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COPENA conference at NGU, August 18-22, 1997: Abstract and Proceedings

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REPORT

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Summary:

IGCP project 371 COPENA (Structure and Correlation of the Precambrian in NE Europe and the North Atlantic Realm) is a major current research and correlation venture in the North Atlantic Region and the European Precambrian Craton.

In 1997 the annual meeting of COPENA was arranged at the Geological Survey of Norway in Trondheim, Norway. The meeting focussed on recent advances in understanding the evolution the Proterozoic orogenic belts.

This report contains the abstracts submitted to the meeting, and also includes the conference proceedings and a list of participants.

Two field excursions were arranged in connection with the meeting. The field guides were published as NGU-reports 97.132 (Proterozoic geology and Scandian high-pressure overprinting in the Western Gneiss Region) and 97.133 (Proterozoic basement and Scandian geology of the outer Trondheims fjord).

Keywords: Berggrunnsgeologi	Prekambrium	Stratigrafi
Strukturgeologi	Petrologi	Geokronologi
Geokjemi	Geofysikk	Fagrapport

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COPENA CONFERENCE AT NGU, TRONDHEIM, NORWAY

Abstracts and Proceedings
August 18-22, 1997

Proterozoic Orogenies and Plate Interactions: The North Atlantic Region in Space and Time

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PROGRAM

Monday August 18

8:30:	Registration, Coffee
10:00-11:00	Opening Remarks: Øystein Nordgulen Welcome to NGU: Ron Boyd Information and practical arrangements
11:00-12:00	Project Report. R. Gorbatschev and S.V. Bogdanova: *Collisional and accretional boundaries in Precambrian Europe* .
12:15-12:45	Keynote: K. C. Condie (30 min): *Episodic growth of juvenile crust and the supercontinent cycle*
12:45-13:00	Discussion
13:00-14:00	Lunch
14:00-17:30	First Session of Papers

GENERAL

14:00-14:20	S. A. McEnroe, T. Torsvik and L. Blom: *New Paleomagnetic data linking Laurentia and Baltica in the Mid-Proterozoic*

PALEOPROTEROZOIC OF LAURENTIA

14:20-14:40	J. Ketchum, N. Culshaw, S. Barr, C. White and T. Brown: *Paleoproterozoic evolution of the Makkovik-Ketilidian orogen: overview and new insights from eastern Labrador, Canada*
14:40-15:00	M. Marker, O. Stecher, M. Whitehouse, D. Scott, D. Bridgewater and J. van Gool: *Age of deposition, provenance and tectonic setting of metasediments from supracrustal sequences in the Palaeoproterozoic Nagssugtoqidian Orogen, West Greenland*
15:00-15:40	Discussion and Refreshments
15:40-16:00	M.A. Hamilton: *U-Pb geochronology and Nd isotopic evolution of the Ketilidian Orogon, south Greenland: implications for correlations with the Penokean, Makkovikian and Svecofennian Orogens on the south margin of Laurentia Baltica*

PALEOPROTEROZOIC OF BALTICA

16:00-16:20	E. J. Hanski, H. Huhma, M. I. Lehtonen and P. Rastas: *Isotopic (Sm-Nd, U-Pb) and geochemical evidence for an oceanic crust to molasse evolution of the Palaeoproterozoic Kittilä greenstone complex, northern Finland*

16:20-16:40	T. Torske: *The Caravarri formation of the Kautokeino greenstone belt, northern Norway; foreland basin sediments in front of the Lapland - Kola thrust belt*
16:40-17:10	Discussion
17:30-?	Ice-breaker

Tuesday August 19

9:20-13:00	Second Session of Papers (Note 9:20 Starting Time)

PALEOPROTEROZOIC OF BALTICA (continued)

9:20-9:40	V. V. Proskurjakov, V. A. Bogachev, V. V. Ivanikov, and N. B. Philippov: *Proterozoic magmatic association in eastern Fennoscandia as an indicator of geodynamic environment.*
9:40-10:00	V. V. Ivanikov, and N. B. Philippov: *Geochemical evidence for the geotectonic setting of early Proterozoic metabasalts in the Ladoga region (Russia).*
10:00-10:20	P. M. Evins, N. Ahtonen, M.-L. Airo, J. Mansfeld, and K. Laajoki: *Preliminary Observations from a New Archaen Gneiss Region in the Eastern Part of the Kemijärvi Complex, Northern Finland.*
10:20-10:40	F. P. Mitrofanov and T. B. Bayanova: *A new geochronology of the formation of the Kola rift-obduction system*
10:40-11:20	Discussion and Refreshments
11:20-11:40	V. Vetrin: *Proterozoic granitoids from the region of the Pechenga structure and the Kola superdeep borehole section: evidence of petrology and metallogeny*

EARLY MESOPROTEROZOIC OF LAURENTIA

11:40-12:10	Keynote: T. Rivers and D. Corrigan (30 min): *Convergent margin on southeast Laurentia during the Mesoproterozoic: tectonic implications*
12:10-12:30	M. A. Hamilton: *New U-Pb geochronological results from the Mesoproterozoic Nain Plutonic Suite, Labrador, and implications for the origin and emplacement of massif anorthosites and related rocks*
12:30-13:00	Discussion
13:00-14:00	Lunch

14:00-16:30 Third Session of Papers

EARLY MESOPROTEROZOIC OF LAURENTIA (continued)

14:00-14:20 Å. Johansson, and D. G. Gee: *The Eskolabreen granitoids of southern Ny Friesland, Svalbard Caledonides - geochemistry, age and origin*

EARLY MESOPROTEROZOIC OF BALTICA

14:20-14:40 S. V. Bogdanova, E. V. Bibikova, S. Claesson and R. Gorbatschev: *A Palaeoproterozoic accretional orogen in the east European Craton*

14:40-15:00 T. S. Brewer, J. S. Daly and K.-I. Åhäll: *Constraining crustal growth in south-west Sweden*

15:00-15:30 Discussion and Refreshments

15:30-15:50 A. Birkeland, E. M. O. Sigmond and M. Whitehouse: *From Archaean to Proterozoic on Haradangevidda*

15:50-16:10 J. Mansfeld: *The Mo tonalite - the earliest Gothian rock in southeastern Norway*

16:10-16:30 Discussion

16:30-18:30 Poster Session with Refreshments (Posters remain up throughout meeting)

Wednesday August 20

8:30-18:20 Conference Field Trip:

PROTEROZOIC BASEMENT AND SCANDIAN GEOLOGY OF THE OUTER TRONDHEIMSFJORD REGION

Thursday August 21

9:30-13:00 Fourth Session of Papers (Note 9:30 Starting Time)

EARLY MESOPROTEROZOIC OF BALTICA (continued)

9:30-9:50 J. Andersson: *1,45-1,30 Ga anorogenic granites in the southeastern part of the Sveconorwegian orogen, SW Sweden; tectonometamorphic implications and their use as structural markers*

9:50-10:10 Ø. Skår: *The Precambrian geology in the Sognefjord area, western Norway*

10:10-10:30 K.-I. Åhäll, D. H. Cornell and J. N. Connelly: *The Oslo lineament; a zone of repeated crustal weakness since early Mesoproterozoic times*

10:30-11:00 Discussion and Refreshments

11:00-11:20	E. M. O. Sigmond: *The Precambrian geology of central southern Norway*
11:20-11:40	J. V. Korhonen, H. Säävuori and L. Kivekäs: *Petrophysical characteristics of central Fennoscandian upper lithosphere*
11:40-12:00	P. Padget: *Aspects of the stratigraphy and structure of the Bamble Region, S. Norway*
12:00-12:20	T.-L. Knudsen: *From protocrust to lower crust: The Geochemical evolution of metasediments from the Bamble Sector, Southern Norway*
12:20-13:00	Discussion
13:00-14:00	Lunch
14:00-17:30	Fifth Session of Papers

LATE MESOPROTEROZOIC OF LAURENTIA

14:00-14:20	T. E. Krogh: *Seventy-Five Million Years of Convergence Recorded in the Parry Sound Shear Zone in the Central Gneiss Belt of the Grenville Province*
14:20-14:40	C. G. Barnes, D. R. Smith, W. Shannon: *Origins of 1.1 Ga granitic magmas on either side of the Grenville front, Texas, USA*

LATE MESOPROTEROZOIC OF BALTICA

14:40-15:00	C. Möller: *Decompressed eclogites and late-orogenic deformation, Sveconorwegian (-Grenvillian) orogen, SW Sweden*
15:00-15:30	Discussion and Refreshments
15:30-15:50	T. Andersen: *Sweconorwegian (Grenvillian) Rejuvenation of the Continental Crust in S. Norway*
15:50-16:10	J.-C. Duchesne and U. Schärer: *The anorogenic Rogaland anorthosites and their possible relation to granite genesis in S-Norway*
16:10-16:30	O. Bolle, H. Diot and J.-C. Duchesne: *AMS study of deformation in the Bjerkreim-Sokndal layered intrusion (Rogaland, Southwest Norway)*
16:30-17:00	Discussion
19:30	Conference Dinner at Ringve Museum

Friday August 21

9:50-13:00	Sixth Session of Papers (Note 9:50 Starting Time)

LATE MESOPROTEROZOIC OF BALTICA (continued)

9:40-10:00	Ø. Nordgulen, R. D. Tucker, B. Sundvoll, A. Solli, A. L. Nissen, K. B. Zwaan, A. Birkeland and E. M. O. Sigmond: *Palaeo- to Mesoproterozoic intrusive rocks in the area between Numedal and Mjøsa, SE Norway*

PROTEROZOIC OF CENTRAL EUROPE

10:00-10:30	Keynote: M. Grad and A. Guterch (30 min): *Structure of the earth's crust between Precambrian and Variscan Europe in Poland from seismic data*
10:30-10:50	Discussion and Refreshments
10:50-11:10	P. Bankwitz and J. Hofmann: *Proterozoic basement in the Variscan foldbelt of Central Europe*
11:10-11:30	M. Suk and V. Bezák: *Pre-cambrian units in Alpine-Carpathian system*

TRANSATLANTIC CORRELATION

11:30-11:50	K-I. Åhäll and F. Gower: *Correlations between late Paleoproterozoic Baltica and Laurentia from critical examination of Gothian and Labradorian tectonic settings*
11:50-12:15	Concluding Discussion and Closing Remarks
13:00-14:00	Lunch

LIST OF POSTER CONTRIBUTIONS

P. E. B. Armitage: *Structural geological study of a Precambrian metasupracrustal deformation zone between Mjelde and Skorelvvatn, Kvaløya, Troms, Norway*

A. Braathen and B. Davidsen: *Polyphase deformation in the early Proterozoic Karasjok Greenstone Belt*

T. S. Brewer, S.-Å. Larson and D. P. F. Darbyshire: *Petrogenesis of Transscandinavian Igneous Belt granitoids: implications from southern Sweden*

T. S. Brewer, J. F. Menuge: *Mesoproterozic volcanism in southern Norway*

A. Davidson and O. van Breemen: *A compressional setting for A-type plutonism, Greenville Province, Ontario, Canada*

R. O. Greiling and A. G. Smith: *Late Proterozoic rifting and passive margin evolution of Baltoscandia*

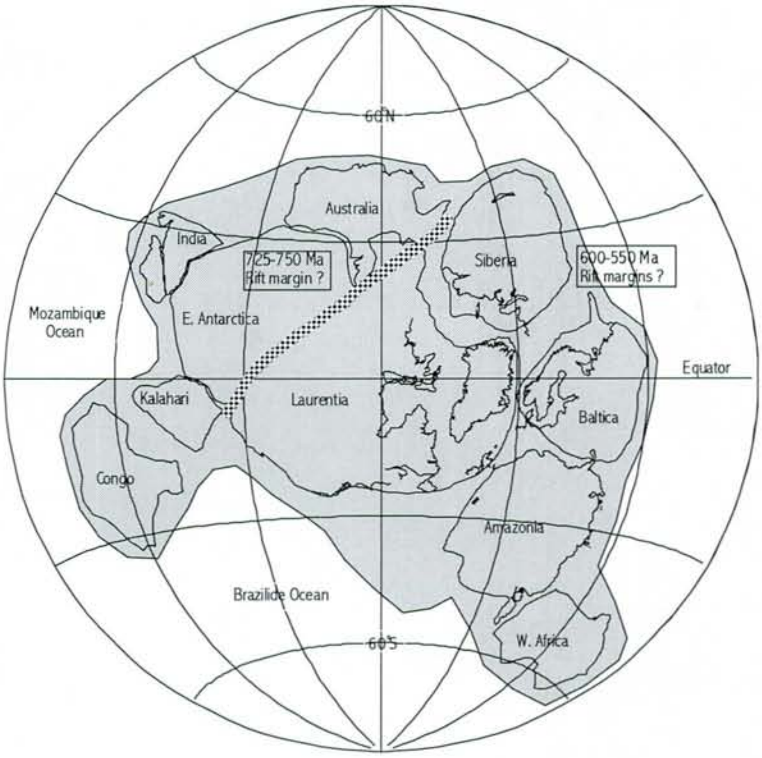
J. V. Korhonen, L. Zhdanova, A. Chepik, J. R. Skilbrei, S. Aaro, R. Vaher and H. Nevanlinna: *Fennoscandian magnetic anomaly data base*

J. V. Korhonen, L. Zhdanova, A. Chepik and H. Säävuori: *Magnetic map of northern Finland and Kola*

O. Levchenkov and V. Shuldiner: *The isotopic dating of volcanic rocks and granites of the north Ladoga area and its significance for stratigraphy of the region*

O. Olesen, G. Brækstad, J. Gellein, H. Håbrekke, O. Kihle, J. R. Skilbrei and M. Smethurst: *Magnetic anomaly map Norway and adjacent ocean areas. Scale 1:3 million.*

ABSTRACTS



COPENA -97

PROTEROZOIC OROGENIES AND PLATE INTERACTIONS:

THE NORTH ATLANTIC REGION IN SPACE AND TIME

SWECONORWEGIAN (GRENVILLIAN) REJUVENATION OF THE CONTINENTAL CRUST IN S. NORWAY

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The Baltic shield has a history of crustal accretion extending back into the Archaean. The southwestern part of the shield, which is delimited to the E by the Protogine zone in South Sweden and to the NW by the Caledonian nappes is the youngest part of the shield, in which a major crust-forming event took place during the Svecofennian orogeny, at 1.9 to 1.75 Ga. Later tectonometamorphic episodes have been identified at 1.6- to 1.5 Ga (Gothian or Kongsbergian orogeny) and at 1.25-0.9 Ga (Sveconorwegian orogeny). It has been argued that the southwestern part of the Baltic shield shows evidence of a somewhat irregular westwards younging trend, from a Svecofennian core-area in central south Sweden towards younger ages of crustal accretion in Southwest Sweden and South Norway, related to processes at successive destructive plate margins during the Gothian (or Kongsbergian) orogeny. However, Nd model ages of the dominant Precambrian lithologies from the Østfold-Akershus, Kongsberg and Bamble sectors of South Norway suggest that these segments of the continental crust have a common pre-history, extending back to at least 1.75 to 1.90 Ga, i.e. into the Svecofennian orogenic period. Little addition of juvenile material to the now exposed parts of the Baltic shield in post-Svecofennian time is indicated by these data.

The Sveconorwegian event in South Norway is characterized by deformation, high-grade metamorphism and emplacement of mafic to granitic intrusions. From available isotopic data, the net contribution of new material from the mantle to the total crust needs not have been large, except perhaps in the Telemark and Rogaland sectors. Towards the end of the Sveconorwegian orogeny, a considerable number of post-tectonic granitic plutons were emplaced, these have been dated to 850-1000 Ma by K-Ar, Rb-Sr and U-Pb methods. Several of the plutons show comparatively low initial $^{87}Sr/^{86}Sr$ ratios (ca. 0.705), which may indicate a significant contribution of relatively young mantle derived material to the granitic magmas, or reflect an origin from a LILE-depleted crustal source. Few Pb and Nd isotope data have been published for these intrusions. The present report gives preliminary data from a study aiming to characterize the composition and geochemical evolution of the unexposed continental crust in the soutwestern part of the Baltic Shield by integrating Sr, Nd and Pb isotope data on late Sveconorwegian granites in the Østfold, Kongsberg, Bamble and Telemark sectors.

Nd model ages on c. 925 Ma granites from the Østfold, Kongsberg and Bamble sectors indicate a distinct "westwards younging" trend of the source of granitic magma, with average crustal residence ages of 1.69 Ga (Iddefjord, Østfold sector), 1.57 Ga (Flå, Kongsberg sector) and 1.50 Ga (Herefoss, Bamble sector). This is correlated with decreasing time-integrated $^{238}U/^{204}Pb$ from east to west, and with a slight, less systematic decrease of $^{87}Sr/^{86}Sr$ at 925 Ma.

The Sr, Nd and Pb systematics of the Iddefjord, Flå and Herefoss granites can be adequately explained by binary mixing between a moderately LILE-enriched crustal endmember ($\varepsilon_{Nd}^{925}= -7.8$, $\varepsilon_{Sr}^{925}= 120$, $t_{DM}= 1.9$ Ga, $\mu=17-22$) and a Sveconorwegian mantle-derived component ($\varepsilon_{Nd}^{925}= 5.9$, $\varepsilon_{Sr}^{925}= -12$, $\mu=7.9$). The fraction of juvenile Sveconorwegian mantle-derived material in the source of granitic magma increases westwards: It is 15-40 % in the Østfold sector, 25-50 % In the Kongsberg sector and 50-70 % in the Bamble sector. The lack of evidence of a westwards younging trend for the upper or exposed continental crust in this area suggests that the systematic variation in the contribution of juvenile mantle material to the granite source is due to introduction of westwards increasing amounts of juvenile material from the mantle into a pre-existing lower crust, before or contemporaneously with crustal anatexis. It is tempting to relate this "underplating" event with the c. 930 Ma anorogenic mafic magmatism in the Rogaland sector, but definite evidence for such a correlation is still lacking.

By the end of the Sveconorwegian period, the continental crust of the southwestern part of the Baltic Shield had acquired a compositionally layered structure. The uppermost part of the crust consisted of rocks with highly elevated Rb/Sr and U/Pb ratios ($f_{Rb} > 21$, $^{238}U/^{204}Pb > 24$), comprising Sveconorwegian metasediments, their yet unidentified source terrane(s) and granitic rocks formed by anatexis of this type of material (e.g. the ca. 1.4 Ga Tvedestrand granite). This crustal domain was penetrated by mafic intrusions, charnockite / augen gneiss intrusions and post-orogenic intrusions.

The structurally underlying "lower" crust consisted of two components: a moderately LILE-enriched crustal component with a crustal prehistory extending back to 1.6 to 1.9 Ga ($f_{Rb} = +7$ to $+ 8$, $^{238}U/^{204}Pb = 17-22$), and a more recent, mantle-derived component. The crustal component served as a source of the 1.15-1.2 charnockite / augen gneiss intrusions in the Bamble sector and to the 989 Ma Grimstad granite (L. Kullerud, unpublished data), and a combination of both components gave rise to the Iddefjord, Flå and Herefoss granites. Introduction of the mantle-derived component amounts to crustal rejuventation by an «underplating» process. The present data allow this process to be tentatively dated to the latest part of the Sveconorwegian orogeny, after emplacement of the Grimstad granite. Possibly, underplating in South Norway may be coeval with, and genetically related to late Sveconorwegian mafic- anorthositic magmatism in the Rogaland-Vest Agder sector.

The LILE and REE depleted rocks of the Tromøy area in the Bamble sector are restricted to meta-igneous lithologies, and are associated with metasediments of the upper continental crust; low LILE concentrations may thus reflect other processes than regional, fluid induced depletion. There is as yet no isotopic evidence for the regional presence of a "LILE-depleted lower continental crust" at depth during the Sveconorwegian orogeny in S. Norway.

1.45-1.30 GA ANOROGENIC GRANITES IN THE SOUTHEASTERN PART OF THE SVECONORWEGIAN OROGEN, SW SWEDEN; TECTONOMETAMORPHIC IMPLICATIONS AND THEIR USE AS STRUCTURAL MARKERS

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In the southwesternmost part of the Baltic Shield in Sweden, the post-Svecofennian rocks were reworked during the Sveconorwegian (-Grenvillian) orogeny (c. 1.2-0.9 Ga). Although the metamorphic imprint of the Sveconorwegian orogeny is evident, the extent and character of the Sveconorwegian deformation is not fully understood.

The strongest tectonometamorphic imprint is observed south of Lake Vänern in the Eastern Segment, which is separated from the considerably less reworked western region by a roughly N-S trending major shear zone of Sveconorwegian age, the Mylonite Zone. The Eastern Segment is characterized by the abundance of rocks metamorphosed at upper amphibolite- to granulite-facies conditions, where high-grade, veined, orthogneisses of granitic to intermediate compositions dominate. The gneisses are intruded by c. 1.45-1.30 Ga granitoids which are considered to be anorogenic in relation to the c. 1.64-1.55 Ga Gothian and the c. 1.2-0.9 Ga Sveconorwegian orogenies. P-T estimates of metamorphic rocks yield temperatures of c. 700-800°C and pressures of c. 9-12 kbar; conditions under which partial melting of granitic rocks will take place where hydrous fluids are present. However, investigations of the c. 1.45-1.30 Ga granitoid massifs in the region show that these intrusions are considerably less reworked than the surrounding country rocks, although partial melting occur locally.

The less pervasive and less veined gneissic fabric in the anorogenic granitoids has been used as evidence for a pre-Sveconorwegian main gneiss-forming event, which predates the emplacement of the anorogenic massifs, i.e. > 1.45 Ga, commonly referred to as the Gothian orogeny. However, using anorogenic massifs as structural markers is difficult since the ability to form a gneissic fabric depends primarily on the mineralogical and textural properties of the granitoids (Vernon & Flood 1987). Differences in competence between intrusions and country rocks, and the presence of early formed foliations such as magmatic or pre-existing solid state foliations are other important factors controlling the response of deformation in the massif at a given stress regime (Paterson & Tobisch 1988; Paterson et al. 1989). Additionally, a bulk heterogeneous strain pattern is common in granitoids deformed in the solid state, resulting in the development of weakly deformed tectonic lenses surrounded by shear zones of high-strain (Choukroune & Gapais 1983; Gapais 1989). Consequently, detailed structural investigations are required in order to accurately interpret the field relations between different rock units in the region.

Detailed studies of a c. 1.37 Ga coarse-grained K-feldspar porphyritic granite massif at Tjärnesjö, in the central parts of the Eastern Segment show that the main parts of the massif have experienced post-emplacement solid-state deformation. It is heterogeneously deformed where rocks within the massif vary from almost massive tectonic lenses, to strongly foliated augen-gneisses, in places migmatitic with stromatic veining. Protomylonitic varieties with garnet porphyroclasts also occur, and strongly gneissic parts of the granite may be difficult to distinguish from rocks belonging to the surrounding gneiss complex in the absence of continuous exposure.

There is a conformal structural pattern between the studied granitoid massifs and the surrounding country rocks where the gneissosity is subparallel *or* crosscuts lithological boundaries. At Tjärnesjö, the gneissosity in the southern part of the granite and the surrounding country rocks defines a NNE-trending, slightly westwards overturned, apparent synform plunging gently to the NE. The synform in part coincides with the southeastern continuation of a Sveconorwegian deformation zone (the Ullared Deformation Zone; Möller et al. 1997).

The structural relations between the studied c. 1.45-1.30 Ga granite massifs and the gneissic country rocks suggest a common tectonometamorphic history. The less pervasive gneissic fabric in parts of the studied anorogenic granitoids is suggested to result from the bulk chemical, mineralogical and textural properties of the studied massifs. Hence, the timing of the orogenic event which caused substantial reworking of the region is bracketed by the intrusion age of the youngest reworked granitoid massifs, the c. 1.37 Tjärnesö-Torpa granites, and the occurrence of c. 0.95 Ga post-kinematic pegmatite dykes. A Sveconorwegian age for this gneiss-forming event is supported by geochronological work on metamorphic minerals from rocks within the region which solely have yielded ages around 1.0-0.9 Ga.

Remnants of pre-Sveconorwegian structures referred to as Gothian (1.64-1.55 Ga) have been described by previous workers in the region. Still, investigations of the structural relations between the c. 1.45-1.30 Ga anorogenic granites and the surrounding gneissic country rocks described here, have failed to recognize the presence of pre-Sveconorwegian structures and consequently conceivably older structures are suggested to have been totally overprinted by the Sveconorwegian event in the studied areas.

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Structural geological study of a Precambrian metasupracrustal deformation zone between Mjelde and Skorelvvatn, Kvaløya, Troms, Norway

***Cand. scient.* thesis**

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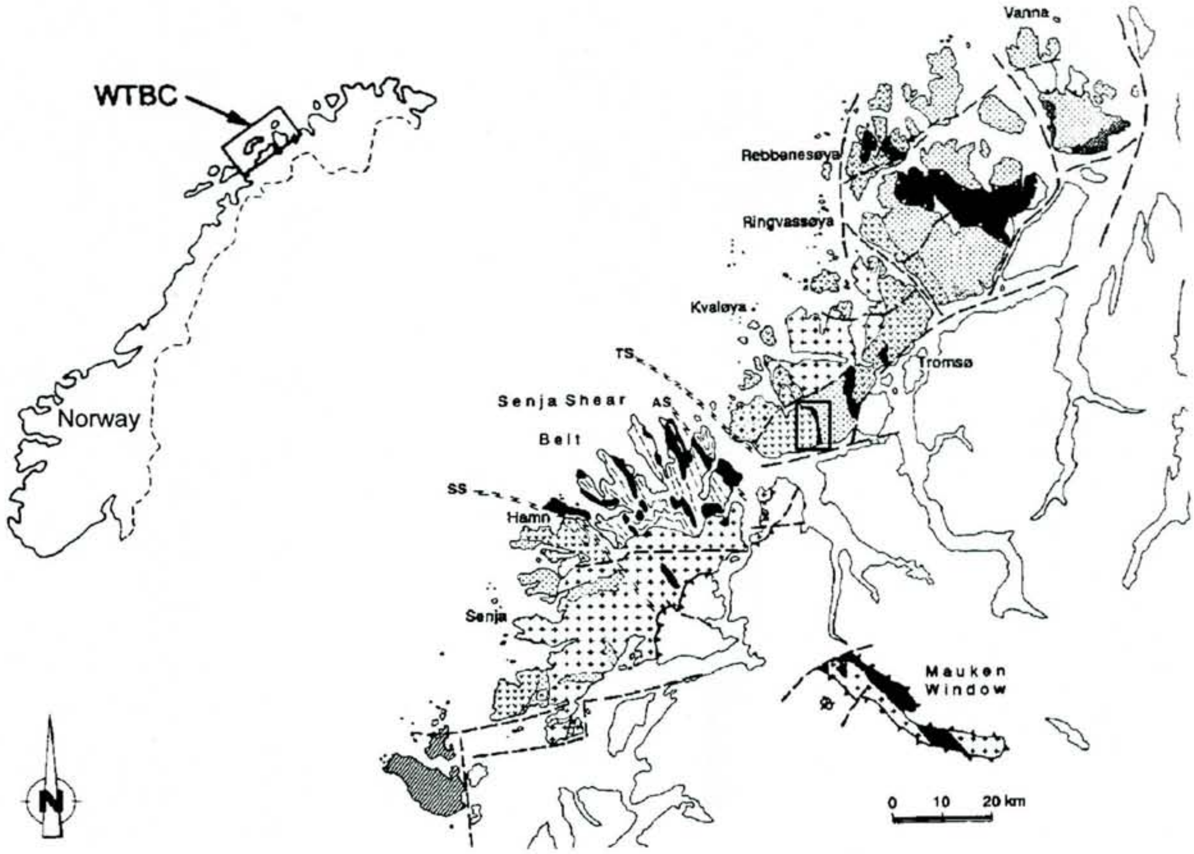
Within the West Troms Basement Complex (WTBC) on southern Kvaløya, a 8 km long and up to 1 km wide, NNW-trending belt of steeply W-dipping metasupracrustal rocks (Skorelvvatn Formation?) is sandwiched between the virtually undeformed Bakkejord Diorite to the west and the foliated Buvik Tonalite/Gråtind Migmatite to the east. Roughly E-W trending felsic dykes cut the main foliation in the Buvik Tonalite and metasupracrustals in the north-east, but the dykes are partly foliation-parallel. An unsuccessful attempt has been made to date these felsic intrusives - they are believed to derive from the Ersfjord Granite, which has a crystallisation age of 1706 ± 15 Ma.



