be an unusual “magmatic blip” within an otherwise stabilized continental crust.

Economic Geology: The volcanic and plutonic rocks of the Nuikalavik - Flowers River association have localized indications of rare-metal (Zr, Y) mineralization, as well as traces of fluorite, Mo and Zn. The Strange Lake granite hosts a substantial deposit (> 50 million tonnes), perhaps the largest in the world, of Zr-Y-Nb-REE-Be-bearing magmatic minerals that formed near the roof of the magma chamber late in the crystallization history of the intrusion.

Epilogue

Northern Labrador is still, for all intents and purposes, an under-explored region. At this time, much of it is off-limits to explorationists because of the impending establishment of a new Canadian national park in the Torngat Mountains. Additionally, parts are also ineligible for commodity staking because of their designation as “exempt mineral lands” under an agreement between the provincial government and Labrador’s aboriginal groups, but this status may change in the near future. Regardless, this vast region still presents a viable exploration target. A few junior exploration companies are still actively investigating previously discovered Ni-Cu prospects, and prospecting for new ones, in the Churchill Province gneisses and the NPS. Other commodities offer prospecting interest as well. The few known occurrences of gold may augur well for more substantial concentrations in hitherto little explored Tasiuyak gneiss. Lamprophyric dykes, known to occur sporadically throughout the region, hold the prospect of having diamond-bearing variants. More exotic minerals may prove to be present; for example, aggregates of small red corundum within some of the metasedimentary gneisses proximal to Nain could portend the existence of larger gem-

quality rubies. Overall, the gneissic and plutonic rocks of northern Labrador constitute a smorgasbord worthy of continued investigation by the exploration fraternity.

The role of BMP in Greenland

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- See presentations on CD-ROM – no abstract available.

The global mineral resource assessment project: A cooperative international project to assess the World's undiscovered non-fuel mineral resources

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Global use of mineral resources will continue to increase for the foreseeable future because of the continuing increase in global population, and efforts to improve living standards worldwide. In response to the growing need for information on the global mineral-resource base, the U.S. Geological Survey (USGS) is leading a cooperative international project, the Global Mineral Resource Assessment Project (GMRAP), to assess the world's undiscovered nonfuel mineral resources. The critical objective of GMRAP is to outline the principal areas in the world that have potential for selected undiscovered mineral resources, and to estimate the probable amounts of those mineral resources to a depth of one kilometer below the earth's surface. GMRAP will begin by assessing a selected subset of commodities and their most significant deposit types for world minerals supply, including copper, lead, zinc, nickel, platinum-group metals, gold, potash (potassium), and phosphate (phosphorous).

A quantitative form of resource assessment will be applied in GMRAP to express explicitly the degree of uncertainty associated with assessments, and to allow economic analysis that can translate geologic-based results into a format useable by decision makers. The USGS 3-part quantitative mineral resource assessment consists of: 1) delineating areas according to the types of deposits permitted by the geology; 2) estimating the amount of resources contained in the undiscovered deposits using appropriate worldwide grade and tonnage models, and 3) estimating the number of undiscovered deposits of each type for each delineated area.

GMRAP is being conducted on a regional, multi-national basis with the cooperative participation of interested national and international organizations. The USGS role includes: coordination of the global assessment; facilitating and conducting workshops and working group meetings; leading quantitative probabilistic estimation of undiscovered nonfuel mineral resources; and, in conjunction with cooperators, publishing assessment products. International cooperators are assisting in: compiling existing geologic maps and related information at appropriate regional scales (~1:1,000,000 or smaller); providing current information on the location, sizes, and geologic types of known mineral deposits and occurrences; and helping gather information about regional mineral exploration history.

The first priority of GMRAP has been formalizing relations with cooperators from countries and/or multinational organizations in seven assessment regions (map at http://minerals.usgs.gov/news/v1n2/1gmrap.html). By the end of 2005 GMRAP will have conducted assessments for copper resources in Central and Southeast Asia, Oceania, Australia, Europe, and the Andes of South America. Assessments for copper resources in Southern Africa, North America, and the rest of South America are being planned in 2006. Global assessments for undiscovered platinum-group metals, lead, zinc, nickel, gold, potash, and phosphate will be completed by 2008. Assessment results will be published with cooperators as they are completed.

GMRAP will provide a consistent, comprehensive level of information and analysis of global nonfuel mineral-resources that will provide all nations a regional and global context for viewing their mineral-resource base; help plan new mineral exploration and sustainable resource development; and aid regional resource, land-use, and environmental planning.

The Arctic IPY 2007-08: Circumpolar Bedrock Geology Map

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- See presentations on CD-ROM – no abstract available.

Greenland geological environments and mineral resources – an overview

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The main geological environments in Greenland and their mineral resource have been described and divided into four main geological environments such as infracrustal regions, supracrustal regions, magmatic provinces, and sedimentary basin regions. Within the various geological environment characteristic mineral deposits are outlined.