Location map (small rectangle indicates study area). Map legend is omitted. WTBC = West Troms Basement Complex, SS = Svanfjellet Shear Zone, AS = Astridal Shear Zone, TS = Torsnes Shear Zone. Modified from K.B. Zwaan, "Geology of the West Troms Basement Complex, northern Norway, with emphasis on the Senja Shear Belt: a preliminary account", NGU Bulletin 427, 1995.

Structurally, the belt is characterised by two-phase ductile deformation (D_1-D_2). D_1 was the foliation-forming phase with isoclinal folding. Structural data have so far failed to show a regular pattern of orientation for F_1 fold axes (trending NW to S with shallow to steep plunges). Stretching lineation (L_1) plunges moderately W to NW.

D_2 structures are represented by (i) macro- and mesofolds (F_2) that fold the main foliation (S_1), and (ii) ductile shear zones (S_2) that partly transect and are partly parallel with S_1 (bend-straight geometry). F_2 folds have moderately to steeply plunging axes with curiously opposing trends (NNE and about SSW). These folds are observed as parasites in a large fold in the north-eastern corner of the study area. The large fold may have formed by drag on the eastern side of a main sinistral shear zone, west of which the rocks are characterised by the regional NNW-trending foliation. S_{2a} comprises a set of steeply dipping SE-striking shear zones with sinistral sense, while S_{2b} zones strike NNE or SSW with steep dips and dextral sense. Structural data show that S_{2b} shear zones have similar orientations to F_2 axial surfaces. Lineation in the shear zones (L_2) seems to be lacking, and slip directions have not yet been determined (via the orientation of drag-fold axes).

A third phase of deformation (D_3) is characterised by brittle extensional faults that strike about SW with steeply dipping slickenlined surfaces. These faults are most likely associated with the Kvaløysletta-Straumsbukta Fault, part of which is believed to run immediately south of the study area and has a downthrow of at least 2 km, resulting from post-orogenic collapse during the opening of the Atlantic Ocean in the Tertiary.

The current study aims to formulate possible evolutionary models for the metasupracrustal belt. It has previously been suggested that the belt may represent an Archean inclusion in the surrounding intrusives. However, there are many lithological, metamorphic and structural similarities to other belts in the region that may represent Proterozoic suture zones.

PALAEOPROTEROZOIC EVOLUTION AND DEEP STRUCTURE OF THE NORTH-EASTERN BALTIC SHIELD

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The following tectonostratigraphic terranes can be distinguished in the region: the Belomorian, Inari, Central Kola and Murmansk (all of them are classified as composite and dispersed), Lapland and Umba granulite (accreted units), and the paraautochthonous Tanaelv terrane. The Belomorian, Inari, Central Kola and Murmansk terranes comprise both Archaean and Palaeoproterozoic units, whereas the Lapland, Umba and Tanaelv terranes are composed of rocks derived largely from Palaeoroterozoic juvenile material.

The formation of the dispersed terranes was initiated during a 2.5-2.4 Ga rifting and a break-up of an Archaean heterogeneous crust into tectonic blocks under transtensional conditions at ENE-WSW extension (in present co-ordinates). Main Palaeoproterozoic rift-origin belts (Kittila-Panajarvi-Windy Belt, Tanaelv-Kolvitsa and Polmak-Pasvik-Pechenga-Imandra/Varzuga) were located along the margins of these blocks. Only the Tanaelv-Kolvitsa palaeorift gave rise to a linear basin with oceanic crust. The closure of this basin at c. 1.9 Ga resulted in a collision at NNE/SSW compression, in a dispersion of the tectonic blocks and in their change into dispersed terranes. The Lapland Granulite Belt is a the largest 1.9 Ga old collisional suture in the region and comprises the Lapland and Umba accreted granulite terranes.

A buried part of this suture is located in the Tersky area, i.e. in the junction zone between the Belomorian and central Kola terranes. A discovery of rocks with Sm-Nd model ages of 2.1-2.2 in the given area (Timmerman & Daly, 1995) favours this conclusion. Terrane boundaries are represented by regional shear zones. Some of these shear zones originated during the extension 2.5-2.4 Ga ago and were re-activated during the collision c. 1.9 Ga ago.

At present, six seismic profiles are available for the north-eastern Baltic Shield and adjacent Barents Sea region: (1) Keivy, (2) Imandra-Varzuga, (3) Belomorian, (4) Pechenga-Kovdor-Kostamuksha as a part of the EU-3 transect, (5) Quartz and (6) Southern Barents Sea. Re-examination of these profiles has revealed some main crustal boundaries considered to be boundaries of the sedimentary cover at the floor of the Barents Sea, the volcano-sedimentary rocks of the Pechenga-Imandra/Varzuga palaeorift, alkaline granites and their host metavolcanics in the Keivy domain, the Lapland granulites, upper and lower crust, a transition layer between lower crust and mantle as well as the Moho surface. These data, results of a 3-D density modelling and the geological model have permitted a tentative deep geological profile across the region, to be constructed.

The Murmansk terrane was thrust to the S-SW onto the Central Kola terrane in the Keivy domain.

The rocks of this domain were thrust further to the S-SW onto the eastern Imandra-Varzuga belt. Deep portions of the Keivy domain are composed of rocks the physical parameters of which are like those of alkaline granites. The Umba granulites and rocks of the buried part of the suture seem to be related to the same terrane. Its south-western contact dipping to the N-NE can be the main thrust and its north-eastern one a back-thrust. But geophysical data show that the main thrust might coincide with the north-eastern contact, which dips to the S-SW.

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PROTEROZOIC BASEMENT IN THE VARISCAN FOLDBELT OF CENTRAL EUROPE

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Central Europe is part of the West European plate due to final collision of the Variscides during the Carboniferous. The plate consists of Cadomian and Caledonian terranes from Gondwana, Avalonia, Armorica and probably from the East European plate. The "classical" Devonian to Carboniferous Variscan sequences are underlain by early Palaeozoic and Proterozoic series with an unconformity in between. In large areas the Hercynian stacking has brought the series into a reverse position. During recent years numerous age determinations have shown the strong imprint of Hercynian tectonics on the units of Palaeozoic and Proterozoic age.

The multistage collision of terranes in Cadomian times in Central Europe (Northern Gondwana) was followed by a period of rifting until the early Ordovician. This resulted in the separation of different microplates and the development of intervening basins. All Proterozoic series are of Neoproterozoic age (upper Riphaean and Vendian). Only from single zircons in sedimentary rocks have higher ages (ca. 3 Ga) been found.

The Pre-Variscan basement beneath the middle and upper Palaeozoic Variscan **foredeep** is composed of Cadomian (Brabant, Lüneburg, East Elbian massifs) and Caledonian units (Avalonian accretion belt, including the southern North Sea). The only rock evidence for a Precambrian basement within the foredeep are anorthosite enclaves in Permian volcanic rocks from a super deep drilling in north-east Germany. Seismic patterns support the presence of the supposed Proterozoic massifs. Precambrian protoliths have also been found south of the Tornquist-Teisseyre zone in drill holes of Schleswig-Holstein and southern Jütland.

In the southwards positioned **Rhenohercynian** zone the Precambrian is represented by: 1. the Ecker gneiss (560 Ma) and 2. enclaves within an upper Palaeozoic magmatic dike in the Harz mountains, 3. the Wartenstein gneiss in the southern Rhenish massif (Hunsrück). Ordovician sediments have been found in several places in the eastern Harz and in the southern Rhenish massif.

The **Mid German Crystalline zone** (MGCZ) is a complex structure including Precambrian relics, for instance Liebenstein gneiss (Ruhla crystalline, Thuringia) and metamorphic complexes of Hohndorf and phyllitic Prettin-Drehna series (to the northeast of Leipzig).

The **Saxothuringian zone** (STZ) is built up in its eastern part from Neoproterozoic series and is strongly overprinted by Hercynian events. This zone is characterized by Hercynian gneissification, nappe tectonics and by tectonic core complexes (Saxon Granulite massif, MP/MT units of the eastern and central Erzgebirge). Less metamorphosed units in Thuringia reveal Sm/Nd and Zr ages between 480 and 520 Ma (Middle Cambrian to lower Ordovician). Indications of a Cadomian unconformity, proven by the absence of Cambrian and/or of early Ordovician sequences are present also in Thuringia as in Saxonia and Lusatia. The protolith ages of the Cadomian basement (intrusions and country rock) range from 740 to 600 Ma (supracrustals from the Münchberg gneiss complex and eastern Erzgebirge) and cluster around 550 Ma (granodioritic to granitic intrusions of the eastern to central Erzgebirge and in Lusatia). In the low grade units, in several places a Proterozoic age is proven by microfossils and by a common stratigraphic succession. The Vendian is widely distributed in the STZ, but Riphean units are dominant with regard to thickness and complexity.

The **Moldanubicum** has a similar seismic stacking pattern of Hercynian age as the STZ. It consists of high grade units up to granulite and eclogite facies. It is possible that the passive margin lithology of the Saxothuringian Cambro-Ordovician continues into the Moldanubian zone. The terrane assemblage of the Moldanubian happened in the lower Carboniferous. The Moldanubian variegated group which in former years was believed to represent the typical Proterozoic of Central Europe, is now seen as early Palaeozoic. This series seems to be deposited on a 2.1 Ga crystalline basement. To the east of the Moldanubicum the Brno massif occurs, which has a basement of 585-540 Ma granitoids. These were deformed into orthogneisses during Hercynian time. Farther to the east an amphibolite from a drill hole south of Krakow yielded an age of 870 Ma and Vendian is proven in the Krakow-Lubliniec zone and the Malopolska massif.

ORIGINS OF 1.1 Ga GRANITIC MAGMAS ON EITHER SIDE OF THE GRENVILLE FRONT, TEXAS, USA

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Middle Proterozoic granites in Texas (1.08 to 1.12 Ga) occur on both sides of the Grenville Front. Previous studies [1] interpreted all Texas Proterozoic granitic suites to be compositionally similar and to share a single tectonic environment. Anderson [2] included them as part of an ~1.1 Ga "anorogenic" magmatic pulse. However, deformation along the Grenville Front occurred after some or all of the granites were emplaced [3], so that at ~1.1 Ga, a regionally uniform tectonic environment was unlikely. The isotopic compositions of these granites are independent of their location; therefore, isotopic data do not permit clear distinctions to be made among mantle or crustal sources, or tectonic settings [4]. In contrast, ~1.1 Ga granites on either side of the Grenville boundary are distinct in terms of their rock types, mineralogy, and trace element compositions [5]. Thus, they do not share a common origin.

In west Texas, the ~1.12 Ga Red Bluff granitic suite (RBGS) was emplaced into an undeformed ~1.25 Ga contact-metamorphosed shelf sequence presumed to overlie the Yavapai-Mazatzal province. These units lie north of the Grenville Front and are considered to be part of Laurentia. In this area, granitic magmatism was also accompanied by emplacement of the rift-related Pecos intrusive complex in west Texas [6] and by injection of steeply-dipping ferrobasaltic dikes. The suite is mostly metaluminous; it consists of early granitic to quartz syenitic sills, a main mass of alkali feldspar granite, small bodies of alkali feldspar syenite, leucogranitic dikes, and late-stage peralkaline arfvedsonite granite. Mafic minerals are iron-rich, with $Fe/(Fe+Mg) > 0.85$; these assemblages result in estimated f(O2) near FMQ. The least evolved granitoids yield zircon saturation temperatures of 1050°C. These features combined with high concentrations of high field strength and rare earth elements serve to classify the suite as "within-plate" A-type. Evidence for a subduction-related origin is absent.

Mass-balance models for the RGBS are consistent with fractional crystallization from a ferrobasaltic parent; trace element tests indicate crystal-liquid separation was inefficient. Partial melting models using known basement rocks as sources fail to reproduce observed trace element abundances and trends within the suite. The mildly alkaline nature of the granitic suite and its lack of subduction-related geochemistry are consistent with an origin in a zone of regional extension [6, 8]. The RBGS is, in most respects, compositionally identical to the late sodic series of the coeval Pikes Peak batholith. These rocks are also thought to have formed by extensive fractional crystallization of basaltic parents, probably in an extensional regime.

In the Llano uplift of central Texas, 1.08-1.12 Ga granites intrude polydeformed 1.20 to 1.35 Ga gneiss, schist, and amphibolite, sparse metaserpentinite and eclogite of the Grenville Province [7]. The tectonic setting of the Llano uplift during magmatism is uncertain. Syn-magmatic deformation within some of the plutons suggests that magmatism accompanied waning stages of Grenville deformation, however other plutons are apparently undeformed. The plutons are remarkably similar in their mineralogy and their elemental and isotopic compositions.

The 1.08 Ga [7] Enchanted Rock batholith (ERB) is typical of the province. It displays reverse concentric zonation [9] and ranges from outer coarse-grained granite, granodiorite and quartz monzonite, to inner fine- to medium-grained quartz monzonite and leucogranite [9]. Intermediate rock types are rare and coeval basaltic or syenitic rocks are lacking. Most ERB samples are metaluminous; a few are slightly peraluminous. Outer zone rocks are two-feldspar porphyritic granites with megacrystic alkali feldspar and local rapakivi texture. Fe-rich biotite is present in both zones; significant amounts of calcic amphibole is present locally in the outer zone. Accessory minerals are magnetite, sphene, zircon, apatite, allanite, and fluorite. Fine-grained, dark colored microgranular magmatic enclaves are metaluminous and have slightly lower silica contents than the host granites. They are interpreted to be hybrid magmas injected into and quenched by the host granitic magma [10]. The enclaves contain alkali feldspar and amphibole crystals inherited from a deeper-seated granitic magma, not the present host granite.

Biotite and amphibole in the ERB show lower $Fe/(Fe+Mg)$ compared to the RBGS, and calcic amphiboles in the ERB are hastingsitic, rather than edenitic as in the RBGS. Ga/Al ratios and Nb, Y, and REE abundances in the ERB are considerably lower than in the RBGS. ERB rocks are generally not classified as A-type, but instead overlap I-, S-, and M-type fields.

The data are consistent with emplacement of two or more magma types in the ERB. Samples from the two zones with similar SiO2 content or Eu/Eu* exhibit geochemical differences (e.g., Fe/(Fe+Mg) in whole-rock samples and biotites, Cs and Hf abundances in whole-rock samples, Pb isotopic ratios). Variations in Sr, Ba, Rb, and Eu/Eu* among outer zone samples are modeled as in situ feldspar fractionation; HFSE and REE ratios are largely controlled by accessory minerals. Inner zone samples probably lack significant cumulus crystals.

The paucity of intermediate and mafic rocks associated with the Llano granites and the large volume of granite in the uplift (~45% of the exposed area [11]), suggest that the granites were anatectic melts of crustal sources. Such melting explains the regional homogeneity of the granites, compared to the extended compositional range of the RBGS. Tonalitic/granodioritic crust is an appropriate source that could yield the high K2O calc-alkaline ERB magmas [12]. Trace element batch melting models combined with the experimental results [13] are consistent with either tonalitic/granodioritic source rocks or granulitic/restitic ones. However, Ba, Rb, and Th data are best explained by tonalitic/granodioritic sources. Such source rocks may have been emplaced during a previous collisional (subduction?) event and persisted after Grenville collision to become involved in the production of post-orogenic granite.

Circa 1.1 Ga granitic magmatism in Texas was apparently manifested as two compositional groups. North of the Grenville Front, the Red Bluff granitic suite represents a pulse of highly evolved syenitic and granitic melts that were derived by fractional crystallization of mantle-derived basaltic parents emplaced in an extensional tectonic setting. South of the Grenville Front, in the Llano uplift of central Texas, 1.1 Ga granitic magmatism is best explained as the result of melting of widespread tonalitic/granodioritic basement rocks. The tectonic setting of the Llano granites is uncertain and further work is needed to determine the relative timing of plutonism, final Grenville deformation, and juxtaposition of Grenville crust with Laurentia.

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FROM ARCHEAN TO PROTEROZOIC ON HARDANGERVIDDA.

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Crust formation in south Norway - ambiguities of time and process.

The Precambrian crust in South Norway is part of the Southwest Scandinavian Domain, interpreted by many to be younger than *c.* 1800 Ma. However, Ragnhildstveit et al. (1994) reported concordant U-Pb isotope ages of single zircons from the Hardangervidda of 2503 Ma. This indicated that the crust of south Norway could have a longer history than previously supposed.

Geology and analytical procedures.

For the present study the same granitic gneiss described by Ragnhildstveit et al. in 1994 was re-sampled for *secondary ion mass spectrometer* (SIMS) analyses of zircons. The analysed sample, a severely deformed and metamorphosed fine-grained pink granite, found *c.* 4 km northwest of Kalhovd, notably west of the Mandal-Ustaoset Fault Zone, belongs to a multiplicity of granites of different ages and sizes which intrude metasedimentary and possibly also metavolcanic rocks.

Zircons were separated from a rock sample of *c.* 20 kg. To avoid any possible contamination of Archean zircons, the crushing and first zircon separation were performed at the Mineralogical-Geological Museum in Oslo where Archean zircons had not previously been handled. After careful selection, zircons were mounted in epoxy, and polished to expose sections through the crystals. Imaging of the crystals by back scattered electrons and cathodoluminiscence, utilizing the secondary electron microscope at IKU Petroleum Research in Trondheim, enables us to interpret the origin of the crystals on which the SIMS-analyses where performed. These analyses were performed using the joint-Nordic facility for geological SIMS (NORDSIM), at the Swedish Museum of Natural History, Stockholm. U-Pb analytical procedures closely follow those described by Whitehouse et al. (1997).

From the Archean to the Proterozoic on Hardangervidda.

Five groups of concordant ages were obtained: c. 1600 Ma (36 analyses), c. 1500 Ma (15 analyses), c. 1100 Ma (2 analyses), 2838 Ma (1 analysis) and 2735 Ma (1 analysis).

The 1600 Ma and 1500 Ma ages record two distinct events. Zircons yielding these ages are igneous with pyramidal prisms and exhibit well evolved oscillatory zoning. 1600 Ma is interpreted as the age of the intrusion, whereas the 1500 Ma age records an input of new magma.

Out of 35 analysed crystals, one came up with two statistically distinct Archean events. The oscillatory zoning appearing from the CL images indicates that both events were igenous. Furthermore, neither the core nor the outer rim are rounded, showing that the crystal had not been abraded. This could indicate that the crystal had not been transported by sedimentary processes for long distances.

The present analyses record one post-igneous event. The age is not well enough represented in the data set to allow *precise* age interpretation, but it is clearly Sveconorwegian. The CL and BSE images show that it appears as distinct overgrowths on igneous crystals and that this event is metamorphic, interpreted from the rather diffuse zonation. This age may represent the event by which the two magmatic pulses at 1600 Ma and 1500 Ma, respectively, were moulded intimately together.

Conclusions.

The main igneous event at *c.* 1600 Ma was succeeded by input of new magma at *c.* 1500 Ma, and subsequent metamorphism at *c.* 1100 Ma. Furthermore, the rock records two Archean magmatic events, close in age but statistically distinct. The lack of abrasion of the Archean zircons justifies the hypothesis that Archean magmatism took place in the same region where the zircons are now found. It is thus likely that processes of Archean magmatic crust formation are represented in the interior of South Norway.

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A PALAEOPROTEROZOIC ACCRETIONAL OROGEN IN THE EAST EUROPEAN CRATON

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A ca. 1000 km wide accretional orogen that was formed by a semi-continuous process between ca. 2.0 and 1.6 Ga ago occupies the entire western part of the East European Craton. This orogen extends from the Ukraine across northeastern Poland, Belarus, northwestern Russia, the Baltic States and Finland to Scandinavia where it merges with the Svecofennian and Gothian orogens of the Baltic Shield (Fig.1). Farther west, a continuation can be traced across northern Scotland, southern Greenland, southernmost Labrador and the Great-Lakes region of North America to the borderlands of Nevada, Arizona, and California. From there, this orogenic belt most probably continues into East Antarctica. This giant belt of accretional continental crust, which took ca. 450 Ma to form, is the oldest sizable non-collisional orogenic belt as yet identified on Earth. It appears to have followed the margin of a Palaeoproterozoic supercontinent that was composed of now distant Precambrian cratons and comprised most of the then existing continental crust. Within that supercontinent, the closest neighbours of ancient Europe were "Laurentia" (i.e. ancient North America plus Greenland), "Siberia" (the western and central parts of present Siberia) and "Amazonia" (the Precambrian craton in the north of South America).

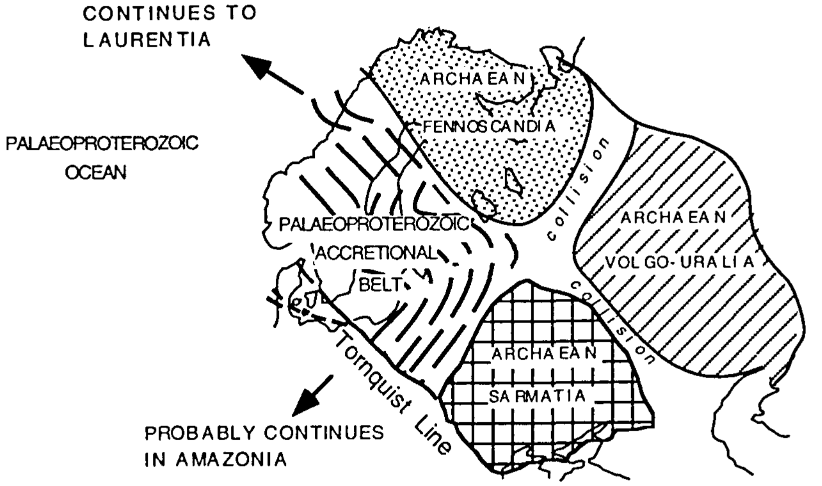

Fig. 1

While the Svecofennian accretional orogen (SF) of the Baltic Shield has been known for a long time, its southern continuation is buried beneath platformal sediments that reach 5 km in thickness. It had therefore been recognized only 5-6 years ago on the basis of drillcore studies, correlation of aeromagnetic and gravity data, and recent isotopic and geochronological research. By now it has been established that similarly to the SF of the Shield, this Baltic-Belorussian-Polish (BBP) part of the orogen was formed between ca. 2.0 and 1.8 Ga ago from juvenile mantle materials with only a small contribution of Archaean sedimentary detritus.

The crustal pattern of the BBP features several 100-200 km wide granulite- and amphibolite- facies belts which are juxtaposed and separated by crustal discontinuities. These belts trend SSW-NNE. Farther north, however, they swing WNW in the northern BBP and join rock-belts found in southern Finland. E-W trending zones of faulting complicate the Palaeoproterozoic tectonic fabric, apparently controlling the distribution of Meso-Neoproterozoic intrusions. The tectonic subdivisions of the crust are manifested by magnetic, gravity, seismic and magnetotelluric heterogeneities both in the crust and the subjacent lithosphere.

Available isotopic data (Sm-Nd, U-Pb zircon and monazite) and petrological, particularly metamorphic studies of the different units of the BBP clearly evidence an accretional nature of the crust. At least three terranes, each containing both granulite- and amphibolite-facies belts, can be identified. They have ages of ca. 2.0-1.9 Ga, ca. 1.9-1.85 Ga and ca. 1.85-1.8 Ga, respectively, reckoned from the southeast to the northwest.

The Palaeoproterozoic crustal evolution appears to have been dominated by a sequence of accretional/compressional events that involved early crustal thickening and tectonic emplacement of granulite-facies units into higher structural levels. This was followed by rifting, crustal extension and magmatic underplating. In this process, successively younger episodes of Palaeoproterozoic accretion affected the previously formed Proterozoic crust.

The tectonothermal activity in the BBP appears to have lasted longer than in the SF. Ductile deformation along distinct belts affected the whole BBP at 1.7-1.67 Ga, while E-W zones of strike-slip movements developed between 1.55 and 1.4 Ga. Similar events have been suggested for parts of southeastern Sweden.

The particulars of the crustal development in the BBP can possibly have been affected by the existence of a thick continent in the Sarmatian crustal segment farther southeast. This continental mass was amalgamated with the other Archaean parts of the East European Craton after ca. 2.0 Ga. A wide Andean-type magmatic belt of ca. 2.0 Ga age along the northwestern edge of Sarmatia indicates a convergent geodynamic regime in the region.

The Palaeoproterozoic coexistence and interaction of contrasting crustal segments in the western part of the craton predetermined much of the subsequent reorganization of the lithosphere during the Proterozoic and also in the Palaeozoic.

AMS STUDY OF DEFORMATION IN THE BJERKREIM-SOKNDAL LAYERED INTRUSION (ROGALAND, SOUTHWEST NORWAY)

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The Bjerkreim-Sokndal layered intrusion (BKSK) (Michot, 1960, 1965; Duchesne, 1987; Wilson et al., 1996) belongs to the Rogaland anorthosite complex (Southwest Norway). This complex intruded into granulitic migmatic gneisses 930 Ma ago (Schärer et al., 1996). It is characterized by a graviational anorogenic tectonic: diapirism of anorthosite massifs (Duchesne et Maquil, 1987) and subsidence of BKSK included by a density inversion resulting from the location of BKSK within lower-density gneiss and anorthosite (Paludan et al., 1994). BKSK can be subdivided into: 1°) a lower anorthosito-noritic part which is layered, solid-state deformed and folded into a doubly-plunging syncline; 2°) a massive and very little deformed quartz mangeritic upper part occupying the core of the syncline.

Anisotropy of Magnetic Susceptibility (AMS) measurements (Borradaile, 1988; Rochette et al., 1992; Bouchz, 1997) have been performed on 300 cores drilled in the upper part, the southern (Sokndal) lobe of the syncline and southeastern quartz mangeritic-monzonoritic apophysis. The results show first that titanomagnetite is govering the magnetic fabrics and gives high mean susceptibility values correlated to petrographic variations. The orientation data (magnetic foliations and lineations) are remarkably consistent with field structures measured in the northern (Bjerkreim) lobe by Paludan et al. (1994) and reveal that the whole massif is cutted by a solid-state deformation with converging lineations. The scalar parameters specify the deformation symmetry and put forward a decrease in the magnetic fabric magnitude towards the top of the intrusion. This latter character confirms the solid-state fabric intensity decrease in the upper part of BKSK because the magnitudes of the magnetic fabric and that of the strain correlate as shown in the southeastern apophysis (Bolle, submitted).

Finally, it appears that AMS, which here finds its first application in a massif of the anorthosite-charnockite suite, could be a new and very sensitive tool for the structural characterization of this type of intrusion.

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POLYPHASE DEFORMATION IN THE EARLY PROTEROZOIC KARASJOK GREENSTONE BELT

Alvar Braathen[1], Børre Davidsen[2]

The Karasjok Greenstone Belt of the northwestern Baltic Shield forms the westernmost, tectonostratigraphically lowest unit in an early Proterozoic mobile belt, traceable from the northern margin of the Karelian Province in Finland northward into Finnmark, North Norway. In Finnmark this nearly 100-km wide mobile belt consists of linear segments of highly strained rocks that are separated by N-S striking thrust zones. The belt records crustal mobilization, tectonic reworking and metamorphism, and stabilization of Archaean and early Proterozoic lithosphere during a 2.1-1.7 Ga cycle of rifting, contraction, and subsequent stabilization and uplift.

The Karasjok Greenstone Belt consists of low- to medium-grade volcanogenic and sedimentary units that are intruded by small intrusive bodies. The entire package is folded in a recumbent synform that can be related to a regional deformation episode, designated **D_1**. This deformation resulted in transposition of primary features and formation of an E-dipping penetrative foliation and banding. In this foliation, a well-developed E-plunging stretching lineation of elongated minerals and, in some cases, volcanoclastic fragments and pillows, occurs. Major D_1 thrusts, evident as mylonites and blastomylonites, are found (i) locally at the base of the belt, (ii) at high tectonostratigraphic levels, and (iii) mark the upper boundary of the greenstone belt. Shear-sense indicators support E-directed displacement along the thrusts.

The superimposed **D_2** episode is evident as open to tight, E-plunging folds of the D_1 foliation. A major low-angle, ductile to semiductile D_2 thrust, which reveals top-to-SSW sense-of-shear, occurs near the base of the greenstone belt. The **D_3** episode is manifested as upright, open and N-S-trending folds of the former (D_1 and D_2) structures. First order D_2 and D_3 folds reveal parasitic folds and crenulation cleavages in the hinge-zones, whereas discrete shear-zones modify the fold-limbs. These folds are truncated by steep NE-SW-striking brittle faults of **D_4** affinity.

The polyphase deformation seen in the Karasjok Greenstone Belt supports a model in which the assembling of the various units in the regional mobile belt occurred from major E-W contraction/collision during the D_1 episode. At this stage the greenstone belt was isoclinally folded during W-directed overthrusting of medium- to high-grade complexes. The following D_2 episode of NNE-SSW shortening and SSW thrust-emplacement suggest dextral and orogen-oblique movement patterns, prior to continued orogen-perpendicular E-W shortening during the D_3 episode. The final faulting (D_4) may relate to a post-orogen shield-scale strike-slip event.

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CONSTRAINING CRUSTAL GROWTH IN SOUTH-WEST SWEDEN

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The oldest crust west of the Mylonite zone in the South-West Scandinavian Domain is represented by a three volcano-sedimentary sequences which are all intruded by c. 1.59 Ga cale-alkaline granitoids of the Göteborg Batholith. The ca. 1.6 Ga Stora Le-Marstrand Formation (SLM), comprising mainly greywacke-type sediments and subordinate metabasalts, was deformed and metamorphosed (at amphibolite facies) prior to the intrusion of the c. 1.59 Ga granitoids. The basalts from this formation have very primitive trace element signatures and depleted Nd isotopic compositions all of which are consistent with their formation in an oceanic island are setting. The c. 1.66 Ga Horred Formation is a sequence of amphibolite facies supracrustals, dominated by intermediate to felisc volcanics, although basaltic compositions are common. The trace element and Nd isotopic compositions of volcanics suggest dervation in an island are setting. The Åmål Formation is the youngest sequence and is composed of greenschist to amphibolite facies supracrustals, which are dominated by intermediate to felsic volcanics. The trace element and Nd isotopic signatures suggest that these volcanics developed along a convergent continental margin. The diversity in the lithological geochemical and isotopic signatures of the three volcanic sequences suggests that the SLM and Horred formed outboard of proto-Baltica and were subsequently accreted during the late Paleoproterozoic. The detailed timing of the collison and accretion of these arcs is not yet fully constrained. The Åmål Formation may possibly have developed on thickened crust which formed as a result of collision between the SLM and Horred Formations before 1.61 Ga. Final Gothian crustal assembly took place after 1.61 Ga and before 1.59 Ga when the evolving collage was stitched together by the Göteborg Batholith. Throughout the late Paleoproterozoic (1.9-1.6 Ga) a convergent plate margin was developed along the (present-day) western edge of proto-Baltica.

PETROGENESIS OF TRANSSCANDINAVIAN IGNEOUS BELT GRANITOIDS: IMPLICATIONS FROM SOUTHERN SWEDEN

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The Baltic Shield forms the major exposure of Precambrian crust in northern Europe and its principal component of Fennoscandia, which is one of the crustal segments of the East European Craton. Crust in the Baltic Shield defines a simple age pattern, with the Archaean in the north east and progressively younger Proterozoic terranes to the south and west. The northern Archaean nuclei provided a cratonic region onto which the Palaeoproterozoic Svecofennian juvenile are terranes were accreted at c. 1.9 Ga. This accretionary event represents a major episode of juvenile crustal growth, which was followed by the intrusion of granitoids in the Transscandinavian Igneous Belt (TIB: 1.85-1.65 Ga) and by rapakivi magmatism in Finland, Estonia, Russia and Sweeden (1.65-1.5 Ga).

The Transscandinavian Igneous Belt (TIB) is a c. 1600 km long by 20-150 km wide belt composed predominantly of granitoid intrusions developed at the western margin of the Svecofennian Province. The granitoids range in composition from quartz monzonites to granites, although some more basic compositions do exist. The majority of the granitoids are metaaluminous or peraluminous in composition, although a small number are very weackly peralkaline. The vast majority of the granites can be classified as I-type, with some being aluminous A-type.

In southern Sweden TIB granitoids are characterised by e_{Nd} values of 0.7 to 2.8 and depleted mantle ages (TDM) of 1.94-2.11 Ga. There appears to be a trend towards more depleted signatures with time which is consistent with the whole rock geochemistry. The Nd-isotope systematics suggest derivation from a juvenile source, such as the Svecofennian crust, with the addition of a mantle component. In southern Sweden there is no evidence for a significant Archaean contribution to the TIB. The key points to be addressed in considering the petrogenesis of the TIB granitoids are the mechanism for producing large volumes of I-type material and why there are three discrete episodes of magmatism.

MESOPROTEROZOIC VOLCANISM IN SOUTHERN NORWAY

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Remnants of an episode of basaltic volcanism at ca. 1.16 Ga are recorded in the south-west Scandinavian Domain by the Bandak (southern Norway) and Dal (south-west Sweden) Groups. The Bandak Group is the youngest part of the Telemark Supergroup and is exposed in a series of outcrops extending from the Oslo Graben in the east to the Caledonides in the west (Sigmond 1978). In each of these outcrops basaltic lavas are intercalated with conglomeratic and clastic sediments and minor subordinate felsic volcanics. Individual lava flows wary from <1 m to at least 5 m thickness and can be identified by vesicular and highly altered margins. All of the sequences have been metamorphosed to at least greenschist facies, although in some regions lower amphibolite facies assemblages are recorded. Detailed major, trace and rare-earth element data is available for all of the volcanic formations, which demonstrates the predominance of basaltic compositions which are in the main part controlled by fractional crystallisation of plagioclase + pyroxene assemblages. The majority of the basalts are enriched in the light rare-earth elements, although in the youngest most basalts in the central Telemark region (Gjuve Formation) there is a progressive flattening in the REE profiles. Overall however the REE profiles would suggest shallow levels of melting in the mantle, consistent with passive mantle upwelling, with no involvement of a plume. A slight complicaton to such a model is the negative Nb anomalies displayed by all of the basalts, which previously has been interpreted as a subduction related component. However, it is more likely that this is reflecting melting or melt interaction with enriched sub-continental lithospheric mantle. This enriched source was probably created during previous melting and/or extraction episodes prior to this volcanic episode.

This extensive basaltic magmatism is therefore interpreted as being related to extension along the Proto-Baltic margin prior to the Sveconorwegian orogeny.

EPISODIC GROWTH OF JUVENILE CRUST AND THE SUPERCONTINENT CYCLE

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Major peaks in granitoid and greenstone isotopic ages are recognized at about 2.7, 1.9, and 1.3 Ga on all continents, the 2.7 peak being the "tightest" of the three. Nd isotopic results indicate that these three age peaks are times of major worldwide juvenile crust production. Furthermore, the timing of collisional deformations shows that supercontinents formed within 50-100 My of each peak, suggesting a link between juvenile crust production and supercontinent formation. Rates of juvenile crust production may increase during supercontinent breakup, caused by increased mantle upwelling or/and mantle plume activity causing an increase in the production rate of submarine plateaus and arcs, both of which are essential for the growth of continents. Later in the supercontinent cycle, as new supercontinents begin to form over mantle downwellings and mantle plume/upwelling activity decreases, juvenile crust production rate falls off. This could account for the 50-100 My time lag between the three juvenile crust peaks and the corresponding supercontinent formation peaks. >From the age distributions in continental crust, it would appear that Earth history can be divided into three stages:

I) >2.8 Ga, when greenstones and microcontinents formed and collided continuously, although probably not forming a supercontinent until about 2.7 Ga; large volumes of continental crust were probably recycled into the mantle during this stage;

II) 2.8-1.3 Ga, when a clear episodicity is apparent in ages, and where maxima in both juvenile crust and supercontinent production rate occur at 2.7, 1.9, and 1.3 Ga; and

III) <1.3 Ga, when again there is no evidence of episodic ages, yet both juvenile crust and supercontinents continue to form.

Why was the period of time between 2.8 and 1.3 Ga so different from both the earlier and later stages? Could it be related to changes in mantle convection patterns during Stage II? Two scenarios for the origin of the 2.7, 1.9, and 1.3 Ga age peaks merit serious consideration: 1) Supercontinent thermal insulation leads to heating of the mantle beneath supercontinents and to consequent enhanced mantle plume and/or mantle upwelling activity; and 2) Catastrophic overturn of the mantle is initiated by episodes of sinking of cold lithospheric slabs through the 660-km seismic discontinuity to the D" layer, where the slabs are heated to generate plumes. Both scenarios result in a "pulsating" mantle that could account for the three maxima in juvenile crust production, each followed by supercontinent formation. But why only between 2.8 and 1.3 Ga? Before 2.8 Ga, there were either no supercontinents (scenario 1) or no catastophic slab sinking at the 660 discontinuity (resulting in layered convection) (scenario 2). But why was there not another thermal event in the mantle after 1.3 Ga? For scenario 1, perhaps the significant overlap in time between assembly and breakup stages of post-1.3-Ga supercontinents masked the effects of the corresponding thermal insulation events. Alternatively, the Earth may have changed from partially layered convection to entirely whole-mantle convection, thus eliminating catastrophic slab avalanches at the 660 discontinuity after 1.3 Ga.

A COMPRESSIONAL SETTING FOR A-TYPE PLUTONISM, GRENVILLE PROVINCE, ONTARIO, CANADA

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Previously published ages of plutonic rocks in the Central Metasedimentary Belt of the Grenville Province in southeastern Ontario suggested restriction of 1.30–1.23-Ga calc-alkaline igneous activity to a region (Elzevir terrane) which is underlain predominantly by carbonate and volcanic rocks at variable metamorphic grade, and of 1.18–1.15-Ga plutonic rocks to part of an adjacent region to the southeast (Frontenac terrane), which is underlain by a quartzite-pelite-marble association metamorphosed to relatively low-pressure granulite facies. New U-Pb zircon ages extend the younger plutonism throughout Frontenac and into southeastern Elzevir terrane (Sharbot Lake domain). The boundary between the two terranes is a major ductile shear zone, inclined to the southeast and exhibiting thrust-sense kinematics; parallel, subsidiary shears of similar sense occupy the northwest part of Frontenac terrane. Plutons of the 1.18–1.15-Ga Frontenac suite, which has 'within-plate', A-type chemical attributes, are undeformed in the Sharbot Lake footwall and in the interior of Frontenac terrane, but are deformed and recrystallized in the bounding shear zone, where their secondary mineral assemblages locally infer granulite-facies conditions (opx-cpx-grt). However, no evidence for a distinct post-plutonic event has been found among zircon populations extracted from the deformed plutonic rocks. Moreover, published U-Pb titanite and $^{40}Ar/^{39}Ar$ hornblende ages throughout the region imply regional cooling beginning at the time of plutonism. Regional granulite-facies metamorphism in Frontenac terrane appears to have peaked at about the time of emplacement of the earliest members of the Frontenac suite (~1180 Ma) and had waned through titanite closure before crystallization of the youngest plutons (~1155 Ma). The plutonic rocks within the shear zone are thus interpreted to have recrystallized during deformation as they cooled from magmatic temperature. This implies that Frontenac and Elzevir terranes were juxtaposed before, but remained in compression during emplacement of the A-type Frontenac suite. The boundary is further stitched by granite and syenite plutons, undeformed in the shear zone, and dated between 1090 and 1065 Ma.

The anorogenic Rogaland anorthosites and their possible relation to granite genesis in S-Norway

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The Rogaland massif-type anorthosites were intruded coevally with layered intrusions both showing various types and degrees of deformation. Petrogenetic evidence indicates polybaric crystallization and diapirism, and U-Pb zircon ages substantiate that all massifs were formed at 931 ± 2 Ma (Schärer *et al.*, 1996). Since they all post-date last compressional phases by more than 50-70 m.y, deformation within the intrusions must be a result of stress, generated by diapiric emplacement and concomitant sagging of adjacent magma chambers. An important observation is that emplacement of the Rogaland anorthosites overlaps in time with the age of many South Norwegian granites and with hyperite and monzodiorite occurrences, for which geodynamic explanations remain controversial (Andersson *et al.*, 1996). We propose here that their origin is directly related to the Rogaland thermal event, which produces and emplaced extensive gabbroic-anorthositic magma chambers in the lower crust, inducing crustal melting in intermediate and higher crustal levels, to generate the granites.

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PRELIMINARY OBSERVATIONS FROM A NEW ARCHAEN GNEISS REGION IN THE EASTERN PART OF THE KEMIJÄRVI COMPLEX, NORTHERN FINLAND

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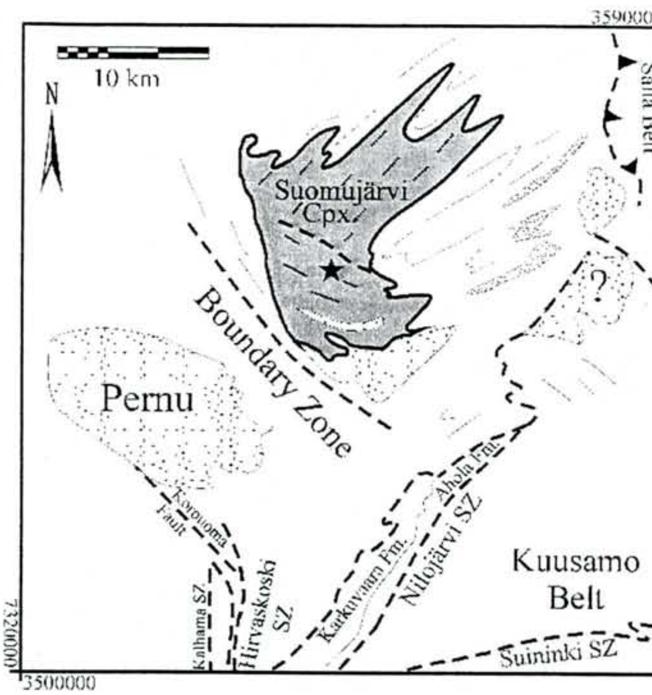
The Kemijärvi complex has previously been represented as a large area of undifferentiated Proterozoic granitoids and gneisses bound by Karelian supracrustal belts in Central Lapland. New preliminary U-Pb geochronological data suggest that a portion of these gneisses and possibly some undeformed granitoids crystallized in the late Archaean. Analyses of zircon fractions from the Jumiskonjoki tonalite gneiss produce a discordia intercept at 2825 ± 27 Ma which is interpreted to be the age of crystallization. Tonalite gneisses similar in age have been described in Archaean blocks north and south of this area. Geochemically this gneiss is typical of Archaean TTG's elsewhere in the Baltic Shield (LREE enriched, low K/Na ratio, and low U content).

Similar, more complexely deformed orthogneisses occur north of this area. This dominantly orthogneissic complex (the Suomujärvi complex) is represented by an aeromagnetically high (25 km^2) arc in the eastern part of the Kemijärvi complex. The boundaries of the Suomujärvi complex have tentatively been drawn according to its potential field characteristics. Its high magnetization is mainly due to felsic to intermediate rocks with densities < 2700 kg/m^3 (granites, tonalite gneisses, and granite gneisses). Based on their low Q-ratios (remanent/induced magnetization), the magnetization is carried by coarse grained magnetite. The related regional Bouguer-anomaly high implies that the Suomujärvi complex is underlain by more dense (>2800 kg/m^3), mafic material such as the high grade schists, gneisses and amphibolites that occasionally crop out in the region.

The NE trending (8X15 km) northern arm is dominated by a NE trending gneissosity associated with subhorizontal SW plunging isoclinal folds. This fabric is cut by a weak moderately SW dipping/NW trending foliation in the SE trending (6X10 km) southern arm. The presence of a strong SW plunging quartz L-S fabric and km wavelength NW verging folds in the southern arm suggest a period of northeastward thrusting in the southern region of the Suomujärvi complex. This thrusting may be related to the same NE-SW shortening that produced similar structures in the Archaean blocks to the north. The ≈ 4 km wide SW boundary between the Suomujärvi complex and the 16 x 8km Pernu granite is marked by a set of NW trending aeromagnetic lineaments as well as parallel elongate strongly magnetic granite bodies with intervening Jumiskonjoki gneisses suggesting the nature of this contact is both intrusive and tectonic. This boundary separates the strongly magnetic (deeper crustal?) Suomujärvi complex to the north from less magnetic rocks (shallower crustal?) rocks to the south. Their magnetic differences may also be due to the relative contribution of mafic parentage to rocks on either side of the boundary. The NE boundary of the Suomujärvi complex is interfolded with paragneisses and quartzites of unknown age. The eastern extent of the paragneissic region is marked by a tectonic zone separating it from the Salla greenstone belt.



THE EVOLUTION OF BASIC MAGMATISM IN THE EASTERN PART OF FENNOSCANDIA.

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(St.Petersburg State University, Russia)

According to available data, late Proterozic (Riphean) basic rocks occur in the northern (north-east) Kola Peninsula and the southern margins of Fennoscandia. In the south, Riphean basic magmatites form a belt of small intrusions, dykes and lava fields extendeding from southern Sweden, through Finland to southern Karelia (Pashsky graben).

Riphean magmatism of the southern part of Fennoscandia can be divided into three main stages: sub-Jotnian, Jotnian and post-Jotnian. These names are based on relationships between igneous rocks and Jotnian deposits.

Jotnian deposits were found in different regions of Fennoscandia: lake Mälaren (Eckerman 1937, Gorbatchev 1962, 1967) - Sweden; Satakunta and Muhos (Simonen, Kouvo 1955) - Finland; lake Ladoga region - Russia and so on. According to the different data, the age range of the rocks is 1.318-1.362 Ga.

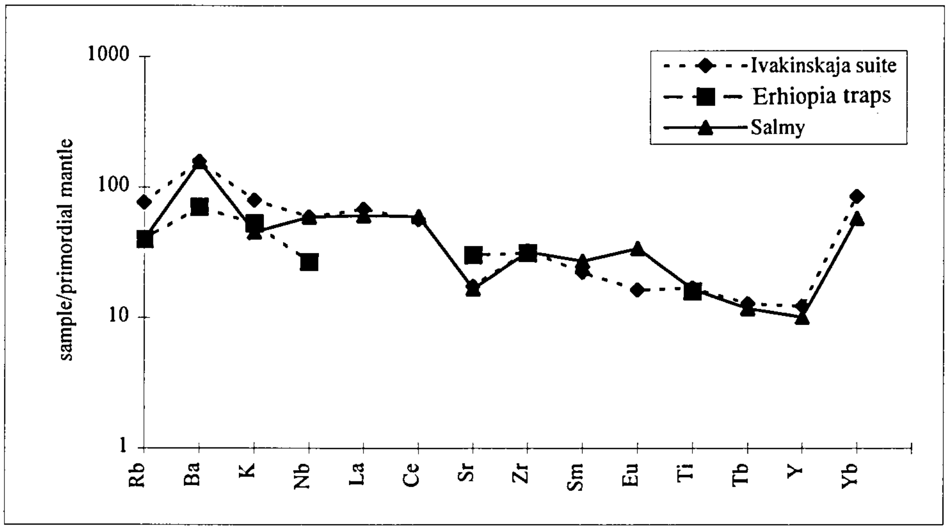
The magmatites of the sub-Jotnian stage are represented by doleritic dykes associating with rapakivi massifs, anorthosites and quartz porphyry dykes in southeastern Finland and southern Karelia. The age of the diabase dyke at Fogla located on the eastern coast of the Åland archipelago is 1.577±12 Ga.

Magmatism of the post-Jotnian stage is represented by dyke swarms and small intrusions of olivine dolerite. These rocks are very similar to each other. They occur on both the Finnish and Sweden coasts of the Bothnian gulf. In the Satakunta area sub-Jotnian rocks cut and overlie Jotnian sandstones. The age of a number of dykes from the Åland archipelago and Satakunta areas is 1.264±12 Ga.

Pashsky graben occupies approximately the whole of the Ladoga lake territory and is filled by a volcanogenic-sedimentary complex. This complex includes a sequence of lava and sandstone layer named the Salmenskaja suite, Valaam sill and Nopunvaara intrusion. The age of magmatic rocks of this complex is 1.352±52 Ga. The same age was shown by Tuna-dolerite dykes of the Southern Dalarna region (Sweden). It allows us to say that the magmatic rocks of the Pashsky graben belongs to the Jotnian magmatic impulse which is simultaneous with sedimentation within the grabens of the southern part of Fennoscandia.

The sub-Jotnian magmatism is similar to early Proterozoic magmatic associations (Sumian-Sariolian). The last one started the continental stage of the eastern Fennoscandia development. Thus, we can say that new stage of continental crust development starting by the sub-Jotnian, affected the Eastern European platform.

Further, the evolution of the southern part of Fennoscandia was by riftogenic processes. Shallow-water basins were formed. These basins started to fill with terrigenous sand-clay deposits. Simultaneously, basic magmatism appeared. This magmatism is similar to traps as regards its chemistry and morphology. The best example of this magmatic type are volcanogenic rocks of the Pashsky graben. The basalts of the Salminsky suite are quite different from other within-plate basalts of the Karelian domain of Fennoscandia in geochemical composition. The same basalts are rare in within- plate geotectonic settings all over the world. So one of the most important aims is to find analogies.



Compared with the most evolved withinplate magmatic complexes of different ages such as the Red Sea Rift and Norilsk trap complexes the similarity to the initial magmatic stage of a riftogenic development was noted. This stage is represented by the Ethiopia traps in the Red Sea Region and the Ivakinskaja suite in the Norilsk region. The similarity of their composition is shown by allmenn spider diagram (Fig). The rocks are enriched in Fe`O, TiO_2, alkalis (especially K_2O), P_2O_5 and LIL elements; depleted in SiO_2, MgO and HFS elements.

Evidence of the early stages of the riftogenic processes is provided by the low degree of melting of by the uprising mantle diapir. The lithosphere was very thick at the time and its destruction was in an early stage.There was an absence of eruption zones or centers. In the history of Fennoscandian development this stage was named aulacogenic. Unfortunately, migmatites of this stage of continental rift development were still not reported from other regions of Fennoscandia. They were eroded later or depressed during the rift development process. Thus, the Pushsky graben magmatites could be the key to understanding Ripean riftogenic processes in southern Fennoscandia.

Post-Jotnian basic rocks are represented by dyke swarms of olivine tholeiites. The chemical composition of these rocks is characterized by higher MgO and lower alkalinity than these of Jotnian. They were not significantly differentiated. It allows us to say something about the continuation of rift development, mantle diapirism and extension of melting processes. Probably, the volcanic products were eroded and now we see only the intrusive dyke complexes.

COLLISIONAL AND ACCRETIONAL CRUSTAL BOUNDARIES IN PRECAMBRIAN EUROPE

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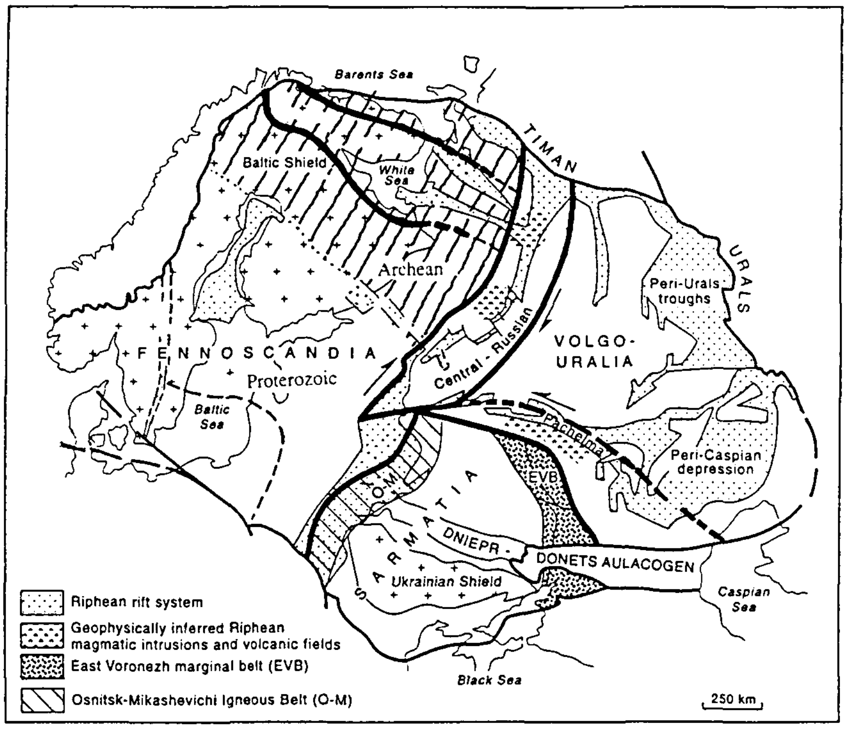
COPENA, study of the Precambrian cratons around the North Atlantic, demonstrates the prominence of collisional orogeny which led to the formation of mega- and supercontinental crustal masses. Conversely, however, this realm has also been affected by rifting and fragmentation of its protocratons.

While such processes can be grouped into constructive and dispersive episodes, comparison between the component crustal segments of the East European Craton suggests substantial regional variation. The latter half of the Proterozoic was dominated by collisional and accretional growth of continents throughout the North Atlantic realm. Before that, however, the Archaean of the Fennoscandian crustal segment and part of Laurentia underwent dispersal between ca. 2.5 and 2.1 Ga ago. In the Sarmatian crustal segment, in contrast, there was at that time assembly of its various terranes. This process of assembly appears to have commenced in the late Neoarchaean but was particularly active between ca. 2.3 and 2.1 Ga ago.

The present structural image of Precambrian Europe is very much determined by the collisional sutures created by the welding together of the three crustal segments Fennoscandia, Sarmatia, and Volgo-Uralia. A fourth segment looms in the north in the shape of the northern terrane of the Kola Peninsula. This terrane was once possibly a part of proto-Barentsia, but these relationships are much obscured by the superimposed Timanide belt.

In marked contrast with the Palaeoproterozoic collisional orogenies in the interior parts of both Precambrian Europe and Laurentia was the long-lived (ca. 2.1 to 1.6 Ga) accretional orogenic situation in what are now the western third of the East European Craton and the southern marginal belt of Laurentia.



The crustal sutures and boundaries in the different parts of the East European Craton have been a particular target of COPENA work. Three of the marked groups of sutures separating the different crustal segments of that craton (the Kola-Lapland, The Central Russian, and the Pachelma sutures) are pronouncedly collisional orogenic features, but vary much in geometry (Tectonophysics 268, p. 1-21), presumably as a function of obliquity of collision, its speed, and the crustal character in the adjoining cratons. The suture between Proterozoic Fennoscandia and Sarmatia along the southwestern continuation of the Central Russian aulacogen is, in contrast, an accretional boundary. In this regard, it is comparable to the boundary between Archaean and Proterozoic Fennoscandia. However, it appears rather better marked both geophysically and in geology, possibly because the

Archaean crust of Sarmatia ends abruptly along this boundary, whereas the Archaean part of Fennoscandia appears to extend for some distance beneath Proterozoic Fennoscandia.