Within the infracrustal environment, not many mineral occurrences are recorded in Greenland but three types are mentioned: Gold in gneiss, nickel and copper in mafic intrusions, and olivine in ultramafic rocks.

The supracrustal rocks include metasedimentary rocks, metavolcanics and banded magnetite-quartzite formation. Special attention is given to the mafic metavolcanic rocks because of their high rate of mineral potential, not least with gold and base metal deposits. These deposits are often related to greenstone belts with mafic volcanics or mixed mafic volcanic and sedimentary rocks. Other mineral occurrences than gold are iron, copper, chromium, tungsten, as well as industrial minerals.

The mineral occurrences in the magmatic environment are the porphyry system related to Palaeogene alkalic intrusion in East Greenland and associated vein systems with gold and silver; veins related to the Caledonian granite and the Julianehåb batholith, which carries tungsten, arsenic, antimony, and gold; the alkaline intrusions in the Gardar province have niobium, tantalum, zirconium, rare earth elements, and cryolite; carbonatite with niobium, tantalum, apatite and kimberlite-lamproite with diamonds are located within the Kangerlussuaq region of West Greenland.

Many of the globally known mineral occurrence types in sedimentary environments also occur in Greenland. Examples are copper in sandstones in Neoproterozoic and Triassic clastic sediments; lead and zinc in shale/carbonate sequences are widespread in the sedimentary basins; a fossil placer represents a placer deposit and celestite an evaporite deposit; lead-zinc veins in sediments occur in the Mesters Vig area including the now closed Blyklippen Pb-Zn mine, East Greenland.

The aeromagnetic data responses of different geological environments yield valuable information on both the primary geological settings and subsequent geological events. The data can be used on a regional scale, but can also be used at smaller scales when descriptions and interpretations of processes related to specific environments or mineral occurrences/mineralizing events are required.

On a regional scale, aeromagnetic data from infracrustal environments will often reflect the deformation and metamorphic history. In general, prograde granulite facies conditions result in heterogeneous higher magnetic anomaly levels than regions at lower metamorphic grade. Large-scale structures and tectonics crosscutting or separating infracrustal environments will in many cases be represented as abrupt changes and/or lineaments in anomaly patterns.

Supracrustal lithologies are in most cases characterized by low magnetic anomaly levels. Strongly magnetic rocks, especially ultrabasic/ultramafic lithologies, result in high magnetic level, local short-wavelength anomalies.

The aeromagnetic responses of magmatic provinces depend mainly on the composition of the magmatic rock. The shape and outline of an intrusion is in most cases derivable from the aeromagnetic responses. The magnetic anomaly levels of extruded basalts are in many cases dominated by the polarity of the Earth's field at the extrusion time.

Rocks from non-metamorphosed sediment depositional environments contain in most cases only a small amount of magnetite. Consequently, such environments are characterized by relatively low and smooth level of magnetic anomaly responses, indicating the thickness of the sediments.

Former, present and future resource assessments in Greenland

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As a consequence of improved geological knowledge and technical advances the way of using and presenting geoscientific data at the Geological Survey of Denmark and Greenland (GEUS), as for many other modern Surveys, has changed considerable during the last couple of decades.

Furthermore, to-days geo-scientific disciplines are challenged with integration and interpretations of a wealth of historical and newly acquired data of varying complexity. Moreover precise high quality reliable results, used for geological interpretations and supporting decision-making are demanded for regions with both high and low level of investigation. An assessment of resource potential and interpretations should meet these challenges. How is the ideal assessment then established? How do we take advantage of the geoscientist and the data, and allow these to interact?

The talk will present different aspects of an assessment of resource potential exemplified by former, present and future assessments carried out by GEUS. Examples on the different geoscientific data available from Greenland and the different ways of presenting and addressing these will be given during the talk. As a part of the talk, a newly applied procedure that statistically integrates and analysis multiple data of various types in order to quantify geological signatures, predict mineral potential and estimate probability for new discoveries, will be presented. The procedure is developed together with scientists from the Geological Survey of Canada.