Another kind of difference is that the suture between Volgo-Uralia and Archaean Fennoscandia is marked by very little if any calc-alkaline volcanism and TTG-type plutonism, while the suture boundaries delimiting Sarmatia feature extensive wide belts of such rocks (marked O-M and EVB in the sketch map). Characteristically, Sarmatia is both chronologically and palaeomagnetically the most "exotic" of all the crustal segments that form the Precambrian craton in Europe. It can therefore be expected to have had a long pre-collisional history of its active margins. The Lapland-Kola suture belt is somewhere in between these two.

As seen in the sketch map, each of the collisional orogenic beltsseparating Fennoscandia, Sarmatia, and Volgo-Uralia have subsequently evolved into Mesoproterozoic ("Riphean") and later rifts and aulacogens. This demonstrates a high degree of structural inheritance throughout time.

As different from the collisional boundaries considered above, the orogenic boundaries within the accretional Proterozoic part of the craton are much less distinctly marked. In that part there were numerous episodes of formation of juvenile continental crust that overlapped in time. Collision during the accretion of island arc terranes has certainly occurred, but the boundaries thus formed have been stitched extensively and obscured by granitic plutonism. Apart from the Archaean-Proterozoic boundary in Fennoscandia, the boundaries of lithological provinces therefore commonly appear to have been more important controls of faulting than the boundaries between age subprovinces. One exception, however, a case of major terrane thrusting, may be the boundary belt marked by a broken line across the southern Baltic Sea in the sketch map. Within the "Svecofennian" rocks in Scandinavia there is younging southwards across this line, while in Lithuania and Poland it is a tectonic boundary between E-W structural grain in the west and NNE-trending stacked, beltiform terranes in the east. Another exception, originally possibly a zone of extension, may be the N-S striking line that is marked by the subsequently formed Vättern rift in southern Sweden.

Elsewhere in the Baltic Shield part of the western accretional. Palaeoproterozoic orogen, however, it took the much later collisional Grenvillian-Sveconorwegian orogeny to create suture-like crustal boundaries.

STRUCTURE OF THE EARTH's CRUST BETWEEN PRECAMBRIAN AND VARISCAN EUROPE IN POLAND FROM SEISMIC DATA

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Determination of the deep crustal structure of the contact zone between the Precambrian Platform of Eastern Europe and the Palaeozoic Platform of Central and Western Europe was the main aim of the deep seismic surveys carried out in Poland during the last three decades. The result of deep seismic soundings have shown that the crust in the marginal zone of the East European Platform the Teisseyre-Tornquist Zone, has highly anomalous properties. The width of this zone ranges from 50 km in central Poland to about 90 km in northwestern and southeastern Poland. The crustal thickness of the Palaeozoic Platform in Poland is 28-35 km, and of the Precambrian Platform 42-47 km, while in the Teisseyre-Tornquist tectonic zone it varies from about 35 km to 50-55 km. The velocities and stratification of the Earth's crust vary distinctly along the Teisseyre-Tornquist Zone. The Teisseyre-Tornquist tectonic zone determined in this manner is a deep tectonic trough with paleorift properties.

In May 1997 a large international seismic refraction and wide angle reflection experiment «POLONAISE» is planned in the area of the contact zone between the Phanerozoic and Proterozoic European crustal domains in Poland.

Late Proterozoic rifting and passive margin evolution of Baltoscandia

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Subsidence analysis has been applied to the late Proterozoic and Palaeozoic sedimentary sequences of the western margin of Baltica during its evolution from intracontinental rifting to a passive margin of the Iapetus Ocean.

Cryogenian and late Neoproterozoic (III) lithostratigraphic information from Scandinavia is compiled both from published and unpublished (T. Thelander, Stockholm) sources and from the first author's observations. These data cover the Dividal Group and Torneträsk Formation at the Caledonian front and particularly the more substantial late Proterozoic sequences in the Caledonian Lower and Middle Allochthons (i.e. lower part of Jämtland Supergroup and equivalents). They have been backstripped and the water-loaded subsidence has been estimated. Stretching parameters, the beginning and end of stretching and duration of stretching have been estimated. Strain rates have been found by applying inverse modelling to the sequences.

Results are displayed on diagrams and palaeogeographic maps. Proceeding on the assumption that pre-separation rifting episodes can be recognised on both sides of the developing oceanic realm, the detailed information on rifting events may be a tool of correlation between primarily opposing passive margins.

U-Pb GEOCHRONOLOGY AND Nd ISOTOPIC EVOLUTION OF THE KETILIDIAN OROGEN, SOUTH GREENLAND: IMPLICATIONS FOR CORRELATIONS WITH THE PENOKEAN, MAKKOVIKIAN AND SVECOFENNIAN OROGENS ON THE SOUTH MARGIN OF LAURENTIA-BALTICA.

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The period *c.* 1900-1700 Ma has long been recognized as an interval of accelerated crustal growth through juvenile arc magmatism on the south margin of an amalgamated Laurentia-Baltica supercontinent, postulated to have extended from the Great Lakes region in North America (Penokean orogen) through Labrador and south Greenland (Makkovikian and Ketilidian orogens) to parts of Scandinavia (Svecofennian orogen). The Ketilidian orogen, a particularly well-exposed segment of this extensive accretionary magmatic arc terrain, has been re-interpreted recently as the result of Paleoproterozoic north-dipping subduction and arc-continent convergence [1]. The orogen comprises, from the northwest to the southeast, 1) an Archean foreland with Paleoproterozoic marginal basins (e.g. Vallen and Sortis Groups; where structurally-reworked, this domain is termed the Border Zone), 2) a voluminous (>30,000km^2), composite calc-alkaline granitoid suite (Julianehåb batholith; JB) with subordinate intra-arc basins, and 3) an extensive forearc system in the southeast. Most components of the orogen are transected by swarms of appinite dykes, injected continuously through the evolution of arc development and accretion. Widespread post-tectonic emplacement of sheets of rapakivi granite, particularly in the south, marked the final stages of evolution of the orogen.

In southwest Greenland, the Border Zone and Julianehåb batholith are separated by a steeply-dipping, NE-striking high-strain zone (Kobberminebugt shear zone) whose extension in southeast Greenland is poorly known. In detail, the forearc system is characterised by two principal lithostratigraphic subdivisions: a Psammite Zone, a variably migmatised assemblage of arkosic sandstones, polymict conglomerates and turbidites interpreted as reflecting proximal, fluvial and shallow water deposition adjacent a Ketilidian arc, and a Pelite Zone, comprising strongly migmatised pelitic rocks perceived as distal forearc sediments.

We have examined zircon, titanite and monazite populations from a variety of units within the Ketilidian orogen to constrain the timing and duration of batholith emplacement, provenance and depositional ages of sediments, and precise ages for high-T/low-P regional metamorphism recorded in the latter. Abraded single-grain and small-fraction zircons from granodiorites and granites of the JB yield generally concordant magmatic U-Pb ages between 1854 Ma and 1796 Ma, with many in the range 1845-1815 Ma. Evidence for significantly older inheritance in grain populations from this magmatic suite is virtually absent. Metamorphic zircon growth and select titanite ages at ~1835 Ma and ~1806 Ma locally reflect conclusions from shear-sense indicators that much of the batholith was emplaced and accreted during sinistral transpression through oblique arc convergence. Elsewhere, ages of titanite from the JB reveal a complex history of slow-cooling and uplift (1840-1793 Ma), as well as local recrystallization during emplacement of the rapakivi granites (1750-1730 Ma).

Isotope dilution U-Pb ages of single grain detrital zircons from psammites in the forearc system SE of the batholith are mostly in the range 1841-1793 Ma, supporting the conclusion that a large proportion of forearc detritus is proximal and was shed directly from the adjacent batholith. The maximum age of sedimentation recorded in two widely-separated psammites, coincident at 1793 Ma, also corresponds with several titanite cooling ages preserved in JB granitoids and may thus chronicle a time of rapid arc unroofing. Preliminary SHRIMP II ion probe analysis of a much larger population of zircon grains from pelites and psammites supports conclusions drawn from conventional analyses, but also reveals the presence in both suites of a finite contribution from earlier Paleoproterozoic (1850-1970, 2100, 2300-2325 Ma) and Archean (~2700 Ma) provenance sources.

A sample of well-preserved, low grade andesite, exposed as a septum within the central Julianehåb granitoids, yielded a moderate amount of intermediate quality zircon prisms which define an age of 1805 ± 8 Ma, interpreted as the time of magmatic crystallization. As such, the volcanics are believed to represent coeval magmatic products related to the JB plutonic suites, and may be eruptive upper-crustal equivalents from similar magma chambers. The relatively young age precludes their origin as pre-batholith crust onto which the Ketilidian arc and forearc were constructed.

On the eastern flank of the batholith a zone of high-strain orthogneisses and mylonites are folded and intruded by a series of axial planar appinitic and granitic dykes. A U-Pb zircon age of 1794 ± 1 Ma for one of the granite dykes provides a minimum age for the timing of the mylonitization, which may correlate with top-to-the-NE displacements recorded in D1-D2 structures in deformed sediments of the Psammite Zone further south. In the latter, D1-D2 and D2 folds are bracketed by syntectonic axial planar appinites at 1793-1783 Ma and lineated hbl-granite at 1792 ± 1 Ma, respectively. Combined evidence from detrital zircon populations and precise dating of some of the earliest fold structures recognized in the deformed sediments thereby strongly suggest that sediment accumulation in much of the proximal forearc was rapid, and followed shortly (synchronously?) by the onset of wide-scale deformation. D3 fabrics, developed within large monoclinal folds during NW-SE shortening, are best constrained by syn-D3 neosomes which locally coalesced into larger S-type granites as high-T conditions persisted. Analysis of single zircon grains from one such granite locality constrains D3 to 1784 ± 2 Ma.

Massive, post-tectonic biotite granite, syenite, monzonite, rapakivi granites and pegmatites were emplaced, predominantly as sheet-like masses in the Psammite and Pelite Zones and in the southeastern border of the Julianehåb batholith, between approximately 1750-1730 Ma. The granitoids (and minor associated norites) represent a final but apparently distinct thermal event in the evolution of the Ketilidian orogen.

Paired tracer (Sr, Nd) isotopic compositions have been determined on Ketilidian granitoids for which precise U-Pb ages are now available. Initial $^{87}Sr/^{86}Sr$ compositions for JB granites and granodiorites, from 0.701789-0.702966, endorse findings of previous workers that these magmas represent juvenile additions derived from depleted mantle. Initial ε_{Nd} compositions for the oldest dated plutons of the JB range from +1.7 to +2.1, and reflect depleted mantle compositions modified by minor contributions from Archean crust. With increasing arc maturity, granitoids ($\varepsilon_{Nd} = -0.5$) initially show more significant input from Archean crust, but ε_{Nd} rises steadily with decreasing age (to $\varepsilon_{Nd} = +3.4$) to compositions near contemporary depleted mantle. Model Nd (T_{DM}) ages range from 1980 Ma to 2280 Ma. The late syn-D2 sheet of hbl-granite (1792 Ma) emplaced within forearc psammites has a similar Nd isotopic composition ($\varepsilon_{Nd} = +3.7$) and appears to have tapped the same magma sources as late granitic members of the Julianehåb batholith.

The growing high-precision U-Pb geochronological database suggests that the principal phase of Ketilidian arc magmatic activity (*c.* 1854-1795 Ma) post-dated that in the earliest Svecofennian (*c.* 1900-1858 Ma) without significant overlap; rather, more direct equivalents are found in the earliest phases of the Transscandinavian Igneous Belt (e.g. 1830 - 1770 Ma; [2], [3]) which intruded older accreted Svecofennian terrains, supporting the general observations of Park [4]. Preliminary evidence suggests that, as in the TIB, Ketilidian arc magmatism may be younger in the N than the S, although data are scant from the northern flank of the Julianehåb batholith.

Although a major phase of Makkovikian plutonism occurred between *c.* 1815-1800 Ma, and leucogranite development is known at *c.* 1795 Ma (coinciding roughly with Ketilidian evolution), high-grade metamorphism and significant earlier granitoid plutonism (e.g. 1870-1895 Ma) in Labrador appear to largely predate events so far recognized in south Greenland (*cf.* [5], [6]). As well, dominantly dextral displacements recognized in the Kaipokok Domain in Labrador have no apparent counterparts in the Ketilidian, where displacements are the result of largely sinistral transpression

The Malin block contains juvenile magmatic rocks which have, in part, ages similar to near-peak metamorphic Ketilidian rocks, at 1782 ± 5 Ma and 1779 ± 3 Ma [7], [8]. However, juvenile calc-alkaline orthogneisses from NW Ireland at *c.* 1750 Ma appear to postdate arc magmatism in south Greenland by over 50 Ma, as do samples from Rockall Plateau [7].

Synorogenic juvenile arc additions between *c.* 1889-1860 Ma represent Penokean magmatism resulting from complex accretion to Laurentian (Superior) rifted margin of Pembine-Wausau arc terrane (at *c.* 1852 ± 6 Ma), followed by accretion of Marshfield terrane (at *c.* 1840 Ma; [9]). Although the equivalent timing of arc accretion to Archean foreland in south Greenland is still unknown, the main phase of arc magmatism apparently largely postdates Penokean activity.

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NEW U-Pb GEOCHRONOLOGICAL RESULTS FROM THE MESOPROTEROZOIC NAIN PLUTONIC SUITE, LABRADOR, AND IMPLICATIONS FOR THE ORIGIN AND EMPLACEMENT OF MASSIF ANORTHOSITES AND RELATED ROCKS.

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The Elsonian Nain Plutonic Suite (NPS) consists of a composite array of predominantly granitoid intrusions and large plutons of massif anorthosite, emplaced anorogenically over some 19, 000 km^2. Associated with the largely adcumulate anorthositic rocks are smaller, but numerous bodies of troctolite and gabbro; ferrodiorite also occurs, probably as late-stage differentiates from anorthosite crystallization [1]. Previous U-Pb geochronological studies of the NPS have focused principally on the potassic, high Fe/(Fe+Mg) granitoid plutonic rocks, which range from monzonite to quartz monzonite to granite. Krogh and Davis (1973 [2]), in a pioneering study, established a nearly-concordant zircon age of *c.* 1295 Ma for granite from Dog Island, one of the easternmost plutons of such composition in the NPS. A spectrum of ages has more recently been recognized from analysis of other granites on the western NPS flank such as (from N to S): the composite Umiakovik batholith (1319 ± 2 Ma, 1316 ± 3 Ma; [3]), Makhavinekh Lake pluton (1322 ± 1 Ma; [4]), and a northern component of the Voisey Bay-Notakwanon batholith (1292 ± 4; [4]). Work in progress (Hamilton and Emslie, *in prep.*) on other members of the NPS granitoid suite support the contention that some peralkaline plutons are as young as ~1287 Ma, while others (mostly monzonites and monzodiorites) are as old as ~1334 Ma; Connelly and Ryan [5] have shown that some monzonites may in fact be at least 1343 Ma in age. Granitic magmatism within the NPS therefore seems to have persisted for a *minimum* of ~55 Ma. U-Pb data on zircon and baddeleyite also permits examination of the duration and high-resolution emplacement chronology of basic magmatism (troctolites, anorthosites, norites, ferrodiorites) in the NPS (*e.g.* [6]). All of the samples described below yield concordant or only weakly (<0.5%) discordant U-Pb results, and this new data helps strengthen models involving genetic ties between anorthositic and ferrodioritic magmatism, in contrast to models favouring association of the latter with the granitoid rocks.

Zircons in NPS leucotroctolites and anorthosites are typically clear to pale pink-brown, euhedral, prismatic grains exhibiting few fractures or inclusions, no overgrowths, and low U (~30 ppm) contents. In residual pegmatitic segregations, rare individual acicular euhedra have been observed which reach up to 30 cm in length. U-Pb data from anorthosites, mostly in the south-central portion of the complex, indicate that the majority of magma batches crystallized over at least 17 Ma from 1322 ± 1 Ma (zircon and baddeleyite; leuconorite, Makhavinekh) to 1305 ± 2 Ma (anorthosite, Koliktalik I.). Within this interval, magmatism was apparently serial, with discrete anorthositic plutonism also occurring at 1319 Ma (Paul Island intrusion) and at 1311 Ma (Kikkertavak Island and Tabor Island anorthosite and leuconorite). Troctolitic pillows comingled with px-qtz monzonite within the Barth Island troctolite attest to emplacement of this layered intrusion as early as 1320 Ma, while larger layered cumulate troctolitic intrusions crystallized at 1311 Ma (Jonathon intrusion), 1307 ± 1Ma (baddeleyite in gabbroic pegmatite, Lower Zone, Kiglapait intrusion), and c. 1305 (Newark Island layered intrusion [7]. The entire magmatic interval for anorthositic and troctolitic magmatism is doubled (to ~35 Ma) by consideration of an Ukpaume intrusion leuconorite (1330 ± 2 Ma; south-central NPS) and leucotroctolite from southernmost Sango Bay (1294.5 ± 1 Ma). Because these bodies intrude as-yet-undated anorthositic plutons, the entire span of 35 Ma must currently be regarded as a minimum duration for anorthositic and mafic magmatism, whose style may be serial (as currently seen) or more or less continuous.

Although no direct ages of the troctolitic Reid Brook intrusion or the associated Voisey's Bay Ni-Cu sulphide deposit have been published, Ryan *et al.* [8] have speculated that rafted olivine-bearing noritic rocks within the Makhavinekh Lake granite (1322 ± 1 Ma) immediately to the west of Voisey Bay may be related to Reid Brook intrusion and thus older than this age. If these olivine-bearing norites are in fact related to the dated leuconoritic 'core' (also 1322 ± 1 Ma, reported here) underlying the center of Makhavinekh Lake granite, then the Reid Brook intrusion need not be significantly older than this age.

Fe-Ti oxide-rich, silica-poor differentiates such as ferrodiorites may contain appreciable amounts of both zircon (8-200 ppm U) and euhedral baddeleyite (~70 ppm U). The duration of most ferrodioritic magmatism (~34 Ma) appears to mirror that described above for most troctolites and anorthosites. Moreover, ferrodioritic rocks appear to have crystallized during roughly identical pulses of magmatic activity recorded by the latter: the oldest diorites yet recognized have an age of 1332 ± 3 Ma (Ukpaume intrusion), followed by marginal ferrodiorites of the Barth Island troctolite intrusion at 1322 Ma, isolated diorites exposed in the Jonathon intrusion at 1311 Ma (apparently simultaneously with surrounding troctolites), crystallization of

Tigalak intrusion ferrodiorites at *c.* 1306 Ma, and the emplacement of sheet-like masses in the southern quadrant of the NPS (Cabot Lake) as late as 1298 ± 2 Ma. In some instances, large and often corroded or embayed zircons have the appearance of being xenocrystic, potentially from earlier-crystallized NPS monzonitic to granitic magmas. By example, zircons from the Satosuakuluk ferrodiorite dyke exhibit such morphology and yield a 1315 ± 2 Ma age, in contrast to a 1301 ± 2 Ma age from magmatic baddeleyite in the same sample. The coincidence of discrete ages and comparability of the timespan of crystallization between troctolitic/anorthositic and ferrodioritic magmatism support models involving the contemporaneous development within AMCG complexes of dioritic magmas from less evolved precursors, as is suggested by mineral compositional trends and tracer isotopic (Nd, Sr) compositions linking the two groups petrogenetically.

Recent mapping of the NE margin of the anorthosite massif has identified a variety of massive to well-layered anorthositic, leuconoritic and leucotroctolitic rocks, dated in part at 1322 ± 1 Ma (zircon). However, an important suite of massive to deformed leucogabbroic to leuconoritic and anorthositic rocks showing variable amounts of secondary alteration, and cut by a diverse series of metagabbro and metadiabase dykes, is also recognized [9]. U-Pb zircon dating of these anorthositic rocks reveals them to be Paleoproterozoic in age, broadly equivalent to established ages of nearby 2110-2135 Ma granitic plutons intrusive into Nain craton as well as with a suite of variably-foliated monzonites and quartz monzonites. Recognition of significant volumes of Paleoproterozoic anorthositic magmatism within this dominantly Mesoproterozoic magmatic province has profound implications for genetic models of massif anorthosite. Comparison is invited with the Mesoproterozoic (*c.* 1435 Ma) Laramie anorthosite complex, Wyoming, recently shown to have intruded adjacent the strongly recrystallized Paleoproterozoic (*c.* 1760 Ma) Horse Creek anorthosite (-granite-monzonite) complex [10].

Correct interpretation of tracer (Sr, Nd and Pb) isotopic data in NPS rocks is based on the recognition that the signatures, for the most part, reflect those of the underlying basement isotopic domains [11]. As shown in an investigation of NPS ferrodiorites and granitoids [12] and an east-west transect study of olivine- and pyroxene-bearing anorthositic rocks across the Nain massif [11], a strong influence of geographic position relative to the Nain-Churchill collisional boundary is revealed by the isotopic signatures. A fundamental east-west subdivision exists, corresponding approximately to the projected trace of the terrane boundary: ε_{Nd} values are less than about -10 *(regardless of rock type)* in most samples underlain by older Nain Province basement to the east, but are greater than about -10 for samples underlain by Churchill Province basement, including Tasiuyak gneiss, to the west. Although initial Nd isotopic ratios are nearly identical between rock types *within* the eastern or western subdivisions, distinctive ranges in initial $^{87}Sr/^{86}Sr$ are correlated with lithological type or compositional grouping. I_{Sr} in the ferrodiorites is at or near the upper (enriched) limits for the anorthositic groups, again supporting models linking the two rock types petrogenetically through progressive contamination of residual liquids from anorthosite crystallization. The underlying basement clearly was a major contributor to the source materials for the granitoid magmas but it also made lesser, but significant, contributions to the anorthositic and ferrodioritic magmas as subsequent contaminants.

Pb isotopic data obtained on Nain and Churchill Province gneisses illustrates that they are characterized by radically different time-integrated U/Pb values. Nain Province, comprising components of early, middle and late Archean crust, has documented μ values as low as about 7.0. In almost all cases separated feldspars from Nain Province crust have $^{207}Pb/^{204}Pb$ ratios <14.40, and $^{206}Pb/^{204}Pb$ <14.10. In stark contrast, late Archean and Paleoproterozoic gneisses in the eastern Churchill Province immediately west of the NPS are distinguished by much more radiogenic compositions (e.g. $^{207}Pb/^{204}Pb$ ratios >14.95, and $^{206}Pb/^{204}Pb$ >15.00). Whereas feldspar compositions from anorthosites west of the projected Nain/Churchill Province boundary are intermediate between that of estimated 1.30 Ga mantle and average Churchill Province crust, those from anorthosites emplaced progressively further east have systematically and gradually lower $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios that eventually overlap with compositions of Nain Province gneisses for the plutons intruded further east into the Nain craton [10]. Pb, Nd and Sr systematics unequivocally reveal the effects of crustal contamination in the basic and anorthositic NPS rocks principally because the magmatic province is favourably underlain by appreciably older basements with divergent evolutionary histories.

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ISOTOPIC (Sm-Nd, U-Pb) AND GEOCHEMICAL EVIDENCE FOR AN OCEANIC CRUST TO MOLASSE EVOLUTION OF THE PALAEOPROTEROZOIC KITTILÄ GREENSTONE COMPLEX, NORTHERN FINLAND

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The Kittilä greenstone complex represents an accumulation of a large volume of Palaeoproterozoic volcanic and associated sedimentary rocks in Central Finnish Lapland, covering an area of more than 2600 km^2. The age and stratigraphic position of the complex has been controversial for a long time. However, recent geochemical and isotopic studies in connection with the Lapland Volcanite Project (GSF) have much improved our understanding of the geochemical characteristics of the complex and the stratigraphic and age relations of its formations (Räsänen et al. 1995, Lehtonen et al. submitted). In this abstract, we report geochemical and isotopic data for mafic metavolcanites and acid porphyries from the Kittilä area and discuss their geotectonic implications.

The supracrustal rocks of the Kittilä area are assigned to the Kittilä Group which comprises two volcanic type formations of a dominantly basaltic composition, the older Kautoselkä and younger Vesmajärvi Formation separated by chemical metasediments of the stratigraphically intermediate Porkonen Formation. On its eastern and southern side, the Kittilä Group is separated from the older, widely occurring quartzites and mica schists (the Sodankylä and Savukoski Groups) by a tectonic contact, whereas coarse-clastic quartzites and conglomerates of the Kumpu Group lie discordantly over the Kittilä Group metavolcanites (Lehtonen et al. submitted).

The mafic metavolcanites of the Vesmajärvi Fm occur as pillow lavas and hyaloclastites and are chemically tholeiitic basalts with Mg# varying between 0.72 and 0.43. Their chondrite-normalized REE patterns range from slightly LREE-depleted to LREE-enriched (Fig. 1). Three clinopyroxene separates and eight whole rock samples define a Sm-Nd isochron with an age of 1990±35 Ma and an initial ϵ_{Nd} value of +3.7±0.2. A similar depleted mantle isotopic signature (ϵ_{Nd} from +3.3 to +4.4) was obtained from the Veikasenmaa Formation which is correlated to the Vesmajärvi type Formation (Lehtonen et al. submitted).

Fine-grained leucocratic igneous rocks are intimately associated with pillowed and massive lavas of the Veikasenmaa Fm in several places in the Kittilä area. They are quartz- and plagioclase-phyric and occur as subvolcanic dykes, lavas and crystal tuff layers up to 10 m in thickness. Fragments of felsic porphyry are found in associated mafic metavolcanites and cogenetic diabases and some of the porhyries are cut by apophyses from the diabases. The reverse is also seen where fragments of a fine-grained mafic rock are found within felsic porphyries. All these features are consistent with the coexistence of basic and acid magmas. Geochemically, the felsic porphyries are low-K dacites to rhyolites with high contents of incompatible elements like REE, Th, Ta, and Zr. Light REE and heavy REE reach levels up to 400 and 100 times chondritic, respectively (Fig. 2).

Felsic porphyries occurring among mafic metavolcanites were chosen from five localities (Kapsajoki, Veikasenmaa, Kiimarova, Yräjärvi, Nyssäkoski) for U-Pb zircon dating. Four of them resulted in mutually similar ages ranging between 2012±5 and 2018±7 Ma while the Nyssäkoski dyke gave a considerably younger age of 1920±7 Ma. The four porphyries belonging to the older age group yielded consistent Sm-Nd isotopic results with ϵ_{Nd} of +3.8 as calculated at 2.015 Ga. This value is very close to that of the Vesmajärvi and Veikasenmaa tholeiites and indicates that an older sialic substrate was not involved in the genesis of these acid porphyries. The younger Nyssäkoski porphyry showed a more unradiogenic Nd isotopic composition with ϵ_{Nd}(1920Ma) of -0.9. The division into two porphyry groups is also evident in the abundances of REE as the Nyssäkoski dyke exhibits a much lower REE level than the other porphyries (Fig. 2).

A quartz porphyry pebble, about 20 cm in diameter, was picked from a Kumpu Group conglomerate at Mantovaara where conglomerates form a 1x5 km wide sedimentary unit lying on mafic metavolcanites of the Kittilä Group. Zircon was extracted from the pebble and analysed for U-Pb isotopes. The results yielded an age of 1928±6 Ma which is very close to that of the Nyssäkoski porphyry (1920±7 Ma). Comparison of the major and trace element analyses also reveals the similarity of the Nyssäkoski dyke and Mantovaara pebble (Fig. 2). The initial ϵ_{Nd} value of +1.1 obtained for the pebble is somewhat higher that that of the Nyssäkoski dyke (-0.9) but clearly differs from the more depleted Nd isotopic composition of the older porphyry group.

The depleted mantle-like initial Nd isotopic ratio of the mafic metavolcanites indicates that they had insignificant interaction with upper crustal sialic material. This together with the absence of cratonic sediments and the presence of N-MORB-, E-MORB-, IAT-, OIB-type mafic metavolcanites suggests that at least part of the Kittilä greenstone complex represents Palaeoproterozoic oceanic crust which was tectonically emplaced onto the Archaean basement. This interpretation is further supported by the presence of ultramafic rocks with ophiolitic mantle characteristics near the eastern edge of the complex (Hanski, in press).

Within error, the Sm-Nd age of the Vesmajärvi Fm overlaps the U-Pb zircon ages obtained from quartz porphyries of the older group. The 2.0 Ga acid porphyries are volumetrically minor but their significance lies in their capacity to corroborate or refute the geotectonic model derived from the geochemical and isotopic composition of the mafic metavolcanites. Namely, if the acid porphyries and associated mafic metavolcanites represent coeval magmatism as suggested by field and petrographic studies and U-Pb isotopic evidence, and if the mafic metavolcanites represent part of an ancient oceanic crust, then the porphyries could not have been products of anatexis of an underlying sialic basement. Instead, the depleted Nd signatures of the porphyries are clearly mantle-derived. The two most likely mechanisms to produce silicic igneous rocks in an oceanic environment are through extensive fractional crystallization of basic magma or hydrous partial melting of mafic oceanic crust (amphibolite). The geochemical composition of the acid porphyries is more compatible with the latter alternative although they seem to have partly gained their highly evolved characteristics via fractional crystallization.

The U-Pb zircon age (1928±6 Ma), Sm-Nd isotopic composition and geochemistry of the pebble from the Kumpu Group conglomerate demonstrate that the pebble was derived from a felsic dyke belonging to the younger porphyry group and hence, the age of these dykes gives a maximum time for deposition of the Kumpu Group sediments. This age constraint coupled with the lithology and structural history of the Kumpu Group (Lehtonen et al., submitted) strongly argue that the Kumpu Group represents molasse-like sediments which were deposited after the obduction, metamorphism and uplift of the underlying Kittilä greenstone complex.

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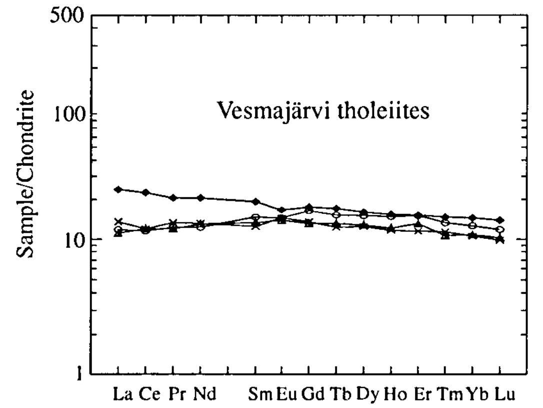

Fig. 1. Chondrite-normalized REE patterns for mafic metavolcanites from the Vesmajärvi Formation.

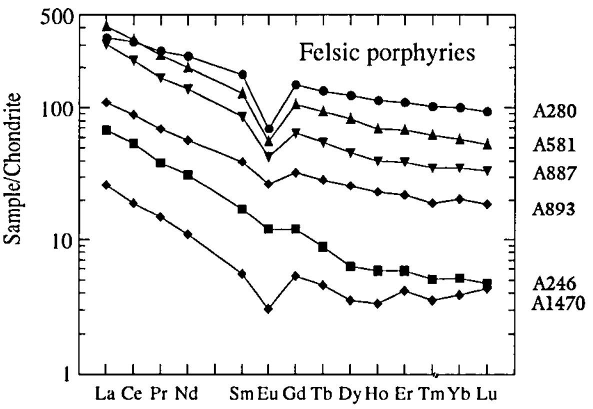

Fig. 2. Chondrite-normalized REE patterns for felsic porphyries from the Kittilä area. A280, A581, A887and A893 represent the 2.02 Ma age group, A246 the 1.92 Ma age group, and A1470 is a pebble from the Kumpu Group conglomerate.

GEOCHEMICAL EVIDENCE FOR THE GEOTECTONIC SETTING OF EARLY PROTEROZOIC METABASALTS IN THE LADOGA REGION (RUSSIA).

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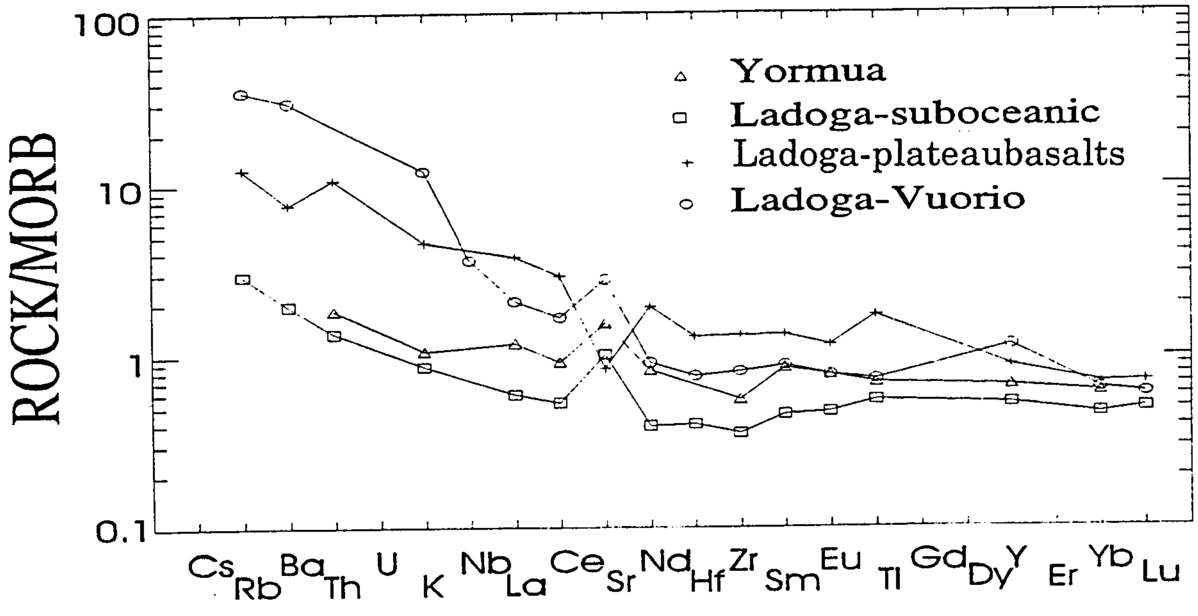
The Ladoga region is located in the boundary zone between the Archean craton and the early Proterozoic Svecofennian mobile belt (Raahe-Ladoga zone). In modern tectonic terms, the northern part of the region (Northern Ladoga block) belongs to a continental margin, but the southern one (Western Ladoga block) belongs to a back arc basin. Those domains are separated by a large thrust - the Mejerskaja dislocation zone. The main structural feature of Northern Ladoga is represented by rimmed domes with remobilized Archean granite-gneiss cores. Marginal parts of the domes consists of metamorphosed volcanogenic-sedimentary deposits of the sortavala suite. The space between the domes is filled with metaturbidites of the ladoga suite.

The relationships between sortavala suite rocks and granite-gneisses are still under discussion. H.Väyrynen (1954) suggested, that the amphibolite chist layers of Northern Ladoga belong to a tectonic nappe. Most Russian geologists consider the Archean basement to be stratigraphically overlain by supracrustal rocks. Thus, the rocks of the sortavala suite form a single volcanogenic-sedimentary cross-section, its lower part comprising terrigenous-carbonate rocks, its higher part - thick covers of plateaubasalts. The last partly belong to the lower Jatulian, partly to higher Jatulian. The age of metavolcanites of the sortavala suite as determined on zircons is 1.97 Ga.

Modern analytical methods were used for geochemical investigation of some metavolcanties of the dome-structures metavolcanites (Kirjavolahtinskaja, Sortavalskaja, Kokkaselkskaja, Impilahtinskaja, Pusunsarskaja). These investigations were carried out to make clear their tectonic setting. A number of rock samples were carefully selected - those not influenced by orogenic granites. The data allow two basalt types to be distinguished. The first is represented by rocks with continental-tholeiitic characteristics (enriched in LIL, HFS, LRE) and comparable with basalts of lower and higher Jatulian age in Karelia. The second type is new for the region. It was found in many studied structures. The geochemical characteristics of this rock type are close to oceanic tholeiites. The average geochemical composition of the rocks predominating in the biggest Kirjavolahtinskaja structure is: SiO_2-48.11, TiO_2-0.83, Al_2O_3-14.75, Fe_2O_3*-11.14, MgO-8.01, CaO-12.74, Na_2O-1.77, K_2O-0.101, P_2O_5-0.071%, Rb-3.3, Sr-125, Ba-28, Th-0.25, Zr-32, Hf-1.15, Ta-0.124, La-2.36, Ce-6.4, Nd-4.3, Sm-1.65, Eu-0.62, Tb-0.47, Yb-1.73, Lu-0.28, Y-18, Sc-41, Cr-240, Co-47 ppm. This composition is similar to metabasalts and metadolerites of parallel dykes of the Jormua, early Proterozoic ophiolitic complex (eastern Finland). The dykes and sills of Kirjavolahtinskaja structure metabasites have approximately the same composition. The difference is only slight increase in Mg concentration.

The basalt types mentioned above could be clearly divided on the asis of a rare elements spider-diagram (Pic.) and Rb-Sr, Sm-Nd isotopic data. The first type has I_{sr} =0.7035 - 0.7056 and ε_{Nd} = (- 0.75) - (-2.93), the second one - I_{sr} = 0.7014 - 0.7056 and ε_{Nd} = +5.58 - +6.03.



From the geochemical data obtained and modern geodynamic models of Svecofennide development, we can consider the suboceanic tholeiites of Northern Ladoga to be result of back-arc spreading. Their tectonic setting and age are similar to allochthonous layers at Outokumpu and Jormua. Thus, we can conclude that the sortavala suite cannot be considered to be a single stratigraphic unit. Probably, the main part of it consist of big fragments of ophiolite obducted on to a continental margin. In this case, the higher parts of the back-arc basin oceanic crust are represented in Northern Ladoga.

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THE ESKOLABREEN GRANITOIDS OF SOUTHERN NY FRIESLAND, SVALBARD CALEDONIDES - GEOCHEMISTRY, AGE AND ORIGIN.

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The lower part of the Caledonian succession of Ny Friesland, called the Lower Hecla Hoek or the Stubendorffbreen Supergroup (Harland et al. 1992, and references therein), is exposed within the large N-S-trending Atomfjella Antiform in western Ny Friesland, northeast Spitsbergen. It is composed of several thrust slices of granitic basement and various metasedimentary units that, at least in part, represent an imbricated cover sequence (Gee et al. 1994). Granitic basement rocks are found in at least three tectonostratigraphic levels: (1) the Eskolabreen, (2) the Flåtan-Instrumentberget, and (3) the Bangenhuk Complexes.

The Eskolabreen Complex is the lowermost exposed tectonostratigraphic unit, outcropping in the core of the Atomfjella Antiform in southern Ny Friesland. It is a banded sequence composed of interlayered granitic and migmatitic gneisses and concordant amphibolites. Earlier U-Pb zircon dating of a band of granitic gneiss has given an age of 1766 ± 10 Ma, with Caledonian overprinting reflected in the lower intercept of 404 ± 8 Ma (Larionov et al. 1995), while an age of c. 2400 Ma has been reported from a gneiss of probable sedimentary origin (Balashov et al. 1993). The latter age probably represents a mixture of late Archean (3.10-2.50 Ga) and Paleoproterozoic (2.10-1.85 Ga) detrital zircons, as indicated by single zircon Pb-evaporation dating (A. N. Larionov, in prep.). U-Pb zircon dating of the Bangenhuk and Flåtan-Instrumentberget granitoids has yielded upper intercept ages in the range 1720-1780 Ma (Gee et al. 1992, Johansson et al. 1995).

Here, we report additional U-Pb zircon datings supporting a Paleoproterozoic age for granitic gneisses within the Eskolabreen Complex. A small lens of nearly undeformed granite at the north side of the Stubendorffbreen valley yields an age of 1749 ± 18 Ma, and an adjacent more deformed variety an indistinguishible age of 1748 ± 21 Ma. Zircons from a granitic gneiss layer at the north side of the Eskolabreen valley are extremely U-rich and discordant, yielding only an ill-defined upper intercept of c. 1770 Ma. Zircons from a leucocratic neosome from the north side of the Smutsbreen valley yield an upper intercept age of 1734 ± 5 Ma, suggesting that the migmatitization experienced by the Eskolabreen gneisses also was late Paleoproterozoic in age. The lower intercepts for these samples range between 350 and 400 Ma, and may reflect disturbance of the U-Pb system during the pervasive Caledonian deformation, as well as later Pb loss.

The Eskolabreen Complex granitic gneiss samples plot as true granites in the Total Alkali vs. Silica diagram. In the B-A-diagram of Debon & Le Fort (1982), the samples are all metaluminous. On multi-element "spider" diagrams and REE diagrams, the Eskolabreen gneisses are generally similar to the Bangenhuk granitoids (Carlsson et al. 1995), being high in many trace and rare earth elements. On tectonic discrimination diagrams, they plot as A-type or within-plate type granites, just as the Bangenhuk granitoids. Sm-Nd analyses yield initial ε_{Nd}-values close to -1, slightly less negative than for the Bangenhuk granitoids, but still suggestive of crustal derivation of much of the magma.

The data so far obtained suggest that these granitoid units represent the same suite of late Paleoproterozoic within-plate granites, intruded into pre-existing continental crust, variably deformed and migmatized in Paleoproterozoic time, and later sliced up into different thrust sheets during the Caledonian orogeny, with the Eskolabreen Complex having undergone the most pervasive Caledonian deformation.

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PALEOPROTEROZOIC EVOLUTION OF THE MAKKOVIK-KETILIDIAN OROGEN: OVERVIEW AND NEW INSIGHTS FROM EASTERN LABRADOR, CANADA

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The northeastern seaboard of Canada is underlain by vestiges of two Archean cratons (Nain and Rae Provinces) and four marginal orogenic belts (Torngat, Makkovik, Labrador, and Grenville) of Paleo- and Mesoproterozoic age. The recent initiative by LITHOPROBE to study this geologically diverse region has generated a wealth of new information on the crustal history and tectonic assembly of the northeastern Canadian Shield. Crustal events in the Makkovik Province, located between the Nain and Grenville Provinces in eastern Labrador, are now better understood due to LITHOPROBE-sponsored structural, geochronological, geophysical, and geochemical investigations over the past three years. This work has implications for the correlative Ketilidian mobile belt of southern Greenland

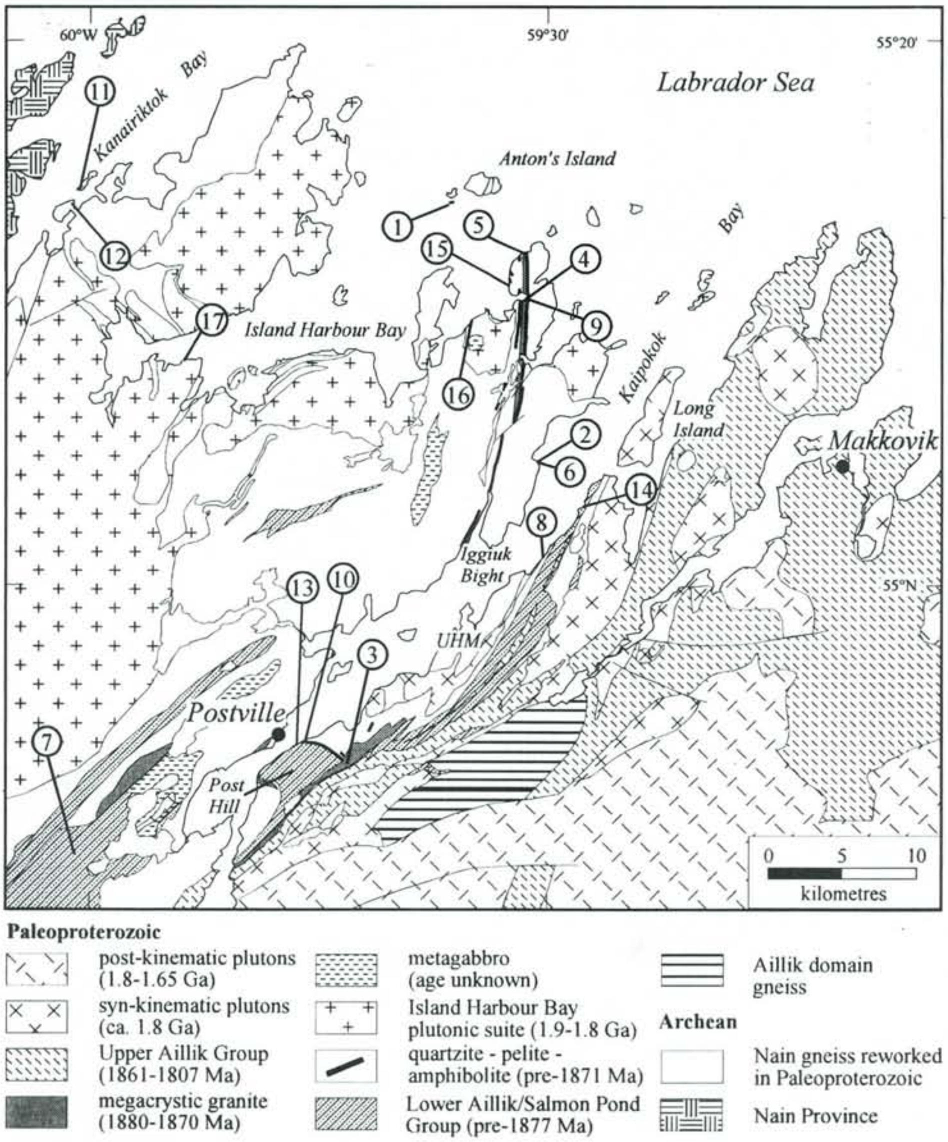
The Makkovik-Ketilidian orogen can be broadly divided into a northern domain of variably reworked Archean gneiss with lesser Paleoproterozoic supracrustal rocks and plutons, and a southern domain of juvenile plutonic rocks and volcanic and (or) sedimentary sequences of Paleoproterozoic age. Archean crust is not documented in the southern domain, and published Nd data indicate that it extends for only a short distance beneath the southern domain. Our structural, geochronological, and geochemical work in the Makkovik Province mainly centres on the northern domain (Kaipokok domain) and its tectonic boundaries with the Nain Province to the northwest and a felsic volcano-plutonic terrane to the southeast (Aillik and Cape Harrison domains). The Kaipokok domain has a Paleoproterozoic crustal history that both pre- and post-dates accretion of the Aillik and Cape Harrison domains. This history, outlined in detail below, makes reference to structural boundaries, lithologic units, and sample locations indicated on the accompanying map which outlines our study area. All quoted ages are U-Pb results; those not followed by a sample number indicate that the data is taken from the literature.

Rifting and passive margin sedimentation represent the earliest Paleoproterozoic events in the Kaipokok domain, which at this time was still part of the Nain craton. Intrusion of Kikkertavak diabase dykes at 2235 Ma and deposition of quartzite after this event mark stretching and subsidence of Nain crust. The quartzites contain only Archean detrital zircons (samples 9 & 10), indicating that the Nain Province was likely the sole source of detritus. Earliest volcanism in the Lower Aillik Group, a package of mafic volcanic and siliciclastic rocks overlying the passive margin sequence, is dated at 2178 Ma (sample 13) and may also be related to continental rifting. This may also be the age of early mafic volcanism in the Moran Lake Group (Labrador) and Vallen and Sortis Groups (Greenland) which are loosely correlated with the Lower Aillik Group. Detrital zircons in psammite overlying the volcanic unit are predominantly Paleoproterozoic (2050-2200 Ma), but Archean zircons are also present (sample 14). The youngest concordant grain constrains deposition of the psammite to after 2013 Ma.

The Kaipokok domain records some of the earliest Paleoproterozoic tectonic events documented in Northeast Laurentia. In the southwestern Kaipokok domain, ca. 1890 Ma granites cut Paleoproterozoic tectonic fabrics in Archean gneiss, and a foliated Kikkertavak dyke in the study area (sample 1) contains 1896 Ma metamorphic zircon formed during amphibolite-facies deformation. These events may be linked to thin-skinned thrusting of Lower Aillik rocks over their Archean basement and to thick-skinned thrusting within the basement (D1). Ages of cross-cutting plutons constrain the D1 events to predate 1884 Ma (sample 15) and 1877 Ma (sample 3), respectively. The postulated eastward vergence of thrusting and these temporal constraints suggest a causal link with east-west compression in the Torngat orogeny rather than with accretion of Makkovikian terranes in the southeast, although this link is speculative. Widespread intermediate to felsic plutonism between 1884-1871 Ma (samples 2, 3, 4, 11, & 12) in the Kaipokok domain followed early thrusting. Ca. 1871 Ma plutonic rocks in the northwest (samples 11 & 12) are syn-kinematic with respect to an early stage of dextral displacement (D1?) on the Kanairiktok shear zone at the northern margin of the Makkovik Province.

Dextral reactivation of a thick-skinned thrust zone at 1841 Ma (sample 5) is related to D2 deformation and metamorphism in the Kaipokok domain. D2 fabrics overprint an 1857 Ma member (sample 17) of the Island Harbour Bay Plutonic Suite, a large, peraluminous, calc-alkaline to A-type batholith underlying the northeastern Kaipokok domain. Some Island Harbour members are as young as 1784 Ma (sample 16), indicating prolonged plutonic activity that is thought to record a transition from subduction-related to within-plate magmatism. The age of oldest units clearly linked to the Island Harbour suite is not known, but geochemical data suggest that an 1884 Ma quartz monzodiorite (sample 15) may be an early member. Plutonism, metamorphism, crustal anatexis, and dextral strike-slip shearing in the Kaipokok domain occurred between 1841-1784 Ma, with most ages recording late-kinematic magmatic and metamorphic activity between ca. 1810-1795 Ma (e.g., samples 6 & 7). This also marks a period of widespread volcano-plutonic activity in the Aillik and Cape Harrison domains that followed early volcanism dated at 1861 Ma. The time of northwestward thrusting along the Kaipokok-Aillik domain boundary is not well constrained, but later dextral shearing along this boundary zone continued after emplacement of a pegmatite dyke at 1784 Ma (sample 8). Post-Makkovikian reactivation of the Kanairiktok shear zone at ca. 1690 Ma is indicated by muscovite $^{40}Ar/^{39}Ar$ data from greenschist-facies mylonites within this zone. Reactivation is considered a distal manifestation of the Labradorian orogeny to the south.

The extant data indicate that Paleoproterozoic tectonic, metamorphic, and magmatic events in the Makkovik orogen spanned >100 m.y. The plate tectonic setting of early orogenic activity is speculative, but later events including orogen-wide magmatism, and dextral transpression focused along the allochthon-parautochthon boundary, are undoubtedly linked to accretion of the Aillik-Cape Harrison terrane within an overall Andean-type margin setting. Much of the syn-kinematic A-type plutonism throughout the Makkovik Province followed this collision, suggesting that it likely occurred inboard from the active margin within a transpressional setting.



FROM PROTOCRUST TO LOWER CRUST: THE GEOCHEMICAL EVOLUTION OF METASEDIMENTS FROM THE BAMBLE SECTOR, SOUTHERN NORWAY

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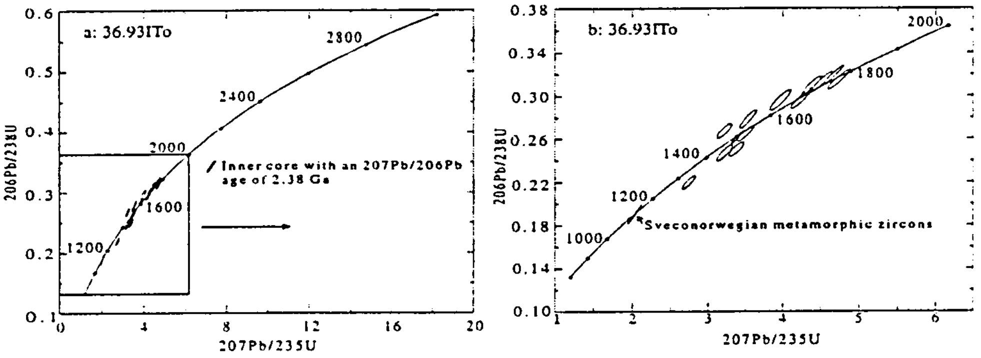
Mineral phases in high-grade metapelites allow a quantitative estimation of the water content of the fluid phases and the rocks are well suited for a characterization of the metamorphic P-T conditions. High-grade metasediments have also some interesting characteristics regarding the pre-sedimentary evolution of the source terrain: Sedimentation tends to average out heterogeneities to produce a sediment composition representative of the average of the eroded area and similar to the average of post-Archaean shales (PAAS, Taylor & McLennan, 1985), which suggests a relatively well-known pre-metamorphic composition. Zircon is a resistant mineral during erosion and sediment deposition, and information on the actual age distribution of the source terrain can be inferred from U-Pb chronology on detrial single zircons.

1. The Sveconorwegian evolution. The coastal Bamble granulites of southern Norway are dominated by metapelites, semi-metapelites and quartzites intercalated with mafic granulites on a cm to 10 metre scale. These were intruded by gabbros at ca. 1200 Ma, prior to the Sveconorwegian high-grade metamorphism at ca. 1100 Ma. This gabbro crystallization is generally defined as the first stage of the Sveconorwegian evolution of the rocks of the Bamble and related Kongsberg Sectors. Mineral inclusion assemblages in high-grade metapelitic garnets record pressure conditions of 3.6 ± 0.5 kbar and up to 850 C° (Knudsen, 1996), which can be related to the contact metamorphic effect of the nearby gabbro intrusions. This suggests that the rocks of the high-grade Bamble Sector were at the transition between low and medium crustal levels prior to the granulite facies metamorphism. The metapelitic high-grade mineral assemblage and the core (Bt + Grt + Pl) geothermobarometry are consistent with peak P-T conditions of 7.5 ± 1.6 kbar, 840 ± 45 °C, and $CO_2/H_2O/CH_4 = 76/24/8\cdot10^{-3}$ (mole%; In the COH fluid system) can be calculated for the granulite facies metapelites. The present data suggests a crustal thickening of 10 - 15 km (ca. 3.9 kbar) for the coastal granulites during the peak Sveconorwegian metamorphism. There is a temperature increase of ca. 100°C when going southwards from the amphibolite- facies Kongesberg and Bamble Sectors (Munz, 1990; Hagelia, 1989; Nijland, 1993) to the coastal granulites. An accompanying average pressure increase in the order of 0.5 kbar (a depth difference of 1.5 to 2 km), indicates that the coastal granulites represent the deepest exposed levels of the present south Norwegian crust.

The amphibolite and granulite facies metasediments of the Bamble Sector have all flat LILE patterns when normalized to Post Archaean Average Shales (PAAS; Taylor & McLennan, 1985) or Average Upper Crustal values (Wedepohl, 1995). The modelled three-stage lead evolution suggests, however, that the amphibolite facies quartzites and granulite facies metasediments have aquired high U/Pb, low Th/U values prior to Sveconorwegian times, followed by an uranium depletion during the Sveconorwegian peak metamorphism. This can be related to an escaping aqueous fluid.

2. The pre-Sveconorwegian evolution. The minimum detrital zircon age limits the sedimentation in the high-grade Bamble Sector to no earlier than 1367 ± 25 Ma (U-Pb zircon SIMS age; Knudsen et al., 1997a) and the inferred rift related, active tectonic setting suggests a relatively short time span between intrusion crystallization, uplift, erosion and deposition of the clastic sediments. The three-stage Pb evolution modelling suggests that the sediment precursors evolved in high U/Pb, upper crustal environments for a considerable longer time than since 1.37 Ga (i.e. back to ca. 1.9 Ga). The high-grade metasediments show marked low values (compared to PAAS) in Sr, P, Cu, high Y value and high pre-Sveconorwegian U/Pb values, which can all be related to a provenance dominated by evolved granites. The high-grade metasediments have peak frequency detrital zircon ages in the ranges 1.70 to 1.75 Ga and 1.45 to 1.55 Ga (Figure), which indicate that these were important periods of granite crystallization. The close resemblance between the calculated model ages of 1.7 to 2.1 Ga (Andersen et al., 1995; Knudsen et al., 1997b) and the maximum and peak frequency detrital zircon ages of 1.94 Ga and 1.70 to 1.75 Ga, respectively, indicates that the Nd model ages of the metasediments actually reflect the crustal residence times. The Svecofennian (2.1 to 1.9 Ga) can have been an important period of juvenile crust formation in the Bamble Sector, with little juvenile material added to the sediment precursors thereafter, but a prolonged period of intra-crustal reworking from ca. 1.7 to the onset of erosion and sedimentation (at 1.37 Ga or later).