Trans-Hudson Orogen of North America and the Himalayan-Karakoram-Tibetan Orogen of Asia: Structural and thermal evolution of the lower and upper plates

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The Trans-Hudson Orogen (THO) of North America and the Himalaya-Karakoram-Tibetan Orogen (HKTO) of Asia preserve a Paleoproterozoic vs. Cenozoic record of continent-continent collision that is notably similar in scale, duration and character. In THO, the tectonothermal evolution of the lower plate involves (1) early thin-skinned thrusting and Barrovian metamorphism, (2) out-of-sequence thrusting and high-T metamorphism, and (3) fluid-localized re-equilibration, anatexis and leucogranite formation. The crustal evolution of the Indian plate in HKTO involves (1) early subduction of continental crust to UHP (ultra-high pressure) eclogite depths, (2) regional Barrovian metamorphism, and (3) widespread high-T metamorphism, anatexis and leucogranite formation. The shallow depths of the high-T metamorphism in HKTO are consistent with the early to mid-Miocene ductile flow of an Indian plate mid-crustal channel, from beneath the southern Tibetan plateau to the Greater Himalaya. Melt weakening of the lower plate in THO is not observed at a similar scale due to the paucity of pelitic lithologies. Tectonothermal events in the upper plate of both orogens include pre-collisional accretion of crustal blocks, emplacement of Andean-type plutonic suites, and high-T metamorphism. Syn- to post-collisional events include emplacement of garnet-biotite-muscovite leucogranites, anatectic granites, and sporadic metamorphism (up to 90 Ma following the onset of collision in THO). Comparing the type and duration of tectonothermal events for THO and HKTO supports the notion of tectonic uniformitarianism for at least the later half of dated Earth history, and highlights the complementary nature of the rock record in an older “exhumed” orogen compared to one undergoing present day orogenesis. It also provides a tectonothermal context for the recent discovery of sapphires in the Kimmirut area of southern Baffin Island for which a younger geological analogue is the world-class mining district of Mogok in Myanmar.

Current exploration activities in Greenland

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- See presentations on CD-ROM – no abstract available.

The role of GEUS in Greenland

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The *Geological Survey of Denmark and Greenland*, GEUS, is a Danish State Research Institute in the Ministry of the Environment, defined and run according to the Danish law for all such Danish institutions. It is part of *Geocenter Copenhagen,* a practical and conceptual co-operation between GEUS and Geological and Geographical Institutes of Copenhagen University. Approximately 300 employees in nine departments work in five programme areas: *Databanks and information*, *Water resources*, *Energy resources*, *Mineral resources*, and *Nature and Environment,* within a total budget of 275 million DKK (2004). Most of the approximately 500 projects carried out every year are focused on Denmark and Greenland, but more global activities are also becoming important. Besides research, GEUS provides advice to Danish and Greenlandic authorities and participates in commercial projects.

Geological Survey activities in Greenland reach far back into the past. Today, the co-operation with the *Bureau of Minerals and Petroleum,* BMP is at the centre of many activities, especially those concerned with energy resources and mineral resources. As a result of agreements between the governments of Denmark and Greenland, approximately 32 million DKK out of GEUS' budget appropriation of approximately 155 million DKK must be used for projects in Greenland. In addition, BMP adds some 18 - 20 million DKK to help fund scientific research in projects, which BMP sees as especially important for the support and development of Greenland resources. These projects are often jointly planned and funded by BMP and GEUS. In the talk, a brief description of examples of activities related to geological mapping, regional geochemistry, airborne geophysical mapping, mineral resource assessments and other important projects.

GEUS participates in the administration of mineral rights in Greenland, assisting the BMP with specific procedures related to the issuing and monitoring of licenses, hereunder also the use and storage of all geological reports from companies operating under a mineral exploration or exploitation license in Greenland. GEUS also participates in the international promotion of Greenland's mineral resources, and provides services to the international mining and oil industries.

Surficial geology and drift prospecting, northern Baffin project

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In 2005 the Canada–Nunavut Geoscience Office, in collaboration with the Geological Survey of Canada, the University of Alberta, Dalhousie University and Polar Continental Shelf, expanded the 2003 North Baffin Project from Ice Bound Lakes (NTS 37G; Little et al, 2004), to Conn Lake (37E) and south Buchan Gulf (37H/south). The area lies along the northwest coast of Baffin Island coast between Bylot Island and the Clyde foreland. Radically different ice sheet reconstructions have been published for these flanking areas, making the study area an excellent location to test ice sheet interpretations. The primary objective of this study is to reduce the mineral exploration risk in this remote area by improving the existing geoscience knowledge base. Outcomes of this project include surficial geology maps at 1:100 000 scale, and collection of drift, stream and bedrock prospecting samples. To date, 321 till samples have been collected.

Prior to fieldwork, predictive surficial geology maps were created using supervised classification techniques on Landsat TM and RADARSAT I data. The predictive maps were used during selection of sample sites. To better understand the provenance of samples studies of ice-flow indicators, sea-level variations, geomorphology, and in-situ terrestrial cosmogenic nuclide (TCN) dating of boulders were undertaken.

Based on preliminary results and regional reconstructions, the area was likely glaciated to the shelf margin by ice flowing from the Foxe Ice Dome at the Last Glacial Maximum, until about 14 ka. As deglaciation continued, ice retreated on to Baffin Island, becoming known as the paleo-Barnes Ice Cap. Deglaciation was interrupted by a readvance (Cockburn) at 9.6 ka, forming extensive moraines in the study area. Continued deglaciation resulted in the damming of several lakes in the study area and formation of Degeer or cross-valley moraines. Complications to the glacial history result from overprinting of both erosive and non-erosive basal thermal regimes at various stages of the deglaciation (a likely characteristic along much of the eastern margin of Canada). To resolve this, new applications of TCN were developed that compare the TCN concentrations in glaciolacustrine deltaic sediment, till, and large (2x2x2 m) boulders to quantify variations in the plateau-wide paleo-erosion rate and to qualitatively assess the duration of glacial transport and ice velocity.

Palaeoproterozoic orogenesis in Greenland, and correlation with eastern Canada

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The Precambrian basement of Greenland is dominated by Archaean orthogneisses. However, large parts were intensively reworked in several Palaeoproterozoic orogenic belts with highly variable amounts of juvenile addition to the continental crust. The age of the Palaeoproterozoic orogenic activity decreases from c. 2000-1900 Ma in north to <1800 Ma in the south, indicating a gradual southward movement of the locus of the Palaeoproterozoic plate-tectonic activity.

The oldest record of Palaeoproterozoic orogenic activity occurs in East Greenland, where the crystalline basement to the East Greenland Caledonides contains intrusive rocks dated at c. 2000 Ma. In North-West Greenland, the E-W-trending, granulite-grade Inglefield mobile belt predominantly consists of juvenile Palaeoproterozoic ortho- and paragneisses, which probably formed in a convergent plate-tectonic environment along the northern margin of an Archaean continent in the present Thule district. The sedimentary component, deposited between 1980 and 1950 Ma, comprises quartzites and a thick sequence of marble in its southern part, overlain by metagreywackes. The precursors of these rocks were intruded by felsic to intermediate intrusive tonalitic-granodioritic complexes and large quartz syenitic intrusions at c. 1950–1915 Ma. High-grade regional metamorphism at c. 1920 Ma was assiociated with extensive partial melting and formation of S-type granites. The Inglefield belt continues westwards across Nares Strait into the Thelon zone on Ellesmere Island.

The slightly younger, collisional Rinkian fold belt farther south in central and northern West Greenland is characterised by thrusting and folding of Archaean orthogneisses and a major Palaeoproterozoic cover sequence, the Karrat Group, with the now exhausted Zn-Pb mine at Maarmorilik. The northern part of the Rinkian fold belt was metamorphosed at granulite facies presumably at around 1870–1860 Ma, whereas metamorphism in its central and southern parts at c. 1850 Ma varies from upper greenschist to granulite facies. Most of the Rinkian fold belt is flat-lying and contains evidence of first NE- and then NW-directed tectonic transport. In the central part of the belt, he last fold phase during continued crustal shortening resulted in very large, spectacular, upright dome structures and tight synclinal cusps. In the northern part, the granulite facies Prøven igneous complex was emplaced at 1870 Ma into tectonically interleaved, flat-lying basement and cover. Isotopic studies have recently confirmed that the Prøven igneous complex consists of remelted Archaean crust, and thus, no truly juvenile Palaeoproterozoic plutonic rocks are present in the Rinkian fold

belt The crustal melting to form the Prøven igneous complex may have been related to delamination of mantle lithosphere after the onset of the continental collision and replacement by upwelling, hotter lithospheric magma. The Rinkian fold belt correlates with the Baffin and Foxe belts in Canada, and a palinspastic reconstruction prior to the opening of the Labrador Sea and Davis Strait places the Prøven intrusive complex at the eastern continuation of the Cumberland Batholith of the same age.

To the south of the Rinkian fold belt in central West Greenland lies the likewise Palaeoproterozoic Nagssugtoqidian orogen, which is characterised by a strong, ENE-trending tectonic fabric. It has recently been proposed that a suture (and not unreworked Archaean basement) separates the Rinkian and Nagssugtoqidian belts, and that they respectively represent the northern and southern continental blocks of a very large common collisional orogenic system: together, the Rinkian and Nagssugtoqidian belts form a zone of Palaeoproterozoic orogenesis in central–northern West Greenland that is more than 1100 km wide. The central part of the Nagssugtoqidian orogen itself was the site of collision and tectonic intercalation of Archaean gneisses and much less voluminous Palaeoproterozoic juvenile rocks. The latter occur in the Ussuit unit, which comprises clastic and chemical metasedimentary rocks, andesitic to basaltic metavolcanic rocks, and the intrusive, 1920–1870 Ma calc-alkaline Arfersiorfik complex. Another calc-alkaline pluton, the Sisimiut complex, occurs farther south. These calc-alkaline complexes represent a pre-collisional phase of arc magmatism. A subsequent phase of northwest-directed thrusting during early collision was followed by continued N–S contraction and folding. Peak collisional granulite facies metamorphism in the Nagssugtoqidian core took place at c. 1850 Ma. The timing of plate tectonic events, the rock types and the kinematics of the structural evolution of the Nagssugtoqidian orogen correlate closely with those of the Torngat orogen in Labrador, which in the palinspastic reconstruction trends at right angles to the Nagssugtoqidian orogen. The plate-tectonic configuration that led to this geometry is at present uncertain.