A composite, resorbed inner core-detrital zircon $^{207}Pb/^{206}Pb$ age of 2.38 Ga (Figure), indicates an Archaean age component in the sediment provenance area. This has apparently not severely affected the Nd model ages of the metasediments, but is probably an indication of the presence of a minor Archaean crustal component in southern Norway.



Detrital zircons from a selected quartzite from the high-grade Bamble Sector, southern Norway

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PETROPHYSICAL CHARACTERISTICS OF CENTRAL FENNOSCANDIAN UPPER LITHOSPHERE

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The petrophysical programme of the GSF has produced a data base for density, susceptibility, intensity of remanence and lithological type of 131 085 samples from whole country for search of natural resources, bedrock mapping and crustal and environmental studies. Together with potential field anomalies and structural models the data provides a possibility to separate deep anomaly components from surficial ones and combine magnetic and gravity anomaly sources. Studies of the carriers of magnetization and litostratigraphic and geochronological correlation are under way. The GSF works towards a geophysical crustal model, that would answer on line to basic quantitative questions of the nature of anomaly sources and provide information on the correlation of geology and geophysics for scientific studies and practical work.

The Finnish aeromagnetic anomalies are caused by c. 20% of bedrock volume bearing ferrimagnetic minerals. Mafic rocks with bulk density greater than 2800 kg/m^3 amount to 18% of all samples. From 45% to 70% of these cause magnetic anomalies. Their remanent magnetization is normally higher than induced. Thus their direction of magnetization is defined by the remanence and may be different to the Earths main field. Smaller density and more acid composition correspond to smaller average iron content and normally to smaller magnetization. As an exception to the positive correlation of magnetization with density late and postorogenic felsic batholiths are, on average, associated with elevated magnetization, caused by coarse grained magnetite (Korhonen et al. 1997a). The ferrimagnetic Q-values vary depending on mineral and grain density. For coarse grained magnetite Qf is normally less than 2, for its alteration products higher up to 8 and for pyrrhotite from 15 to (Lahtinen and Korhonen 1996). The Qf-values increase with decreasing grain size and thus on average from deeper crustal levels to more surficial origins.

Regionally the frequency of rocks causing magnetic anomalies vary from a few per cent on migmatite areas of Southern and Western Finland to almost hundred per cent on the southern part of granite batholith of Central Finnish Lappland. Ninety per cent of the values of intensity of magnetization in hand samples fall in the range from 0.25 to 12 A/m. The most frequent intensity is 1.5 A/m. Stronger magnetizations than 20 A/m occur in 1% of the cases. Coarse grained magnetite is the main carrier of magnetization in c. 70% of cases. Highest frequencies of magnetic rocks occur in dykes (37%) and volcanic rocks (28%) as compared to 15% per cent of plutonic and metamorphic rocks (Korhonen et al. 1997a).

Average crustal scale magnetizations were compared with average magnetic anomalies in 25 km x 25 km squares. The strongest anomalies were of order 800 nT and were associated with acid rocks with magnetizations up to 1 A/m. The average magnetizations associated with average basic compositions were many fold of this but average magnetic anomalies only a fraction. The difference in correlation may be caused by on one hand by smaller average depth extent of basic rocks and on the other hand by occurence of magnetic mafic rocks below granite batholiths, as gravity interpretations suggest. The mafic magma has been the carrier of heat that melted the elder upper crust, thus producing the batholith (Rämö 1991, Elo and Korja 1993). Hence gravity and magnetic anomalies and petrophysics may be used in interpreting evolution processes of the Earths Crust.

Satellite magnetic anomalies reveal depth integrated magnetizations (DIM) from 40 kA to 60 kA in the Svecofennian Domain of Finland and from 50 kA to 90 kA in the Karelian Domain (Nolte and Hahn 1991). The surficial magnetizations are 0.78 A/m ja 0.95 A/m respectively (Korhonen and Säävuori 1995). The combined average Upper and Middle Crustal thickness is 34 km on both domains (Korja et al. 1993). Supposing that the magnetic properties are the same than at the Earths surface down to Lower Crustal boundary, it was calculated that 23 kA and 38 kA of DIM remained to be explained for the domains. Either the Lower Crust is weakly magnetic, as suggested by Ravat et al. (1992), or both Lower Crust and uppermost part of Mantle down to Curie isotherm of magnetite are causing magnetic anomalies.

In the former model the Middle Crust must be more magnetic than the Upper Crust to explain the difference in DIM. Mafic granulites and high grade rocks of surficial bedrock sections were used to estimate the likely middle crustal magnetization. By supposing that from 30% to 50 % of the Middle Crust is weakly magnetic a magnetization of 3 A/m was obtained. The thickness of magnetic Middle Crust was interpreted to be 11 km for

Svecofennian Domain and 15 km for Karelian Domain. The latter estimate is in good agreement with thickness given by Malaska and Hytönen (1997) but the former is 3 km smaller than the average seismic estimate.

We have no observation of completely weakly magnetic mafic plutonic or hypabyssal rock population in Finland. Therefore we compiled another model by using geothermally determined Curie depth from model of Kukkonen (1996) as the lower limit of magnetic Lithosphere. Magnetizations of Lower Crust (2 A/m) and uppermost Mantle (1.1 - 1.2 A/m) were calculated from data of plutonic mafic and ultramafic rocks in the Finnish Petrophysical Database. DIM values of 59 kA ja 82 kA were obtained (Korhonen et al. 1997b). The estimates are higher than published average DIM values. They are possible, however, because compiled satellite magnetic anomalies do not contain all long wavelength Crustal components and, therefore, the interpreted DIM values are smaller than in nature.

Planned reflection seismic sections of continental Finland will assist in comparing these two models with each other by allowing more detailed models. The effects of temperature to the magnetization at depth must be taken into account in more detail. Better estimates of lithospheric long wavelength magnetic anomalies are required. Compiling the model will thus be a joint work between several fields of Solid Earth geophysics.

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FENNOSCANDIAN MAGNETIC ANOMALY DATA BASE

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The Nordic geological surveys and the Petersburg Geophysical Expedition compile a Fennoscandian aeromagnetic anomaly grid on 1km x 1km net based on existing digital data sets (Korhonen 1980, Korhonen et al. 1985, Korhonen et al. 1995a-b, Ruotoistenmäki et al. 1996, Sokol 1977). The map extends from 54°N to 72°N in Latitude and from 4°E to 42°E in Longitude, covering the Shield area and some of its margins. The aim of the work is to provide an overall magnetic data set for regional geological studies near state borders and for major geological compilations, like the digital geological map of the Fennoscandian Shield. Simultaneous compilations of a Bouguer anomaly map and a data base of average petrophysical properties of the same area are under way. The map is planned to be ready by the end of 2000. A preliminary magnetic map on a scale of 1:2 mill, compiled from the data base will be shown and discussed.

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MAGNETIC MAP OF NORTHERN FINLAND AND KOLA

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A set of aeromagnetic maps on a scale of 1:1 mill for the northeastern part of the Fennoscandian Shield is being compiled by the Geological Survey of Finland (GSF) for the Finnish part and Petersburg Geophysical Expedition (PGE) for the Russian part. The set consists of two sheets. The southern one covers Central Finland and Karelia and the northern one Northern Finland and Kola. The southern sheet is near complete (Korhonen et al. 1995), the compilation of the northern sheet was initiated this year and is planned to be completed in 1999. A preliminary version of the northern sheet will be shown.

The Finnish part of the map is based on the high altitude (150m) aeromagnetic survey of the GSF in 1951-72 (Korhonen 1980) and on a survey of Finnish border zone in 1993. The Russian part is based on surveys on the same altitude in 1955 - 1975 (Sokol 1977) and on a survey of the Russian border zone in 1992 - 1995. The remaining gaps will be filled in 1997 - 1998.

The maps are aimed to assist in mineral prospecting, bedrock mapping and crustal and environmental studies, especially near Finnish - Russian border, where they help understanding the continuation of geological structures. To interprete the map petrophysical summaries will be drawn from the Finnish petrophysical data base and Russian petrophysical archives. We aim to describe the overall magnetic properties of major geological units of the area and separate deep seated and near surface magnetic sources from each other. In the latter half of the project we plan interpreting selected major geological sections like Lappland Granulite Belt and Pechenga Formation.

Starting 1997 the magnetic data matrix will be used in compiling a digital magnetic map of Fennoscandian Shield (1:1 mill scale) as a joint venture of Nordic geological Surveys and the PGE, where a geological and a Bouguer anomaly map will be made as well.

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SEVENTY-FIVE MILLION YEARS OF CONVERGENCE RECORDED IN THE PARRY SOUND SHEAR ZONE IN THE CENTRAL GNEISS BELT OF THE GRENVILLE PROVINCE

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The Central Gneiss Belt of the Grenville Province has been described as an aggregate of structural domains assembled during the Grenville Orogeny, at mid-crustal levels largely through sub-horizontal ductile flow.[1] Among these the Parry Sound domain composed largely of mafic granulite forms a circa 35 by 75km NE trending block with the NW margin forming the allochthonous boundary with the probably underlying more felsic Britt domain. Gneissic layering within the Parry Sound domain is highly variable and mainly vertical whereas in the boundary zone it together with mylonitic fabric are boundary parallel with dips of 10-40 degrees to the south. Truncations of structures to the north, lithological contrasts, an inverted metamorphic gradient and structural indicators have been interpreted as indicating that the boundary is a thrust zone involving NW directed transport.[1] Here we provide a rigourous test of this hypothesis by direct dating of new growth zircons in metadiabase and boudin infill that date the onset of metamorphism and the cessation of ductile flow respectively. Discordia lines for host rocks are used to prove that no similar significant metamorphism occurred between the time of emplacement of the protolith (usually circa 1600 or 1450 Ma) and the time of the last thermal event also recorded in metamorphic metadiabase zircons. The results document convergence between 1153$\pm$2 and 1077$\pm$2 Ma ago that produced a downward propagating ductile shear in the boundary zone and widespread 1077-1095 Ma metamorphism in rocks underlying the thrust zone.

All ages quoted below are based on replicate zircon determinations for which data are less than 1% discordant and accurate to $\pm$2 or 3 Ma. Samples were collected across about 5km of a circa 30° SE dipping deformation zone, on the extention of the same zone 70km to the NE, as well as at 7 locations in the footwall.

Tectonically interleaved mafic gneisses of different texture and character in the uppermost sample were assembled prior to emplacement of unstrained infill pegmatite at 1153 Ma although 1161 Ma wall rock zircons indicating the time of regional metamorphism are present. Below this zircon tips from pegmatitic infill in ruptured deformed anorthosite give ages of 1145 Ma, whereas those in a later gash vein filled mainly with quartz have overgrowths formed at 1139 Ma; a 1159 Ma grain again is a relic from regional metamorphism of the host.

Zircons from a dilatent infill from an amphibolite zone below the anorthosite formed at 1124 and 1129 Ma although an older 1148 Ma grain was also present. Zircons from a dilatent zone from a second lower amphibolite horizon have tips formed at 1104 Ma whereas those from an adjacent tonalitic layer formed at 1104 and 1128 Ma. Near the base of the shear zone, 70km to the NE a dilatent infill from a basal mylonite contained abundant new zircons formed at 1077 Ma which gave the time of the latest deformation, whereas most grains from an infill in the overlying granulite gneiss formed 1104 Ma years ago. In the footwall below this boundary zircons in migmatite formed at 1082 Ma whereas metadiabase (pseudo-eclogite) 2 km N of the boundary grew zircons at 1085 Ma. Those from metadiabase from 6 other sites from 0-15 km north and south of the domain grew in the interval 1078 to 1095 Ma and orthogneiss discordia confirm that in these locations this was the first post circa 1450 Ma metamorphism. Footwall metamorphism is coeval with or only slightly younger than late thrusting. A mechanism of cooling from above with downward propagating ductile flow piggy-backing the already cooled upper earlier thrust zones is required. Identical ages for metadiabase zircons and boudin infill zircons imply rapid heating and short-lived episodes of ductile deformation.

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THE ISOTOPIC DATING OF VOLCANIC ROCKS AND GRANITES OF THE NORTH LADOGA AREA AND ITS SIGNIFICANCE FOR STRATIGRAPHY OF THE REGION

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Isotope data for the Sortavala Series in the area of the North Ladoga region has been obtained. The Sortavala Series, comprising amphibolites (metatholeiites) mainly, represents one of the most important units of the zone of juxtaposition of the Karelian massif and the Svecofennian belt relative to the stratigraphy of the region. The position of the Series in a stratigraphic sequence is constrained by the following considerations: it overlies the granites of the Archean basement (2700-2900 Ma) and is overlain unconformably by metaturbidites of the Ladoga Series of Kalevian age. Volcanic rocks of the Sortavala Series were correlated either with metatholeiitic covers (Tohmajärvi) or with dykes of neighbouring regions of Finland which range in age from 2200-2100 to 1970 Ma (Vuolla et al. 1992). Accordingly, the position of the Sortavala Series could not be accurately defined and was regarded to be Jatulian or Ludikovian.

It was difficult to determine the isotopic age of the Sortavala Series until recently due to the absence of syngenetic zircons in the basic volcanites. As a result of our research work the layers of acidic volcanites were found to contain appreciable amounts of zircons. There are two kinds of zircons. Long prismatic fissured crystals with short pyramids and with evidence of partial solution not older than 1990±40 Ma, corresponding to the time of formation of the Sortavala Series. Larger, short prismatic crystals, even more fissured and strongly resorbed grains, containing protonuclears, are abundant. Their age appears to be Archean (2920±50 Ma). The presence of ancient crust material in the acidic volcanic melt is also evidenced by values of t_{DM}= 2700 Ma and l_{Nd}=1.5.

Zircons from the central part of the large metabasic differentiated dyke were studied as well. The dyke is found inside the granite basement close to the base of the Sortavala Series cover. The dyke is interpreted to be a supply channel for the volcanic melt. The age of these zircons is 1963±19 Ma. Within the limits of experimental deviation the ages of the metadacite from the cover and of the metabasic rock from the dyke coincide and are close to 1970 Ma. This value corresponds to the age of the ophiolitic complex at Outokumpu and of the tholeiitic dykes of East Finland (Vuollo et al., 1992). The same age is obtained for basic-ultrabasic sills from Ludicovian in the Onega area (Puchtel et al., 1995).

The 1970 Ma value is significant in two respects. As to geodynamics it fixes a time when the final breakup of the continental crust in the Svecofennian back-arc basin took place and ophiolitic and tholeiitic complexes formed inside the break locality. As to stratigraphy it defines the age of the last pre-Kalevian event and supports the data by Huhma et al. (1991) about the young (younger than 1920 Ma) age of the Kalevian.

The upper boundary of the Kalevian deposits of the Ladoga Series is constrained by the age of granites which cut it. Inside the North Ladoga domain, where rocks are metamorphosed to epidote-amphibolite facies, the Ladoga series is cut by the Impiniemi tonalites which are also slightly metamorphosed. Zircons from the granites are prismatic with blunt-pointed pyramids. They belong to a single generation. The edges of the prisms and pyramids are not dissolved, although electronic microscopy has found evidence of the effect of overprinting processes on the surfaces of individual grains. Isotopic data demonstrate significant losses of radiogenic Pb from the outer parts of the grains. Selective dissolution and aeroabrasive treatment of the grains allowed extraction of material with almost undisturbed U-Pb relations, and these relations defined the age of the granites as 1871±12 Ma.

Inside the West Ladoga domain, where analogues of the Ladoga Series rocks are metamorphosed to granulite facies, the most ancient magmatic rocks intruding them are represented by enderbites. The age of zircons from them has been determined by Kotov et al. (1972) as 1871±6 Ma as well. This age fixes the end of sedimentation inside the Svecofennian back arc basin and the beginning of the orogenic stage.

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THE MO TONALITE – THE EARLIEST GOTHIAN ROCK IN SOUTHEASTERN NORWAY

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The Precambrian crust in the southern part of the Baltic Shield exhibits a pronounced westward younging. To the east, the oldest part comprises the 1.9-1.8 Ga Svecofennian Domain, which is followed to the west and south by the 1.85-1.66 Ga old Transscandinavian Igneous Belt (TIB). Located further to the west is the heterogeneous Southwest Scandinavian Domain (SSD). The SSD comprises different rocks and regions with varying ages and metamorphic histories. U-Pb zircon ages interpreted as rock forming ages range between 1.7 and 0.9 Ga, whereas metamorphic ages are dominated by the Sveconorwegian orogeny at 1.2-0.9 Ga. The SSD is divided into segments by north-south trending shear zones which mainly were formed during the Sveconorwegian orogeny. It is believed that the crust in the SSD was created by westward accretion of juvenile arcs during the Gothian orogeny c. 1.75–1.5 Ga ago, a model supported by the juvenile calc-alkaline chemistry of these oldest rocks (Åhäll et al., 1991; Åhäll et al., 1995). This model is, however, in conflict with isotope investigations in southern Norway where both Pb-Pb and Sm-Nd isotope systematics indicate the presence of crustal material older than 1.7 Ga (Andersen et al., 1995), and recently detrital zircons with Svecofennian ages were identified in the Bamble sector, more than 300 km from the nearest exposed Svecofennian crust (T.-L. Knudsen, this meeting proceedings).

In order to address the problems of the earliest crustal components in the SSD, a geochronological study has been initiated around the lake Storsjøen, 70 km NO of Oslo in southeastern Norway. The area is dominated by different granitoids where the potassic Odalen granite forms the largest unit. This granite has been compared to the Trysil granite further to the north which is part of the Transscandinavian Igneous Belt and has an U-Pb zircon age of 1673±8 Ma (Heim et al., 1996). In the Storsjøen area, the Odalen granite has intruded a tonalitic suite located around the small village Mo. Furthermore, this tonalite is surrounding a megaxenolith of a locally well preserved supracrustal unit. The area has been affected by later metamorphism and deformation probably during the Sveconorwegian orogeny. In order to evaluate the earliest crustal forming history in the area it is therefore necessary to use isotope methods less sensitive to later alterations and the study is mainly based on U-Pb zircon age determinations and Sm-Nd whole rock analyses. Preliminary U-Pb zircon geochronology of the tonalite at Mo indicates an age in the interval 1.8-1.7 Ga which would then be the oldest rock within the Southwest Scandinavian Domain in Norway. Further geochronological data together with suggested implications for the earliest crustal growth in the SSD will be presented during the meeting.

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AGE OF DEPOSITION, PROVENANCE AND TECTONIC SETTING OF METASEDIMENTS FROM SUPRACRUSTAL SEQUENCES IN THE PALAEOPROTEROZOIC NAGSSUGTOQIDIAN OROGEN, WEST GREENLAND.

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The Palaeoproterozoic Nagssugtoqidian Orogen in West Greenland hosts a number of dissected supracrustal suites of uncertain age and provenance. Recent investigations using single zircon ion-microprobe U-Pb dating carried out both at ANU [1] and at the NORDSIM laboratory in Stockholm together with single zircon LAM-ICP-MS 207Pb/206Pb dating at University of Montreal [2] and whole rock Sm-Nd data at University of Copenhagen have shown that their metasediments were mainly deposited in Palaeoproterozoic time though their detritus have both Proterozoic and Archaean sources. The combination of these methods and good field control provide important tools for interpreting the origin, evolution and tectonics of the Nagssugtoqidian supracrustal suites, which have generally been strongly tectonised and fragmented during Nagssugtoqidian deformation. Reconstructions show that the suites tend to follow major tectonic boundaries which in turn may represent sutures.

The Nagssugtoqidian Orogen is subdivided into a southern (SNO), central (CNO) and northern (NNO) segment. The SNO represents the deformed southern foreland of Archaean gneisses intruded by the 2.04 Ga Kangâmiut dyke swarm [1]. Nagssugtoqidian deformation, monitored by these dykes, increases northwards towards the CNO which is thrust onto the SNO. The CNO forms the core of the orogen. Its southern part consists of 2.8-2.7 Ga old granulite facies gneisses which in the northwest are intruded by the voluminous 1.92-1.94 Ga Sisimiut charnockite [1]. The northern CNO (and SW NNO?) consists of 2.8-2.7 Ga old gneisses which are intensely thrust-intercalated and folded with a supracrustal sequence intruded by 1.92-1.94 Ga island arc quartz-diorites (the Arfersiorfik association) [3,4]. The Nordre Strømfjord steep belt (NSSB) near the boundary between the CNO and NNO has lithologies similar to the northern CNO rotated into a near-vertical position. Most of the mapped supracrustal sequences are located in the CNO and SNO. The NNO contains additional, less well studied supracrustal belts the majority of which are thought to be Archaean. These are not treated further here.

The supracrustal sequences in the SNO are found as two different suites. The SNO/CNO boundary suite of pelitic to quartzitic metasediments is located along the northern edge of the SNO where they occur as thin, continuous N-dipping panels that are thrust interleaved with Archaean gneisses in a 10-15 km wide zone. The Ikertôq suite occurs tightly folded with the enclosing Archaean gneisses further south in the SNO and is dominated by supracrustal amphibolites, rusty schists with subordinate marble and ultrabasic rocks. Similar rocks occur scattered in transposed isoclinal folds inside the SNO/CNO boundary suite to the north.

The CNO contains two major supracrustal sequences. The Nordre Isortoq suite, located between the southern and northern parts of the CNO, occurs interlayered (tectonically repeated?) with Archaean gneisses in an ENE-trending belt with a sediment thickness of up to 6-8 km. It consists of pelitic to psammitic, turbiditic granulite-facies metasediments. A few thin marbles, amphibolites and hornblenditic layers occur locally. The Nordre Isortoq suite has been studied in the west and in the east, while the central link is little known. During field work it has been treated as one continuous suite though there are notable structural differences from west to east. In the west it is folded into large-scale folds, while in the east it forms part of a straight, steep structural belt which includes layers of Proterozoic 'charnockitic' gneisses. In the east it is bordered northwards by a unit of leucocratic gneisses intruded by basic dykes (the Qorlortoq unit) not found in the west. The Nordre Strømfjord suite in the northern CNO is spatially related to and intruded by quartz-diorites of the 1.92-1.94 Ga Arfersiorfik arc association. The suite is disrupted and attenuated during thrust interleaving with Archaean gneisses and subsequent extension and is found as dismembered levels in a folded thrust stack [4]. Amphibolite to granulite facies pelitic to psammitic metasediments dominate the suite. There is no consistent stratigraphy but thin impure marble tends to be located at tectonic boundaries to the Archaean gneisses together with thin supracrustal amphibolites and pods of suggested mantle peridotite [5] suggesting that these boundaries represent a crustal suture.

The NSSB hosts a number of <1-2 km thick continuous, sometimes isoclinally folded layers of highgrade clastic metasediments, thin marbles and mafic-intermediate metavolcanics, the NSSB suite. These are interleaved with highly deformed Archaean gneisses and highly strained equivalents of the Arfersiorfik association.

The combined whole rock Sm-Nd, ion-microprobe U/Pb and LAM-ICP-MS Pb/Pb zircon studies on metasediments from the various supracrustal suites in the Nagssugtoqidian Orogen have until now shown that at least three different Palaeoproterozoic supracrustal settings are represented in addition to at least one Archaean.

Metasediments from the SNO/CNO boundary suite give Sm/Nd model ages (T(DM)) at 2.82-2.76 Ga indicating a provenance as the nearby Archaean gneisses. A SHRIMP analysis [3] shows detrital zircon ages of 2.85-2.1 Ga, with a peak at c. 2.4 Ga, and metamorphic overgrowth at 1.84 Ga thus bracketing the age of deposition. A sample in the west gave a tight range of U/Pb and LAM-ICP-MS Pb/Pb zircon ages of 1.85-1.8 Ga with rare 2.05-1.85 Ga grains but a T(DM) of 2.44 Ga. The marked discrepancy between the Nd model age and the zircon ages together with the remarkable homogeneity of the U/Pb and the Pb/Pb ages suggest that the zircons in this sample were formed during highgrade metamorphism. A metasediment from the Ikertôq suite gave a T(DM) of 2.41 Ga suggesting that this extensive SNO suite contains a Palaeoproterozoic component. The results from the SNO suggest that thick clastic sediments derived largely from Archaean sources were deposited on Archaean basement in a basin or at a continental margin between SNO and CNO in Palaeoproterozoic time. The sequence was later juxtaposed with Archaean gneisses during southward thrusting of the CNO and metamorphosed at c. 1.85 Ga. The Ikertôq supracrustal suite with its large mafic-ultramafic component may like the SNO/CNO boundary suite further north have been disrupted and folded during the CNO overthrusting. Its rocks might tentatively indicate involvement of oceanic material. The abrupt loss of the 2.04 Ga Kangâmiut dykes as the boundary from the SNO to the CNO is crossed together with the structural and isotopic data suggests that the SNO/CNO boundary represents a major Nagssugtoqidian tectonic break, which in the west is marked by the calc-alkaline Sisimiut charnockite with a major Palaeoproterozoic juvenile component

The northern margin of the Sisimiut charnockite intrudes into the western end of the Nordre Isortoq suite metasediments. This part of the belt is also intruded by Opx-granitoids at 2.8 Ga (U/Pb J. Connelly, pers. comm. 1996) showing that at least part of the supracrustal suite was deposited in the Archaean. The western part of the Nordre Isortoq metasediments give T(DM) ages at 2.90-2.76 Ga in agreement with the field observations that these rocks are intruded by Archaean gneisses. However, metasediments from the eastern part of the belt yield T(DM) ages at 2.35-2.38 Ga strongly suggesting that the two parts of the belt are of different age. A LAM-ICP-MS analysis from the western part of the suite yields Pb/Pb ages at 2.65-1.8 Ga, while a Rb/Sr study yields a 2.8 Ga isochron suggesting that these sediments were deposited in Archaean time (F. Kalsbeek, pers. comm. 1994).

Detrital zircons from populations in the Nordre Strømfjord suite metasediments have yielded SHRIMP ages of 2.10-1.95 Ga with a few c. 2.2 Ga and rare Archaean grains [3]. Since the zircons are mainly large and poorly rounded it is concluded that these sediments were rapidly deposited from a nearby pre-Arfersiorfik association arc complex, and that new zircon growth occurred during c. 1.85 Ga metamorphism [3]. A T(DM) age at 2.36 Ga agrees with this conclusion, and provides additional evidence that the thrust interface between Nordre Strømfjord suite and its Archaean gneissic 'basement' may represent a Nagssugtoqidian crustal suture.

Metasediments from different layers of the NSSB suite gives T(DM) ages at 2.26-2.38 Ga. Populations of zircons which are more rounded than in Nordre Strømfjord suite the give LAM-ICP-MS ages of 1.95-1.8 Ga and ion-microprobe ages of 2.10-1.80 Ga with some rare Archaean grains. Metamorphism occurred at c. 1.85 Ga. This suggests rapid deposition from a nearby, c. 2.1-1.9 Ga old source with little input of older continental detritus as in the Nordre Strømfjord suite. This strongly favours a common tectonic setting for the two suites in agreement with the field relations. The age-isotopic results from metasediments in the eastern Nordre Isortoq suite is also reminiscent of those in the Nordre Strømfjord suite. A correlation between these two suites requires a large-scale, synformal fold repetition around the Qorlortoq unit or, alternatively, another thrust repetition.