The youngest of the Palaeoproterozoic orogens, the Ketilidian orogen in South Greenland, is separated from the Nagssugtoqidian orogen by the North Atlantic craton. The latter is an Archaean crustal block c. 600 km wide which, besides emplacement of Palaeoproterozoic basic dykes, only underwent very mild thermal overprinting and localised conjugate faulting within a N–S orientated compressional stress system. In South Greenland, the northwestern border zone of the Ketilidian orogen comprises platform-type detrital sediments of Archaean provenance (the Vallen Group) and overthrust primitive tholeiitic pillow lavas (the Sortis Group, possibly of ocean floor origin). A juvenile, calc-alkaline continental arc, the Julianehåb batholith, forms the bulk and central part of the orogen and is thought to be the result of NW-directed oblique subduction of oceanic crust at the southern margin of the North Atlantic Craton. The Julianehåb batholith was largely emplaced during sinistral transpression. It ranges in age from 1854–1795 Ma, and the beginning of the arc magmatism in South Greenland thus coincides in time with the main Nagssugtoqidian continent-continent collision in central West Greenland. The observed jump of orogenic activity from West to South Greenland is likely to reflect plate-tectonic jamming in the former region at c. 1850 Ma so that when the northern, Nagssugtoqidian margin of the North Atlantic Craton docked against the Rinkian belt, subduction of oceanic crust began on its southern margin. The third component of the Ketilidian orogen besides the border zone and batholith, is a metamorphosed fore arc on the southern, outboard side of the batholith itself. It is largely built of

detritus from the magmatic arc but also comprises locally gold-bearing mafic to andesitic metavolcanic rocks, e.g. at the recently opened Nalunak gold mine in Kirkespirdalen. The fore arc rocks were deposited, deformed, and ultimately underwent extensive partial melting during the narrow time interval 1794–1785 Ma. Finally, the rapakivi suite of South Greenland was emplaced at 1755–1732 Ma as high-level tabular intrusions fed by narrow dykes and folded into broad arches separated by narrow cusps. No presently exposed parts of the Ketilidian orogen contain evidence of post-accretion collision with another orogen. The western correlative in Labrador of the Ketilidian orogen is the Makkovik Province, which however consists of a collage of smaller arcs and includes younger components; direct correlation of individual components is difficult.

Geology and metallogeny of central Labrador: A review

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This paper deals with the geological components of central Labrador, namely the southern Nain craton, Makkovik Province and younger cover and intrusive rocks, that for the most part have correlatives in Greenland. It complements the companion paper on northern Labrador (Ryan this volume).

The Nain craton is the western component of the fragmented Archean North Atlantic Craton (NAC) that also occupies much of west-central Greenland. The Nain craton is bounded by Paleoproterozoic orogens: in the west the Southeastern Churchill Province (Trans-Hudson Orogen) and in the south the Makkovik Province. The Southeastern Churchill Province is a correlative, at least in part, of the Nagssugtoqidian belt of northern Greenland whereas the Makkovik Province represents an extension of the Ketilidian belt of South Greenland. The Southeastern Churchill and Makkovik provinces are truncated in the south by a series of accreted terranes, ranging in age from 1.7 – 1.4 Ga, now contained within the Grenville province. These together with southern margin of the Makkovik Province were all deformed during the Grenvillian orogeny ca. 1.0 Ga.

Southern Nain Craton

This is composed mainly of high-grade Archean gneisses and granitoid plutons formed in a series of events between 3.3 and 2.8 Ga. (James et al 2002). Intercalated with these are two northeast-trending metavolcanic greenstone belts referred to as the Hunt River (3.1 Ga) and Florence Lake (3.0 Ga) belts. The southern Nain craton was metamorphosed in an early (Hopedalian) event ca. 3.1 – 3.0 Ga, and in a later (Fiordian) event ca. 2.9-2.8 Ga. The Fiordian event was associated with widespread granitoid intrusion in the form of the Kanairiktok Intrusive Suite.

The Hunt River and Florence Lake belts are the most important units with respect to mineral potential. They are composed mostly of mafic metavolcanic rocks with the remainder being metasedimentary, felsic metavolcanic and serpentinized ultramafic rocks. The Florence Lake belt is similar in composition to the Hunt River belt but has a slightly higher content of ultramafic and felsic volcanic rocks. The principal difference is the younger age and lower metamorphic grade of the Florence Lake belt. The mafic volcanic rocks are interpreted as basaltic komatiites and have an overall MORB-like signature (James et al

2002). The ultramafic rocks are present as thin sheets generally < 10 m thick and largely converted to talc-magnesite-serpentine assemblages. Their protolith is uncertain but some, on the basis of their chemistry and local preservation of spinifex texture (Miller 1996), have been suggested to be komatiite flows. The felsic volcanic rocks have a calc-alkaline affinity and vary from rhyolite to dacite in composition.

A Greenland equivalent of the Hunt River and Florence Lake belts may be the Tartoq Group of the southern NAC in West Greenland.

Mineralization: Ni-Cu-PGE mineralization in the form of pyrrhotite-pyrite-pentlandite mineralization is mainly associated with the ultramafic flows of the Florence Lake belt, the principal occurrences being in the Baikie sub-belt. The Baikie prospect is the best known of these and has given drill-core assay values of 2.19% Ni and 0.22% Cu over 11.32 m, and 1.86% Ni, 0.32% Cu over 1.21 m. The sulphides are also locally enriched in PGE (up to 93 ppb Pt and 1209 ppb Pd; Wilton 1996). The Boomerang showing at the southern end of the sub-belt contains up to 2.1% Ni in graphitic metasediment associated with the ultramafic rocks. A Kambalda-style environment has been suggested (e.g. Miller 1996) for the mineralization. In this model, the prevailing thin flows probably represent channel overflows or distal sheet flows. Thick units indicative of channel environments are sparse. A critical component of the Kambalda model is the presence of sulphide-enriched sediments that can be thermally eroded and assimilated to provide a source of sulphur for massive sulphide formation and Ni-Cu concentration. Sulphidic metasedimentary units are locally present in the Florence Lake belt and may offer a prospecting guide in this respect.

A different style of base-metal occurrence is represented by the Copper Hill and Treasure Island prospects located at the southwestern end of the Florence Lake belt (Wilton 1996). These are hosted by metadiorite — amphibolite and gneissic rocks, and contain massive pyrrhotite-pyrite with minor chalocopyrite-sphalerite-magnetite mineralization. The sulphides are enriched in Ni (up to 800ppm), Cu (up to 0.22%) and Zn (up to 1950ppm) and have somewhat elevated levels of Pd and Au. The Copper Hill occurrence also locally contains up to 6.8 ppm Ag. The occurrences have been suggested by Wilton (1996) to have an orthomagmatic origin but this has not been confirmed.

Cu-Zn-mineralization is associated with the felsic volcanic — volcaniclastic rocks of the Florence Lake belt, generally as disseminated pyrite ± chalcopyrite mineralization of VMS style. Massive sulphide is rare and mineralization is more commonly of disseminated or stringer style. Metal values are generally low; however, the Knee Lake prospect has given values of up to 6.7% Zn over a strike length of 150 m in cherty, exhalative metasedimentary rocks.

Au mineralization is locally present but is not as widespread as in other Archean cratons. Some of the ultramafic rocks in the Florence Lake belt are locally associated with intense iron-carbonate alteration (which has largely converted the protolith to siderite/dolomite), and arsenopyrite. The style is reminiscent of mesothermal gold mineralization but to date has yielded only minor gold values of up to 0.4 ppm. The Aucoin occurrence is the only gold occurrence located outside of the greenstone belts and is found within diorite-monzonite plutonic rocks in the northwest part of the southern Nain craton. It contains Au in

association with galena and pyrite in a series of en-echelon quartz veins and is associated with intense carbonate alteration. Visible gold has been reported and trench chip-sample assays average 2.6 g/t over 4.3 m. The mineralization is probably of mesothermal style.

The Makkovik province

The Makkovik province is a triangular segment of Archean and Paleoproterozoic crust deformed in the Makkovikian orogeny ca 1.8—1.7 Ga. The northern part consists of reworked Archean gneisses of the Nain Craton. These are unconformably overlain and overthrust by the ca. 2100–2000 Ma (Ketchum et al 2002) metasedimentary and mafic volcanic rocks of the Moran Lake and Lower Aillik groups that probably represent passive margin sequences developed on the rifted southern margin of the Nain craton. To the south, these are in tectonic contact with the subaerial felsic volcanic rocks of the Upper Aillik Group (1860 to 1807 Ma), probably formed in a back-arc or rifted back-arc environment (Ketchum et al 2002). All units have been intruded by a number of granitic plutonic suites that fall into roughly three age intervals (Kerr, 1994; Ketchum et al 2002):

1895 to 1870 Ma: Probable arc-related calc-alkalic plutons
1815 to 1790 Ma: Syn- to posttectonic plutons that overlap the Makkovikian Orogeny
1720 to 1715 Ma: Posttectonic plutons of high silica, A-type character.
Collectively, these dominate the southern part of the Makkovik Province.