The new isotopic data on deposition and provenance of metasediments provides key information for the tectonic reconstruction of the Nagssugtoqidian Orogen. An ε(Nd) plot of metasediments within the Nagssugtoqidian Orogen projected back in time shows two distinctive groups of T(DM) c. 2.4 Ga and c. 2.8 Ga, where most analyses have similar slopes. This indicates that the source material of the two groups have a high degree of similarity. Combined with geological data it is clear that the orogen hosts two major settings of Palaeoproterozoic supracrustal rocks which were tectonically destructed during Nagssugtoqidian deformation and which may follow crustal sutures. The southern, SNO/CNO boundary suite represents turbiditic? continental margin/basin deposits eroded from an Archaean hinterland while the northern, Nordre Strømfjord-NSSB, suite consists of rapidly deposited sediments in an active Palaeoproterozoic island arc environment along with igneous activity. The Palaeoproterozoic eastern Nordre Isortoq suite may have an evolution that is related to the latter or represent a separate suite, while the Archaean western Nordre Isortoq suite was inherited by the Nagssugtoqidian orogen.

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NEW PALEOMAGNETIC DATA LINKING LAURENTIA AND BALTICA IN THE MID-PROTEROZOIC

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The Rodinia supercontinent results from attempts to link the Grenvillian-Sveconorwegian orogenic belts (1300-1100 Ma) around the world. In this postulate, Laurentia forms the core of the supercontinent and the Scandinavian Caledonide margin of Baltica is constrained to face the Greenland part of Laurentia. Previous paleomagnetic work demonstrates that Laurentia and Baltica may share a common drift-history from ca. 750-600 Ma. In this account we discuss new paleomagnetic data correlated with isotopic ages from Proterozoic rocks in southwestern Sweden, in the Egersund and Bamble regions, south Norway, and in the Adirondack Mountains, USA, in order to test the Rodinia supercontinental fits for the period 1.1-0.9 Ga. The Sveconorwegian orogen (1.1-9.0 Ga) in southwestern Sweden consists of a granulite region, in high-pressure granulite-facies with peak temperatures up to 770°C and pressures to 10.5 kbar, and a western region with amphibolite-facies rocks. Samples with high magnetic stability and containing titanohematite yield key poles for Baltica at 1.1-0.9 Ga. New paleomagnetic poles derived from intrusions in the Egersund region, Norway, with crystallization ages from 0.93-0.92 Ga are examined in relationship to time-correlative Swedish poles. The oxides in mafic intrusions vary from magnetite+ilmenite+spinel to spinel+hemo-ilmenite. These show a wide spectrum of coercivities. Samples of metasedimentary gneisses with ilmeno-hematite from the Adirondacks Mountains in the Ottawan Orogen, at ca. 1.1 Ga., have high stability though mafic intrusions with hemo-ilmenite + magnetite display mixed stability. Hemo-ilmenite anorthosites have high stability, those with magnetite are less stable. The Adirondack paleomagnetic pole may reflect the significantly younger hornblende cooling ages at ca. 0.9 Ga. from the region. These results are compared to new poles derived from granulites and amphibolites in the Bamble region, Norway, which represent cooling from peak metamorphism at 1.1 Ga. Collectively, our new data provide a sound basis for testing the Rodinia postulate between 1.1-0.9 Ga and provide a new reconstruction for the continents bordering the North Atlantic for this time period. In addition, the new paleomagnetic data does not allow for a "Grenvillian" loop in the Apparent Polar Wander Path for Baltica between 1.0 and 0.9 Ga.

NATURE AND TECTONIC SIGNIFICANCE OF 1.5 GA IGNEOUS ACTIVITY IN LAURENTIA-BALTICA

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Attention has been drawn to the similarities between the *ca* 1.50 Ga old volcanic rocks of the St Francois terrane and those of the Rjukan Group of southern Norway (Menuge and Brewer 1996). These extensive bimodal volcanics have geochemical signatures often described as "within-plate" or "anorogenic". Elsewhere along the southern margin of Laurentia-Baltica, rocks of similar age were created in an orogenic environment in the Pinwarian of Labrador (Gower et al. 1996) and possibly in adjacent parts of Quebec (Perreault, 1996). This contribution suggests how these diverse rocks may be related.

Geology and geochronology

The geology of the St Francois terrane of SE Missouri, which has a subsurface extent of at least 60 000 km^2, has been described by Kisvarsanyi and Kisvarsanyi (1990). It consists of an inlier of predominantly 1.5-1.4 Ga old alkalic, silicic igneous rocks which, beneath Palaeozoic cover, intrude c. 1.6 Ga old granitic gneisses of the orogenic Central Plains terrane. Rhyolitic tuffs and lavas, overlying comagmatic subvolcanic biotite granites, constitute the oldest exposed rocks of the St Francois terrane and have yielded U-Pb zircon ages of up to 1.48 Ga (Bickford et al. 1981; Van Schmus pers. comm.). Magnetite trachytes occur rarely as flows and more commonly as minor intrusions. Basic rocks include early layered intrusions and basalt dykes. Rocks similar to the St Francois terrane are known from subsurface samples over a wide area of the U.S. midcontinent, with U-Pb zircon crystallization ages of 1380-1480 Ma, generally older in the east and younger in the west (e.g. Bickford et al. 1981).

The geology of the Rjukan Group, comprising the Tuddal Formation and the disconformably overlying Vemork Formation, has recently been summarised by Menuge and Brewer (1996). The Tuddal Formation is lithologically diverse, composed of metamorphosed crystal tuffs, tuffs, ignimbrites, rhyolites and volcanogenic sediments. A recent U-Pb zircon study (Dahlgren et al. 1990) dated magmatic zircons from a Tuddal Formation rhyolite at *ca* 1500 Ma. The Vemork Formation is composed of metamorphosed basaltic lavas and sedimentary rocks. Individual lava flows range in thickness from 0.5 to 5 m and are intercalated with cross-bedded sandstones, conglomerates and shales.

Geochemical evidence for the tectonic setting of the St Francois Terrane and the Rjukan Group

Some geochemical and other features of the St Francois Terrane and Rjukan Group volcanics are shown in Table 1. The chemical and isotopic composition of the Rjukan Group has been discussed in detail by Menuge and Brewer (1996). Discussion of the St Francois Terrane is based on our own unpublished chemical and isotopic data. The age, chemical composition and structural relationships to pre-existing rocks of the Rjukan Group and the St Francois Terrane are similar, with the notable exception that basic magmatism was volumetrically far more important in the former than in the latter. Although they have A-type trace element signatures, the overwhelmingly peraluminous chemistry of both the St Francois terrane and the Rjukan Group acid volcanics is inconsistent with an anorogenic or within-plate setting and they should more properly be referred to as aluminous A-type volcanics (King et al. 1997). Instead, a post-orogenic setting is likely. Their compositions are consistent with derivation by partial melting of calc-alkaline rocks generated in a subduction zone environment. Such rocks are present in the form of the Central Plains terrane in the US midcontinent. The basement of the Rjukan Group is uncertain but source rocks resembling the Transscandinavian Igneous Batholith (TIB) would be consistent with the data. The negative Nb anomalies of the St Francois terrane basic rocks suggest either that the basaltic magmas were generated in a region of the mantle previously subjected to subduction zone metasomatism, or that the magmas were substantially contaminated by interaction with crustal rocks during their ascent. In contrast, the absence of negative Nb anomalies in the Rjukan Group basalts is more consistent with derivation from a mantle source unaffected by subduction zone processes.

Table 1

St Francois terrane	Rjukan Group
1) Mainly acidic with minor basalts	1) Similar volumes of acid and basic rock
2) Acid volcanics peraluminous to mildly metaluminous; HFSE-enriched, A-type chemistry Initial ε_{Nd} = 2.4 to 4.9	2) Acid volcanics peraluminous; HFSE-enriched, A-type chemistry; Initial ε_{Nd} = 1.0 to 4.5
3) Basaltic rocks tholeiitic; Negative Nb anomalies; Initial ε_{Nd} = 4.0 to 4.7	3) Basaltic rocks tholeiitic; Positive or zero Nb anomalies; Initial ε_{Nd} = 3.0 to 4.3
4) Underlain by, and intruded into (?) Central Plains terrane (granitic and rhyolitic rocks ca 1.6-1.65 Ga old with T_{DM} ages of c. 1.9 Ga)	4) Basement unknown - possibly TIB-like (calc-alkaline granitoids ca 1.6-1.8 Ga old with T_{DM} ages of 1.8-2.0 Ga)

Tectonic setting of *ca* 1.5 Ga magmatism in Laurentia-Baltica

In Labrador, *ca* 1.5 Ga old orogenic granitoids occur in the Pinware and Mealy Mountains terranes; minor felsic intrusions occur in the Groswater Bay and Lake Melville terranes to the north (Gower et al. 1996). Granitoids on the north shore of Quebec have been correlated with the Pinwarian by Perreault (1996) but remain undated. In southern and western Norway and in southwest Sweden, both orogenic and bimodal anorogenic 1.51-1.50 Ga old rocks occur (Åhäll and Connelly, 1996). A linear belt of ca 1.5 Ga old rocks is thus defined in Mesoproterozoic continental reconstructions. The impingement of a mantle plume is not a favoured explanation because of this linear arrangement, the presence of orogenic and post-orogenic rocks of indistinguishable age, and the absence of picrites, non-minimum melt acid rocks or other evidence for abnormally high geothermal gradients.

We propose that late or post-orogenic bimodal volcanism resulted from crustal extension in the overriding plate above a northward dipping subduction zone. In this model, orogenic igneous rocks should exist at depth or beneath cover to the south in both the US midcontinent and south Norway. Extensional forces may have resulted either from northward subduction itself or from subsequent rifting, possibly associated with the formation of the Grenville ocean, as suggested by Kay et al. (1989). In the former case, continental collision occurred early in Baltica and increasingly later to the southwest; in the latter case, ocean opening started in Baltica and propagated to the southwest.

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A NEW GEOCHRONOLOGY OF THE FORMATION OF THE KOLA RIFT-OBDUCTION SYSTEM

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The earliest crust-forming processes in the region are Late Archean in age. In the interval between 2.9 and 2.5 Ga ago, the following rocks were formed: granulites (2850-2640 Ma) and enderbites (2830-2640 Ma), gneisses (2930-2580) and tonalites (2930, 2740, 2650, 2580 Ma) – in the infrastructure; volcanites, including komatiites (older than 2740 Ma), and sediments, including BIF (older than 2740 Ma), and basic-ultrabasic intrusions – in the supracrustal greenstone belts. Also, anorthosites (2650-2610 Ma), monzonite-mangerites (2760 Ma), granites, aplites, and pegmatites (as old as 2560 Ma) are known.

In terms of Archean geodynamics, the region is known in Russia as the "Kola granulite-greenstone area". The following major Archean geodynamic units are distinguished: greenstone belts, gneiss terranes, crustal asthenospheric (migmatitic) and lower-crustal sub-asthenospheric (granulite-restitic) domains. The Archean plate tectonics is understood as the tectonics of thin mini-plates, which are underlain with a ductile middle-crust layer and, below, the anorthosite (basic) - enderbite - granulite lower crust, which is a peculiar homologue of the part of the upper mantle that lies beneath the mantle asthenosphere.

The understanding of the Early Proterozoic geology (2500-1600 Ma ago) comes from a thorough study of rift belts and adjacent granulite-gneiss domains. Metasedimentary and metavolcanic rocks constitute belts – terranes. Granulites, meta-anorthosites, charnockites, tonalite gneisses and migmatites are grouped into domains. On the basis of geologic-petrological data and interpretations of detailed geophysical reconstructions, F.P.Mitrofanov believes that most of the primary substance of the domains (protoliths) is represented by a middle- to lower-crustal basic-anorthosite-granulite matter obducted and repeatedly transformed by plutonic-metamorphic processes. As a model of these transformations, the authors have taken a long-term pulsation history of reworking of garnet meta-anorthosite, enderbite-charnockite and granulite, which together compose a significant portion of the Lapland granulite domain. Specifically, massive anorthosites (2450±10 Ma) were transformed through coronites (2410±10 Ma) and garnet-clinopyroxene granulites (1943±3 Ma) to hornblende(±garnet)-plagioclase schists (1905±5 Ma) during the time period of no less than 450 million years.

Age datings on zircon have also indicated a very long time interval of high-pressure transformations of charnockite-granulite associations: 2.42, 2.32, 2.13, 2.03, 1.94-1.90, 1.87, 1.73-1.71 Ga ago, i.e., a 700 million year long interval. Datings from 2.03 to 1.94-1.90 Ga testify to an asynchronous nature of the most intensive, but not the sole stage of the Lapland high-pressure granulite metamorphism in different infracrustal domains of the region and in different parts of the domains.

Garnet meta-anorthosite and high-pressure metamorphic rocks provide markers of compression geodynamic regimes. Within the Kola intracontinental deep-seated collision structure, geodynamic processes of compression (in the infrastructure) and extension (in rifts) appear to be synchronous. The time of formation of sedimentary-volcanic rocks of the Pechenga rift structure – 2.45-1.70 Ga ago – corresponds to the entire interval of formation of high-pressure metamorphic rocks in infracrustal domains – 2.42-1.70 Ga. The stages of intensive deformation and recrystallization of infracrustal rocks in shear zones and in rotation structures (2.32, 2.13, 2.03, 1.94-1.90 Ga) coincide with the stages of volcanism (2.32, 2.11, 1.97, 1.90 Ga in Pechenga), diking and emplacement of intrusions in adjacent areas. Intrusions are represented by layered basic intrusive bodies and multiphase alkaline massifs, including the alkaline granites, i.e., typical formations of extension geodynamics. The interval of formation of layered basic intrusions (between 2500 and 2400 Ma) coincides with the epoch of formation of garnet meta-anorthosites (coronites) – key markers of collision environments.

Therefore, the summarized data for the Kola collision suggest very long-term, unitary, conjugated and synchronous "extension-compression" geodynamics, rather than successive stages of extension (2.5-2.4 Ga ago) and compression-collision (2.0-1.9 Ga ago).

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DECOMPRESSED ECLOGITES AND LATE-OROGENIC DEFORMATION, SVECONORWEGIAN (-GRENVILLIAN) OROGEN, SW SWEDEN.

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Garnet-pyroxenites and associated rocks in the Sveconorwegian orogen of SW Sweden show evidence of a peak-pressure stage in the eclogite facies. These decompressed eclogites are the first described occurrences of Precambrian eclogites in Scandinavia. A clockwise Sveconorwegian P-T-t history is suggested, beginning in the amphibolite facies, progressing through the eclogite facies, decompressing and reequilibrating in the high- to medium-pressure granulite facies, and cooling through the amphibolite facies.

Textural relations suggest the former coexistence of the plagioclase-free assemblages garnet + clinopyroxene + quartz + rutile + ilmenite, garnet + clinopyroxene + kyanite + rutile, and garnet + kyanite + quartz + rutile.The former existence of omphacite is evidenced by up to 45 vol-% plagioclase expelled as small grains within large clinopyroxenes. All matrix plagioclase is secondary and occurs either as expelled from clinopyroxene, or in fine-grained, granulite facies reaction domains formed during resorption of garnet and kyanite. Compositional zoning in large garnets shows rimwards decreasing spessartine-contents and Fe/(Fe+Mg)-ratios, increasing pyrope-contents, and sharp drops in grossular at the rims. This zoning is interpreted as a prograde growth zoning partly relaxed by intracrystalline diffusion, with rim compositions reflecting reequilibration during granulite facies decompression and heating. The matrix reaction textures evidence decompression at granulite facies conditions; P-T estimates from micro-domains with clinopyroxene + plagioclase + quartz + garnet indicate pressures of c. 10-12 kbar and temperatures of c. 750-800 °C for a stage of the granulite facies decompression. The preservation of the prograde zoning suggests that the rocks did not reside at high temperatures for more than a few millon years. Metamorphic disequilibrium and "frozen" reaction textures also suggest a rapid exhumation.

The decompressed eclogites occur within a more than 10 km wide deformation zone with oblique normal sense, top-to-the-east (s.l.) displacement, suggesting that extension was a main cause for the decompression and exhumation. The deformation is characterized by a strong, locally mylonitic, amphibolite facies gneissosity, with a subhorizontal or moderately E- or ESE-plunging stretching lineation. Protolith ages (zircon) of pre- and post-tectonic rocks bracket the age of deformation in the eastern part of the zone between c. 1380 and 955 Ma, but metamorphic mineral ages suggest an upper age limit of c. 1000 Ma. Probable tectonic scenarios are Sveconorwegian late-orogenic gravitational collapse or an overall WNW-ESE extension. The timing and deformational character allow correlation of the post-eclogite facies, late-orogenic deformation in SW Sweden with similar extensional deformation in Grenville terrains of Scotland and Canada.

Palaeo- to Mesoproterozoic intrusive rocks in the area between Numedal and Mjøsa, SE Norway

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Recent studies of Proterozoic rocks loosely assigned to the Sveco-norwegian domain in southern Norway have led to revision of previous models of crustal evolution in the area. Abundant evidence shows that substantial generation of crust took place in the Palaeoproterozoic (Svecofennian and Gothian=Kongsbergian). Subsequent modification and addition to the crust by igneous and tectonometamorphic events culminated with emplacement of voluminous and wide-spread granitoid magmatism (c. 900-1000 Ma) during late stages of the Sveco-norwegian orogenic period.

Here we report the results of an on-going project involving regional mapping and geochemical/geochronological work in a previously little-studied area situated between Numedal in the west and Mjøsa in the east. In the area there are a number of supracrustal sequences which have been intruded by a variety of mafic rocks and granitoids ranging in age from >1600 Ma to c. 925 Ma. The granitoids form compositionally distinct plutons and/or units, many of which are characterised by relatively high contents of high-field-strength elements.

The Telemark Supergroup, which occupies the western part of the studied area, consists of ca.1510 Ma-year-old rhyolitic volcanics (the Rjukan Group) overlain by a thick sequence of mainly quartzite (the Seljord Group), and a succession of sandstones and subordinate volcanics (the Heddal Group). These rocks were folded and metamorphosed prior to deposition of the volcanosedimentary Bandak Group.

The Telemark Supergroup is bounded to the east by layered gneisses of the Kongsberg Complex, consisting of garnetiferous biotite gneisses, hornblende gneisses and amphibolites. Further to the east, the rocks of the Randsfjorden Complex include grey, layered biotite gneiss, biotite-hornblende gneiss and biotite-muscovite gneiss, quartz-rich metasandstone, and minor quartzite, hornblende gneiss and amphibolite. Some of the biotite gneisses are probably of igneous origin. West of Mjøsa, supracrustal rocks correlated with the Kongsvinger Group are present as elongate belts within younger plutonic rocks.

In the Gol area, a coarse-grained granitic gneiss with K-feldspar megacrysts has yielded a U-Pb zircon date of 1492 ± 3 Ma. The pluton appears to cut quarzites that have been correlated with the Seljord Group, which is younger than the Rjukan volcanics dated at c. 1510 Ma. This would allow for a fairly short period of time for the deposition of the quartzites on top of the volcanics.

A suite of calc-alkaline, metaluminous granitic to granodioritic gneisses have intruded rocks of the Telemark Supergroup in the Hallingdal-Rollag area. The rocks contain both biotite and dark green hornblende, and there is textural variation from medium-grained and equigranular rocks to coarsely porphyritic varieties. A granodioritic gneiss forming a large pluton near Haglebu has given an age of 1153 ± 2 Ma. The pluton contains xenoliths of metasandstone assigned to the Heddal Group; the date therefore provides a minimum age for this group. A granodioritic gneiss which has intruded a series of rocks including quartzites of the Seljord group, metasandstone and biotite gneiss, was collected for dating at Eiddal. The sample yielded an age of 1146 ± 5 Ma. These dates indicate a fairly substantial magmatic event with emplacement of granitic to granodioritic plutons into supracrustal rocks of the Telemark Supergroup at c. 1150 Ma.

In the southern part of the studied area, the Telemark Supergroup and associated intrusive rocks are separated from the Kongsberg Complex by a prominent shear zone overprinted by cataclasites and breccias resulting from faulting along the shear zone. A coarse-grained, porphyritic granodioritic gneiss intruding supracrustal rocks of the Kongsberg Complex southeast of Prestfoss gave an age of 1500 +5/-3 Ma. Near Hønefoss, the Follum diorite has yielded a date of 1555 +2/-3 Ma. Several other intrusive bodies, including ultramafic to gabbroic rocks, tonalites and granites, also occur within rocks of the Kongsberg Complex.

Several different types of plutonic rock have intruded the Randsfjord Complex. Sheets of tonalitic to granitic gneiss, in some cases forming large plutons, are quite common. The granitoids have variable compositions and textures, and east of Randsfjorden most of the granitic gneisses is reddish and contains garnet in addition to biotite and/or hornblende. There are also some small bodies of gabbro and diorite. North of Hønefoss, an almost completely recrystallised garnetiferous granitic gneiss with relics of rapakivi texture is present. In the same area, garnet-rich biotite gneisses are locally migmatitic. Three intrusive rock types have been dated. A foliated, megacrystic granitoid associated with reddish, garnetiferous granite near Raufoss has yielded a date of 1250 ± 22 Ma. A large pluton of coarse-grained granite with large megacrysts of reddish brown K-feldspar occupies a wide area in the corridor of Precambrian rocks west of Mjøsa. A sample from Vindflomyra (ca 15 km east of Randsfjorden) in the western part of the pluton yielded an age of 1609 ± 1 Ma. Several sheets of foliated granite cut hornblende-biotite gneisses at Støvika near Einavatnet; one sample from a granite sheet gave an age of 1280 +22/-14 Ma.

MAGNETIC ANOMALY MAP
NORWAY AND ADJACENT OCEAN AREAS
SCALE 1 : 3 MILLION

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The survey area covers mainland Norway, Svalbard, part of the North Sea, the Norwegian Sea, the Greenland Sea and the western Barents Sea. Sources of magnetic data include mostly total-intensity airborne and some shipborne measurements in the western part of the Norwegian Sea (see index map). Flight altitudes, directions, and line-spacings of aeromagnetic surveys varied widely; no attempt was made to transform magnetic-anomaly data to a common altitude.

The aeromagnetic data from mainland Norway and the Norwegian continental shelf is interpolated from digitisation of manually drawn contour maps. Digitally recorded aeromagnetic data covering Svalbard and the northwestern Barents Sea have been combined and interpolated to a 1x1 km grid using the minimum curvature method. A 5x5 km grid compiled by the Geological Survey of Canada from various sources was re-gridded to fill in the remaining parts of the Norwegian and Greenland Seas. After some level adjustments these grids were combined into a single 1x1km grid. The magnetic total field is reduced to anomaly values by using the Definite Geomagnetic Reference Field 1965.0 (DGRF 1965.0). The final map is produced using the equal-area colour scale and the pseudo-relief technique with 'illumination' from the southeast. This type of map enhances structural trends, lineations and contrasts not easily discernible in the conventional contour maps.

Project members: Geirr Brækstad, Jomar Gellein, Henrik Håbrekke, Ola Kihle, Odleiv Olesen (Project leader), Jan Reidar Skilbrei, Mark Smethurst.

The map can be obtained from:
Geological Survey of Norway, P.O.Box 3006, N-7002 TRONDHEIM

Other contributors: Amarok NIASA, Fairey Survey, Geological Survey of Canada, Sevmorgeo, National Geophysical Data Center, Naval Research Laboratory

ASPECTS OF THE STRATIGRAPHY AND STRUCTURE OF THE BAMBLE REGION, S.NORWAY

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It has long been known that rocks of undoubted sedimentary origin are present in Precambrian terrain immediately southwest of the Oslo graben and parallel to the Skagerrak coast-line. These are mainly quartzites and pelitic gneisses exhibiting the effects of later magmatic intrusion, metamorphism and structural disturbance. They belong to the so-called Bamble Sector, a geographically, and to some extent a tectonically defined unit which, by general consensus, represents a very early event in the evolution of the region , possibly mid or even early Proterozoic. Apart from the present author (Padget 1990) no attempt has been made to present a combined stratigraphic-structural interpretation which would provide a framework for later geological events. Questions which immediately arise are as follows :

- What is the order of stratigraphic succession ?
- On what foundation, i.e. basement does this succession rest ?
- What is the depositional age of the metasediments ?
- Are there several time-distinct stratigraphic successions present in the area ?

New data. Perhaps the single most important feature is the increasing number of localities where structures of undoubted sedimentary origin are displayed and which can be used to determine the 'way up' of the strata. These include cross-bedding (various scales), ripple marks, polygonal dessication cracks, slump bedding, and flame structures.These features are still relatively rare in the Bamble terrain and usually of limited extent being present in lens-like parts of metasedimentary sequences (low strain areas).
Used with discretion, however, they provide a long needed means of identifying folds as well as the general nature of the succession.

Conclusions. Generally speaking, the main quartzite masses (Kragerø and Nidelva areas) belong to the uppermost part of the succession and define synclinal structures. Stratigraphically below the quartzites occur pelitic and semi-pelitic rocks (often gneissose) and below these a mixed series including volcanic and calciferous sediments. The latter are only seen on the south side of the Levang peninsula (Kragerø) where they terminate against a major shear plane.
Segmentation. Evidence of shearing is widespread in the whole region. This varies in intensity and it is difficult to assess its tectonic importance in a regional sense from a study of outcrops alone. However, a regional interpretation based on all the evidence, new and old, seems to indicate the existence of several major segments separated from each other by shear planes (See map). Each segment has its own characteristic rock types and structures. The main segments are:

- **Bamble** with quartzites etc described above and divided into two parts – Kragerø-Blakstad-Kroken, an elongate synformal structure and Nidelv-Reddal, a strongly folded sequence. The two parts are separated from each other by a major shear, probably with sinistral sense of movement. Fault elements in this structure include the Kragerø Fault and Nidelv Fault Complex (Padget, 1990). The author has speculated as to whether the sediments listed above together with certain conglomeratic horizons are indicative of deposition in rifts developed on an earlier craton. The conglomerates are certainly not basal to the sequence as a whole or to major units in it and could represent localized erosion, transport and deposition in elongate basins. An aeolian environment has also been suggested for some of the sediments (Nijland et al 1993). There are also a number of monoclinal structures north of Kragerø which could reflect downstepping related to rifting.
- **Arendal-Tromøy** with some quartzite but also marble, iron-ores and a series of foliated, felsic to semi-felsic rocks of uncertain origin some of which are in granulite facies A major refold is probably present and if correct provides a simplication of the stratigraphic succession within the segment which is then as follows: 4. grey tonalitic gneiss, 3. quartzite, 2. Grey tonalitic gneiss including cordierite-anthophyllite rocks, marbles and iron-bearing layers, previously the basis for a local mining industry, 1. Pelitic gneiss(oldest)

* **Portør** with some foliated, tonalitic rocks, and a range of dioritic and granodioritic intrusions
The pre-shear relationships of these segments to each other are unknown. As yet, few strain markers have been found which might indicate movement directions.

Hence, the segmentation proposed here is in effect a subdivision of the Bamble Sector, a term widely used when referring to this part of the Precambrian in southern Norway.

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SEISMIC-GEOLOGICAL MODEL OF THE CRUST IN THE LAPLAND-PECHENGA AREA, NORTHEASTERN BALTIC SHIELD

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In 1995-1997, an integrated analysis of geological and seismic data on the Lapland-Pechenga area was performed, and these studies led to a better understanding of deep structure and geodynamic history of the ancient continental crust (Sharov, 1997). The region contains large fragments of the Sørvaranger-Kola and Inari Archean composite terranes, the Lapland granulite belt and Early Proterozoic structures (Polmak, Pasvik, Pechenga), which are part of an ancient rift system (Dobrzhinetskaya et al., 1995; Mitrofanov et al., 1995; Smolkin, 1997). The Sørvaranger and Inari terranes are composed predominantly of Late Archean rocks. The major elements of these terranes are dome-block features, inter-domal synforms and repeatedly deformed "tabular blocks" that extend downwards. The faults dividing the Sørvaranger-Kola terrane into separate complexes (Jarfjord- Kola, Kirkenes, Bjørnevatn, Svanvik) dip beneath the North Pechenga zone, where they have been intersected by the Kola Superdeep Well (SD-3). These faults were activated in the Early Proterozoic as synsedimentary faults. The Inari terrane and its components (Vaggaten, Hihnajarvi and Kaskama) were formed in Late Lopian time, while in the early Proterozoic the Inari dome-block ensemble was almost everywhere transformed into a lens-tabular structure as a result of crustal stacking that proceeded first in the northeastern and later in the northwestern direction. An alternation of granite- gneiss lenses, which have a relatively homogeneous structure, and apparently supracrustal tabular blocks, which show numerous reflectors, is traceable down to a depth of 10-15 km.