Makkovikian deformation occurred intermittently between 2.0 and 1.7 Ga with peak deformation between 1.81 and 1.78 Ga. This was associated with northerly-directed overthusting plus sinistral and dextral shearing.

The northern (Archean basement) part of the Makkovik Province is equivalent to the Border Zone of the Ketilidian belt (Garde et al 2000); the Moran Lake and Lower Aillik groups being the likely equivalents to the Vallen and Sortis groups of that area. However, the central and southern parts of the Makkovik province seem to lack direct correlatives in Greenland, though the similarities in timing of deformation and timing of granitoid plutonism suggest that there was tectonic continuity. In particular the volcanic upper Aillik Group lacks a clear correlative in Greenland, with the exception perhaps of some small roof pendants in the Julianehåb batholith. Similarly, the Julianehåb batholith and the supracrustal rocks of the Psammite Zone have no direct equivalents in Labrador.

Mineralization: The Makkovik Province is known principally for its uranium mineralization but also contains examples of molybdenum, base and precious metal mineralization.

Uranium mineralization was first discovered in 1951 and extensively explored for through the 1960s and 1970s, resulting in the discovery of the Kitts and Michelin deposits. Mining was planned for 1978-79 but was forestalled by the collapse of uranium prices in the early 1980s. There are several distinct mineralization environments that reflect the complex geological history of the region and the repeated introduction and remobilization of uranium. Each is associated with geographically distinct belts (cf., Gower et al 1982):

Stratabound mineralization is found in the Michelin–White Bear Mountain belt where it is hosted by rhyolitic ash-flow tuffs, the main examples being the Michelin, Burnt Lake and Rainbow deposits. Michelin is the largest deposit in the area, containing 1.64 million tonnes, at a grade of 0.13% U_3O_8 and is associated with widespread sodic metasomatism and more local hematization. Ore genesis probably involved leaching of uranium from devitrified volcanic glass by late-stage diagenetic or hydrothermal fluids, followed by deposition along permeable horizons.

Epigenetic mineralization occurs in the Kitts–Post Hill belt as veinlets and shears in reduced units such as pyrrhotite-rich graphitic argillite, iron formation and mafic metavolcanic rocks of the lower Aillik Group, and is usually found adjacent to major shear zones (Gower et al 1982). The principal deposit is the small, high grade (up to 20% U_3O_8), Kitts deposit (185,000 tonnes at 0.73% U_3O_8). Inda, Gear and Nash represent nearby smaller deposits. Shear-related mineralization is also displayed by boulders of highly-deformed granite at the Melody Hill prospect, which average 11.53% U_3O_8.

Pb-Pb ages on uranium mineralization range between 1805 and 1697 Ma (Wilton, 1996), thus supporting an epigenetic origin. Fluids were likely driven by the intense partial melting and dehydration that is visible in the adjacent Archean basement and possibly also by intrusion of syntectonic granites.

Molybdenum mineralization is found in the upper Aillik Group where skarnoid (andradite–biotite–carbonate) uranium-molybdenum mineralization occurs as linear zones in felsic volcanic rocks possibly overlying concealed granitic plutons (Wilton, 1996). The main example is the Aillik deposit, which contains 2 million tonnes at 0.2 0.3% MoS_2. Younger examples of molybdenum mineralization are also found associated with 1650 Ma granites, including the Burnt Lake occurrence and the Round Pond zone. The latter contains zoned Mo-Pb-Cu-Zn mineralization disposed around high-level stocks (Wilton, 1996).

Base metal mineralization occurs in association with the Moran Lake Group. There are two styles. In the first, the unconformity between the Moran Lake Group and Archean gneisses has been the locus for a number of galena-sphalerite-quartz-carbonate veins of unknown age. In the second, the lower sedimentary part of the Moran Lake Group hosts several zones of massive pyrite in black shale, siltstone and chert. These zones are anomalous in Zn and Cu and locally (e.g. Teuva showing) contain sphalerite up to 2.69% Zn (Wilton 1996).

Precious metal mineralization is not well developed, however, minor examples occur in the eastern Central Mineral Belt. Au is associated with mesothermal-style quartz-vein systems at Pomiadluk Point, and Ag-Au is associated with carbonate-galena and molybdenite-fluorite veins peripheral to high-level stocks such as Round Pond.

Younger Paleo-Mesoproterozoic sequences and intrusions

Between 1650 and 1640 Ma, the southern part of the Makkovik province was intruded by voluminous granitoid and lesser mafic plutons of the Trans-Labrador batholith. Satellite

plutons (e.g Burnt Lake and Round Pond, above) extend well to the north into the Makkovik Province. In the west, the batholith was coeval with formation of a sequence of conglomerate, volcaniclastic sandstone and ignimbrite belonging to the ca. 1650 Ma Bruce River Group. This formed a carapace to the batholith and may have developed at least partially in a caldera environment (Ryan, 1984).

Ca. 1460 Ma, the Nain craton and Southeastern Churchill Province were intruded by the Michikamau and Harp Lake anorthosite – granite massifs as part of what is sometimes referred to as the Elsonian event. This was associated with widespread anorthosite – granite magmatism in Labrador but with the possible exception of the Gardar Province, seems to lack equivalents in Greenland.

In the west, the Trans-Labrador batholith is intercalated with the ca.1320 Ma peralkaline volcanic rocks of the Letitia Lake Group and intruded by associated alkalic-peralkalic syenites. These are unconformably overlain by the ca. 1270 Ma Seal Lake Group, a sequence of red sandstones, shales, basalt flows and gabbro sills. All units were variably deformed in the Grenvillian Orogeny between 1000 and 900 Ma and now straddle the northern boundary of the Grenville Province.

The Seal Lake Group is possibly equivalent to the Eriksfjord Formation of the Gardar province of southern Greenland and may similarly be related to a period of crustal rifting between 1300 and 1130 Ma. The Letitia Lake Group and associated peralkaline — alkaline intrusions are somewhat older than this period, however, their composition suggests a link to Gardar-age rifting.

Mineralization: Uranium mineralization of possible hydrothermal character is associated with discordant zones of intense orange carbonate alteration and diatremic brecciation in mafic flows or sills of the basal Bruce River Group. The main example is the Moran C zone prospect which has given grades up to 1.18% U_3O_8 over 1.32 m. The cause of the alteration and brecciation has been suggested to be due to hydrothermal activity associated with syn-depositional faulting and volcanism in the Bruce River Group (Ryan, 1984). The Moran Lake prospects are also currently being explored in the context of an Iron Oxide-Copper-Gold (IOCG) model on the basis of their association with elevated levels of copper and silver, local hematite-rich breccias and an underlying positive gravity anomaly.

Low grade (0.002% to 0.225% U_3O_8), possible unconformity-related, uranium mineralization is found at the Stormy Lake zone near the basal unconformity of the Seal Lake Group. Pb-Pb ages of 990–860 Ma indicate a possible relationship to Grenvillian deformation and low-grade metamorphism (Ryan, 1984).

Rare-metal mineralization is hosted by peralkaline syenites intrusive into felsic volcanics of the Letitia Lake Group. The Mann No. 1 showing contains 1.8 million tonnes of beryllium-niobium mineralization grading 0.35-0.4% BeO and 0.24% Nb_2O_5. Mineralization occurs both within the volcanic rocks and as veins cutting the volcanics and syenites (Miller 1988). Yttrium is also enriched in the volcanic rocks.

Copper mineralization, of the association native copper-chalcocite-bornite-chalcopyrite, occurs in the Seal Lake Group (Wilton 1996) and is thought to be of redbed-volcanic or Keweenawan style. Although largely vein-hosted, the mineralization is restricted to the grey shales, sandstones and basalts of the upper part of the group and is thus broadly stratabound. Vein formation was probably a result of Grenvillian deformation and remobilization. Vein-hosted Cu mineralization is also found in the Bruce River Group.

Ni-Cu mineralization is present in the Michikamau and Harp Lake intrusions. The Michikamau intrusion (Dyke et al 2004) contains nickel sulphide mineralization in troctolitic units adjacent to the intrusion's contact with metasedimentary rocks of the Petscapiskau Group. The Harp Lake intrusion contains a number of small Ni-Cu occurrences, most of which occur in its eastern half (Kerr and Smith 2000). The mineralization is orthomagmatic and exhibits two styles. The predominant one consists of stratiform zones (probably syngenetic) of disseminated sulphide in leucotroctolite — anorthosite. These are low grade (<1% Ni and Cu) with a sulphide content generally < 5%; however, the tenor in sulphide is high at 6.5%Ni and 3.15% Cu. The other style is represented by massive to semi-massive zones that are discordant and appear to be epigenetic. These are low-grade both in terms of both overall Ni-Cu content and tenor in sulphide (<0.5%). The latter style resembles the Ni-Cu occurrences of the Nain Plutonic Suite.

Current exploration activity

Exploration in Labrador languished in the late 1990s — early 2000s due largely to the depressed base metals market. However, a rebound in prices commenced in 2003 and was followed by a gradual renewal of exploration activity. This has been led by continued interest in Ni-Cu, following from the Voisey's Bay discovery of 1994, but also by a resurgence in uranium exploration. Almost the entire Central Mineral Belt is now staked and ground that was last explored in the late 1970s — early 80s is being looked at again. Ni and Cu exploration continues with an active program on the Michikamau intrusion and new staking in the Seal Lake Group.

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