The Lapland Granulite Belt is a packet of tectonic plates, which in some cases have preserved earlier structural elements. These plates dip steeply in the southeastern part of the Belt, the dip gradually becoming less steep in the north, where they extend beneath the Inari terrane and, at a depth of 5 km, are cut off by a zone of subvertical faults (Buyanov et al., 1995).The main structural-tectonic style of the Belt was formed in the Early Proterozoic.

The Pechenga structure is separated at depth, as well as on the surface, into two zones, which have different structural styles. The Northern zone is characterized by a combination of thrust and reverse faults, which dip to the southwest, and normal slip faults and interformational displacements, which dip to the northeast. Some of the normal slip faults and displacements apparently formed in the course of incipient extension of the crust and its sagging accompanied by the formation of sedimentary basins and volcanic troughs. The reverse faults and the feathering faults were formed in the course of compression, when the Inari terrane, together with the Hutojavr complex, were upthrust on the Southern Pechenga zone, and later, on the North Pechenga zone. These thrust and reverse fault movements considerably complicated the sections of the "productive" sequence and the overlying Matert volcanic formation. The "productive" sequence gradually wedges out in the southwestern direction, and is cut off at a depth of 6-8 km by reverse and thrust faults. In the area of the Luotna, Kuorpukas and Shulgjaur faults, the sections of the "productive" sequence are doubled.

The Southern and Northern Pechenga zones are separated by the Poritash and Shulgjaur fault systems, which represent reverse faults in the upper crust and thrust faults at a depth of 6-8 km. The structure of the Southern zone is dominated by numerous thrust and reverse faults of different ages. The early thrust zones were thrown into large folds as a result of left-lateral faulting; subsequently (at the second stage of the left-lateral fault), they were cut off or overlain by later thrusts. For example, the Hutojavr complex and fragments of the granodiorite domes were cut off by a thrust fault end thrust over the rocks of the Southern zone.

The upper crust is characterized by a strong heterogeneity and has a block-imbricate structure, whereas at a depth of 15-45 km, the crustal structure is dominated by horizontal reflectors, which mark horizontal "layering". Thus, the modern subhorizontal seismic boundaries are not related to the boundaries of lithologic-tectonic complexes and are not caused by crustal segregation that took place during the Lopian and (or) Svecofennian orogeny. These seismic boundaries reflect a later subhorizontal "layering", which was probably caused by a newly acquired physical and physical-chemical heterogeneity, mineral phase transformations, zones of cataclasis and decompaction, and by different degrees of fluid saturation.

The Moho interface is the most persistent seismic boundary producing reflection, refraction and converted waves with a various degrees of stability. The waves reflected from some parts of this boundary are recorded as two-three lineups. They are similar in intensity and oscillation forms separated in time by a 0.2-0.5 sec interval. In this case, the transitional lower crust - upper mantle layer has two or three seismic boundaries 5-8 km apart. Areal studies of the region by the DSS and reflection methods have confirmed the existence of a transitional layer beneath the Pechenga structure. The minimum depths down to the Moho interface have been established directly beneath the area of the maximum compensation submergence of the Southern Pechenga zone. A relatively thick (2-7 km), lens-shaped transitional layer occurs under the same zone. The long axis of the lens strikes towards the northwest, i.e. it is discordant to the boundary between the Northern and Southern zones of Pechenga. Possibly, this is the case of a relict heterogeneity (or a relict surface), which was caused by a non-gradual upward movement of the Moho boundary in the lithosphere during the Early Proterozoic.

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PROTEROZOIC MAGMATIC ASSOCIATION IN EASTERN FENNOSCANDIA AS AN INDICATOR OF GEODYNAMIC ENVIRONMENT.

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1. The first manifestation of Proterozoic magmatism in Eastern Fennoscandia is dated at 2.5-2.4 Ga. Leading role belongs to large ultramafic-mafic and granite plutons, forming bimodal magmatic association. Granitoids of this stage (massifs Nuoronen, Keiv and others) are compositionally subalkaline and alkaline and belong to A-type. Layered ultramafic-mafic intrusions (massifs of Olanga group, Monche pluton, Burakovsko-Aganozersky and others) form the peridotite-pyroxenite-gabbro-norite series. Volcanic complexes are limited and are represented by rhyolite analogous by their geochemical characteristics to granites of A-type and basalts. This stage is also related to the oldest manifestation of alkaline and carbonatite magmatism.

Formation of magmatic bodies is caused by the regime of epicratonic extension and corresponds to the initial stage of riftogenesis related to underplating. Deep fracture zones which have been formed at this stage later controlled formation of isolated basins and rift belts mainly of NW and NNW strike which collectively represent a system of conjugate aulocogens. The largest structures of this type are Central-Kola and East-Karelian. According to isotopic-geochemical data magmatic complexes of this stage are characterized by negative value of ε_{Nd} (- 0.8) - (-2.3), which indicates enriched mantle source and denotes extension of the earth's crust. It is possible that in some structures the rifting lead to the splitting of the earth's crust and beginning of oceanic basin formation. Such supposition is most probable for the Vetreny belt structure there cross-section is characterized by big thickness of high-magnesian pillow lavas dated 2.45 Ga and close to zero ε_{Nd} value.

2. Further tectonic evolution of Eastern Fennoscandia manifested in formation of complicated system of rift structures and vast basins of old platobasalts. This is a well known epoch of Karelian Jatulian (2.3-2.1 Ga) with predominant development of continental basalts and their intrusive analogues. Typical complexes of this stage are Fe-Ti basalts and dolerites. Jatulian volcanism was accompanied by sedimentation in shallow water and subaerial setting.

The 2.1-2.0 Ga is a time interval characterized by sharp change of volcanism and sedimentation facies that indicates deep-water environment. In volcanite composition predominates olivine tholeiites and picrites. Pillow lavas are widely spread. Comagmatic intrusive complexes are represented by dolerites and gabbro-wehrlites. Typical examples of such structures are the Pechenga and the Onega structures. Geochemical characteristics of volcanites of this boundary (ε_{Nd} = +2 - +3) indicates an asthenospheric source.

Long development of Early Proterozoic riftogenic systems resulted in formation of structures of Red Sea-type.

3. Final stages of Early Proterozoic continental riftogenesis in Eastern Fennoscandia coincided with origin of Svecofennian and Lapland (?) paleooceans In the eastern part of the Fennoscandian shield the typical Svecofennian magmatic complexes are found in the Ladoga Lake region, in the conjunction zone of the Karelian craton and the Svecofennian mobile belt (Raahe-Ladoga zone). The oldest Svecofennian complexes are found in the northern Ladoga area and are represented by fragments of ophiolite nappes, analogous to the known Outokumpu and Jormua complexes in Finland. In complicated fold ensemble of tectonic nappes the suboceanic olivine tholeiites (ε_{Nd} = +5 - +6) of the back-arc basin dated as 1.97 Ga occur in combination with the Jatulian plateaubasalts (ε_{Nd} = (-0.7) - (-0.2)). Subductional Svecofennian magmatism in the Ladoga Lake area is represented by gabbro-norite-enderbite, gabbro-diorite-plagiogranite and diorite-granodiorite calc-alkaline complexes dated as 1.87 Ga.

Collision of the Svecofennian island-arcs system and the Karelian plate was accompanied by crustal high-aluminous granites of S-type. Postorogenic complexes of the Ladoga Lake area are represented by complicated association of lamprophyres (appenites), apatite-bearing ultramafites, monzonites, syenites and granites are well correlated by the age (~1.8 Ga) and composition with analogous formations in Finland.

4. Initial stages of the Riphean magmatism are characterized by similarity with magmatism caused origin of subjothnian plutons of bimodal gabbro-anortosite-rapakivi-granite association synchronous with

doleritic dyke swarms and sills and basalt-rhyolite volcanic complex (hogland series) dated as 1.64 Ga. This association is related to initial stages of rifting caused by underplating.

Later (1.4-1.3 Ga) took place the formation of Gotnian grabens, magmatic complexes of which are represented by transitional subalkaline ferrobasalts (Salminskaya series) and comagmatic subvolcanic sills (valaam complex). To a certain extent magmatism of this complex stage could be correlated with trap magmatism.

The latest manifestation of Riphean magmatism in eastern Fennoscandia are represented by lamproites of Kostamuksha.

5. In evolution of the Earth's crust in eastern Fennoscandia could be distinguished two important tectono-magmatic cycles (2.45-1.95; 1.65-1.1 Ga), which have similarity with intraplate magmatism, especially in the initial stages, when were formed homological bimodal associations of gabbro-granites (basalt-rhyolites). These cycles are divided by orogenic processes (2.0-1.8 Ga), with which is related generation of juvenile Proterozoic continental crust of the Fennoscandian shield.

CONVERGENT MARGIN ON SOUTHEAST LAURENTIA DURING THE MESOPROTEROZOIC: TECTONIC IMPLICATIONS

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Mesoproterozoic continental-margin magmatic arc suites, formed in the intervals 1450—1420 Ma and 1410—1230 Ma have been identified from that part of southeastern Laurentia subsequently incorporated within the Grenville Province. The presence of these magmatic arcs, coupled with the absence of passive continental-margin sedimentary successions of Mesoproterozoic age, leads to the conclusion that the southeastern margin of Laurentia was active and predominantly convergent throughout the Mesoproterozoic.

Recent research has shown that relative differences in rates of convergence and subduction at active plate boundaries result in either compressive or extensional regimes in the magmatic arc in the overriding plate. In this paper we use the geologic record to infer the time and duration of extensional and compressive regimes of the Mesoproterozoic continental-margin arc on southeastern Laurentia.

Extensional arc settings are inferred from the presence of backarc deposits, including: *(i)* the backarc locations of mafic dyke swarms subparallel to the paleo-continental margin, *e.g.* ~1430 Ma Michael-Shabogamo dykes, 1273 Ma Harp dykes; *(ii)* marine/oceanic backarc basin deposits, *e.g.* ~1290—1250 Ma metavolcanics and metasediments in the Hastings and Frontenac groups (Central Metasedimentary Belt); and *(iii)* continental backarc deposits, *e.g.* ~1270—1220 Ma metasediments and bimodal magmatic products in the Wakeham Supergroup and Seal Lake Group. The arc was *compressional* from ~1495—1445 Ma and from ~1250—1190 Ma during the Pinwarian and Elzevirian orogenies respectively, with the Elzevirian Orogeny being associated with the closure of both marine and continental backarc basins.

The presence of a continental-margin magmatic arc on SE Laurentia during the Mesoproterozoic implies that other coeval magmatism inboard from the arc took place in a backarc setting. Such magmatism was widespread and chemically diverse, and included alkali granitoids (*e.g.* Letitia Lake volcanics, Arc Lake, Redwine and Kipawa plutonic suites), 'within-plate' granitoids (*e.g.* Mulock and Arrowhead Lake plutons) and 'anorogenic' AMCG complexes (*e.g.* Harp, Michikamau, Mistastin and Pentecôte complexes).

Active convergent-margin tectonics on SE Laurentia were terminated by continent-continent collision during the Grenvillian orogenic cycle. This involved at least three distinct episodes of crustal shortening separated by periods of extension. Extensional episodes are correlated with periods of anorthosite emplacement (*e.g.* Morin, Marcy, Lac St. Jean complexes), which are interpreted to have formed as a result of delamination or convective removal of the lower continental lithosphere, allowing asthenospheric magmas access to the base of the crust.

AMCG complexes in and adjacent to the Grenville Province were thus emplaced in two contrasting tectonic environments, *i.e.* the pre-Grenvillian complexes (previously interpreted as anorogenic in origin) were emplaced in a backarc setting inboard from the continental-margin magmatic arc, whereas the Grenvillian orogenic complexes were emplaced in a locally extensional setting in an overall convergent orogen.

Recognition of the Mesoproterozoic convergent margin of southeastern Laurentia suggests that there may be useful parallels with the evolution of the Andes, which has been a convergent margin since the late Proterozoic.

THE PRECAMBRIAN GEOLOGY OF CENTRAL SOUTHERN NORWAY

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In central southern Norway, the polyphasal N-S trending Mandal-Ustaoset Fault Zone separates the Precambrian area into two blocks:

1. **The eastern block** contains the Telemark supracrustals, their basement, and different plutonic rocks intruding them.

   The boundary relations between the Telemark supracrustals and the underlying and surrounding gneisses and granites have been a matter of discussion for over 100 years in Norwegian geology, and a basement to the oldest group, the Rjukan Group, has never been demonstrated before. We have now found this basement, the Gøyst Complex, in the Uvdal area, and also just east of the Mandal-Ustaoset Fault Zone.
   The Gøyst Complex consists mainly of dark-coloured supracrustal rocks, partly migmatitic gneisses with dioritic intrusions. All are folded and deformed in a complex manner.

   The Telemark supracrustals consist of four groups of metamorphosed rocks; three of them are separated from each other by major unconformities: The Rjukan Group (oldest), consisting of acidic and basic volcanic rocks; the Seljord Group, consisting of quarzites; the Heddal Group, conformably overlying the Seljord Group and consisting of metamorphosed sediments and possibly tuffites; and the Bandak Group (youngest) consisting of immature sediments interlayered with basic and acidic volcanic rocks. All four groups have been followed northwards from the central Telemark area to the Caledonian front at Reineskarvet.

   The Rjukan volcanic rocks (1514-1511 Ma) were deposited in a N-S-trending rift basin limited by the Mandal-Ustaoset Fault Zone in the west, and a possible fault also in the east. This basin is of much the same size and has the same N-S extent as the Permian Oslo rift.

   The Rjukan rocks were intruded by numerous igneous rocks. Some of them, the Grotte Suite, (age around 1509 Ma) are probably connected with the rift-forming event. After this period of active rifting and volcanism there followed a long, quiet period with almost complete levelling of the old landscape. The deposition of the pure quartzites of the Seljord Group took place mainly in an epicontinental shelf environment. The Heddal Group was deposited in an environment where some volcanic activity took place. The sediments of these two groups cover a larger area than the Rjukan volcanics and have an eastward areal extension independent of the earlier rift basin, a fact supporting the drastic differences in depositional and tectonic environment during the deposition of the Rjukan and the Seljord Groups. The metamorphosed sedimentary and volcanic rocks of the Bandak Group have been deposited with an angular unconformity on the older folded and eroded groups. The rocks along the western boundary were deposited along an active fault margin, while the eastern boundary seems to be a post-depositional fault following the Numedal valley. Thus the Bandak Group could also have been deposited in a intracontinental rift basin, but it was smaller and contained fewer volcanics than found in the Rjukan rift.

2. **The western block** consists of about 80-90 % intrusive rocks of different ages, different composition (mainly granitic) and showing all degrees of deformation from migmatitic gneisses to massive rocks. In this vast igneous-dominated area there are smaller areas with (inclusions of) mainly pure quartzites and some supracrustal gneisses. A fine-grained pink granite (the Mårsbrotet granite) intrudes all the different orthogneisses, foliated granites and the supracrustals had a U-Pb zircon age of 1649 +33/-19 Ma. This implies that the supracrustals west of the fault predate the Telemark supracrustals. The quartzite inclusions are found scattered all over Hardangervidda. This could imply that a quartzite blanket once (more than 1700 million years ago) covered most of the area. Thus, also in this distant past the «Hardangervidda» could have been a relatively flat-lying area, maybe a broad shelf area or a peneplain covered with orthoquartzites.

PRE-CAMBRIAN UNITS IN ALPINE-CARPATHIAN SYSTEM

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Identification of Pre-cambrian blocks in younger orogenic systems is important since it enables us to understand deep structures of continental crust. It is important especially when orogenic belts which flank the shields, are destroyed and their fragments incorporated into new belts, or are overlapped, as in the case in the European Alpides.

The middle crustal sheet (granitic - gneissic) in the Alpine-Carpathian system belongs either to Pre-cambrian, or to Hercynian units. Two Pre-cambrian block branch southwards from the Czech Massif (the Moldanubian Unit on the west and the Brno Unit on the east) into the Alpine basement, at least as far as the Insubric line. Below the Western Carpathians the Brno Unit continues also eastwards. According to the newest interpretations its southern boundary is irregular and over the central parts of Slovakia it extends up to 100 km southwards of the northern margin of the Carpathians. The southern fragments of the Brno Unit (if they ever existed?) were separated from this area during Penninian ocean rifting and their location is not known to date. The assignment of Pre-cambrian units beneath the Pannonian Basin and in the Dinarides to Laurasian or to Gondwanian units respectively, is still problematic.

THE PRECAMBRIAN GEOLOGY IN THE SOGNEFJORD AREA, WESTERN NORWAY

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The gneisses of the Western Gneiss Complex (WGC) in the Sognefjord area of western Norway, have been affected by three orogenies: the Gothian (1700-1500 Ma), Sveconorwegian (1250-900 Ma) and Caledonian (420-365 Ma).

During the Gothian Orogeny major parts of the rocks in the WGC were formed, and in the Sognefjord area they comprise various granitic, syenitic and gabbroic rocks and quartzites. The plutonic rocks comprise calc-alkaline granodiorites and gabbros, alkaline granites, quartz syenites, syenites and gabbros. Their Sr and Nd isotopic characteristics indicate that they formed from mostly juvenile mantle melts. These rocks were deformed into various homogeneous and heterogeneous gneisses, and metamorphosed prior to the regional migmatization event, dated to be approximately 1600 Ma in this area (Milnes et al. 1988).

From the Sveconorwegian Orogeny only late post-kinematic composite intrusions of felsic and mafic magma (1030-920 Ma) are identified in the Sognefjord area. The largest plutons are composed of mostly porphyric monzogranite, quartz monzonite, and minor amounts of monzogabbro. Minor intrusions and dykes are composed of equigranular granite, quartz syenite, syenite, and monzogabbro. The intrusives are all alkaline and anorogenic. Sr and Nd isotopes values for the rocks are consistent with melting of Gothian rocks, mixed with variable, but generally small amounts of juvenile mantle melts. In the Sognefjord region only weak effects of Sveconorwegian deformation are observed, but a stronger degree of deformation is reported from Eksingedalen in the southern part of the WGC (Grey 1978), and in the Jotunheimen area in eastern parts of the complex (Priem et al 1973).

The Caledonian Orogeny caused strong deformation of the WGC, but no magmatism is reported from the southern part of the complex. The degree of deformation increases strongly westwards where high-pressure rocks, such as eclogites are present (Milnes et al. 1997). This study was performed in the middle part of the Sognefjord area, where the effects of Caledonian deformation and metamorphism are limited to local amphibolite and greenschists facies shear zones.

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THE CARAVARRI FORMATION OF THE KAUTOKEINO GREENSTONE BELT, NORTHERN NORWAY; FORELAND BASIN SEDIMENTS IN FRONT OF THE LAPLAND - KOLA THRUST BELT

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The Palaeoproterozoic Alta-Kautokeino rift has been defined on the basis of the lithological characteristics of its rock contents. However, as no rift-marginal master faults have been demonstrated, it remains structurally cryptic.

This presentation re-interprets the Caravarri Formation in terms of foreland basin molasse-type deposits, derived from the continental collision orogen which thrusted the Lapland Granulite Belt, 120 km farther east, westwards onto the Karelian Craton.

The intervening, heavily covered area is underlain by an Archaean basement dome surrounded by metasupracrustal cover rocks, to a large extent also thrusted westwards as imbricated, par-autochthonous sheets.

The Caravarri Formation forms a NNW-SSE running mountain ridge, Caravarri (891 m asl), rising above the densely covered Finnmarksvidda plateau (400-500 m asl). The formation is well exposed for about 25 km along strike and is up to 6 km wide. It has intermediate to steep easterly dips, and has a preserved stratigraphic thickness of about 4 km.

It consists of coarse sandstones and conglomerates, interpreted as subaquatic and alluvial fan deposits.
The Caravarri Fm is subdivided into three segments, separated by inferred faults. The segments are distinctly different in mineralogical and textural maturity of their lithic clasts, and form separate sedimentary entities. For two of them, sediment transport from an easterly direction can be demonstrated.
The third segment has not yielded reliable directional structures.

The Caravarri Fm rests with depositional contact on the underlying, poorly exposed, silt-and-sandstone dominated Bik'kacåk'ka Fm. The eastern boundary of the Caravarri Fm is tectonic, and interpreted as a steeply east-dipping reverse fault, with a hangingwall block of older supracrustal strata ramped up onto the Caravarri sandstones.

The re-interpretation of the Caravarri as a molasse deposit preserved in front of remnants of a Svecokarelian thrust belt implies that the lower, Cas'kejas Formation metabasalts may also have formed in the same, foreland basin. — Paul F. Hoffman proposed, ten years ago, that many Palaeoproterozoic foreland basins in the Canadian Shield differed from actualistic ones by the occurrence of mafic magmatism in addition to sediment deposition. That may apply in the present case too.

PROTEROZOIC GRANITOIDS FROM THE REGION OF THE PECHENGA STRUCTURE AND THE KOLA SUPERDEEP BOREHOLE SECTION: EVIDENCE OF PETROLOGY AND METALLOGENY

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The Early Proterozoic Pasvik-Pechenga rift zone is located in the northwestern part of the Kola Peninsula.The Kola superdeep borehole (SD-3) is drilled in the northern part of the Pechenga structure and reaches a depth of 12262 m, which allows observation of the distribution of deep granitoids and gives valuable information for study of their petrology.

Proterozoic granitoids in the Archaean rocks are represented by the Northern-Pechenga complex of "Red Granites", quartz diorites of the Kaskeljavr complex in the southern part of the Pechenga, and porphyritic granites of the Litsa-Araguba complex in the eastern part of the structure and the Vainospää massif in its western part.

Muscovite-microcline granite-like metasomatites, 2225 ± 5 Ma in age, are found in the SD-3 at depths of 12172-12235 m.They are formed from Archaean gneiss by reworking in tectonic zones by carbon dioxide-enriched fluids derived from Early Proterozoic subalkaline trachybasalts (2214 ± 54 Ma) of the Pechenga structure.At the present erosion level, granite-like metasomatites are present in the northern part of the Pechenga structure, where they form 3 subparallel bands from 1.2 to 3 km in width and up to 15-20 km in length.The upper age limit for metasomatites is geologically defined by the localization of weathered fragments of these rocks in the gravellites of the third sedimentary strata of the Pechenga sequence. In comparison to the gneiss, the metasomatites are specialized in rare-elements and are enriched in Zr, Y, Nb, Th, La, Ce, Nd, Pb, F, P, and also Fe, Ti, Cu, Ni, Cr and V. By the investigation of the U-Pb and Pb-Pb systems in the gneiss and metasomatites, the heterogeneity of the sources of the material for metasomatites have been established (Vetrin et al., in press). The nature of Pb in the metasomatites is assumed to result from mixing of Pb from gneiss with lead from trachybasalt mantle sources, and then with high-radiogenic lead of an upper-crustal source which appeared with the penetration of anatectic bodies of Svecofennian granites 1762 ± 2 Ma in age.

The granitoids of the Kaskeljavr complex form 5 massifs covering an area of 400 km^2 to the south of the southern zone of the Pechenga structure. The massifs, which have been studied by remote methods from depths of a few hundred meters down to 2-3 km, form lens-like, root-less, synorogenic plutons with internal structures conforming to their contacts. The age of the granitoids is estimated at 1940 ± 17 Ma (Pb-Pb method). In the majority of petrochemical diagrams, the granitoids form an unbroken range of compositions from diorites to plagiogranites, with a predominance of quartz diorites. They have a low initial $^{87}Sr/^{86}Sr$-ratios measured on titanite of magmatic origin, indicating that the source of the initial melt resulted from differentiation of a basaltic magma. The granitoids, which are enriched in Cr, Co, Ni, Cu and V, but are poor in lithophile elements, crystallized relatively deep in the crust at P~5-6 kb, T~750°C. The shift of the massif to the upper levels of the crust occurred in the process of movement from south to north. The connection between the granitoids and their associated ore deposits is not established.

Porphyritic granites form 5 massifs with a total area of 900 km^2 in the eastern part of the Pechenga structure and coincide with a fault with NE-SW trend. The age of the granites is determined to be from 1815 ± 50 Ma (U-Pb method) to 1720 ± 25 Ma (Rb-Sr method). A similar age (1.79 Ga) has been established for the granites of the Vainospää massif, located in the Inari area to the west of the Pechenga structure. Numerous bodies of fine-grained porphyritic granites with an age of 1765 ± 2 Ma are revealed by a the SD-3 borehole in the interval between 9,5 and 11 km. Substantial variation in isotope charateristics ($\varepsilon_{Nd}(t)$ from +6.6 to -11.1, T_{DM} from 2309 to 2744 Ma, $^3He/^4He$ from 0.33 to $1.6x10^{-6}$) attest to the intensively developed processes of cust-mantle interaction during the formation of the granites of the Litsa-Araguba complex. The first phase of the complex is represented by quartz diorites, syenodiorites and monzogabbro, formed from the mantle asthenolite that upwelled to the bottom of the granite layer of the crust. Granites and granodiorites of the phases 2-4 were formed by differentiation of the secondary crustal chambers of anatectic melt of calc-alkaline composition. Intrusions and dikes of granosyenite, syenite and quartz monzonite formed from residual melts during the differentiation of asthenolites after the consolidation of the anatectic magma chamber. The granitoids are specialized in Pb, Zr, Sn, Mo, Ba, Th, U and REE, partly localized in small ore deposits of molybdenum-porphyry and tungsten-rare-metals-molybdenum.

The data presented show the essential role of processes of crust-mantle interaction during the formation of the granitoids from the region of the Pechenga structure.

THE OSLO LINEAMENT; A ZONE OF REPEATED CRUSTAL WEAKNESS SINCE EARLY MESOPROTEROZOIC TIMES

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Cathodoluminescence images were used to select zircons for ion probe U-Pb dating of detrital grains and metamorphic overgrowths from three Proterozoic metasedimentary units; the Bamble gneiss in southern Norway, the Stora Le - Marstrand (SLM) and Skagerrak Formations in SW Sweden. Because of their position on either side of the Permian Oslo Rift, they could provide a link between the eastern and western halves of the Sveconorwegian Province.

Detrital zircons from an SLM metapsammite gave Pb-Pb ages in a restricted interval at about 1.6 Ga. Volcanic zircon morphology and lack of rounding point to an immature sedimentary environment, consistent with the inferred island arc setting. Multiple-spot analyses of detrital grains gave near-concordant U-Pb data that provided a 1.60 Ga maximum age for the SLM Formation, thus superseding a previous ca. 1.76 Ga Sm-Nd age (cf. Åhäll and Daly 1989).

A Bamble metaquartzite from the Kragerö area, shows a broad distribution of Pb-Pb zircon ages between 2.6 and 1.5 Ga. Thick metamorphic rims are in accordance with high-grade Sveconorwegian metamorphism. Multiple-spot analyses on young detrital zircons yielded a maximum depositional age that invites re-examination of previous 1.6-1.54 Ga age constraints for the Bamble metasupracrustal gneisses. A late Archean grain confirms the presence of such old crustal components in SW Norway whereas the broad age spectrum of the detrital zircons is consistent with derivation from continental crust.

The Skagerrak Formation is a recently recognised volcano-clastic unit, occurring as megaxenoliths in western parts of the 0.92 Ga Bohus granite. Most zircons from a dacitic sample gave concordant to near-concordant U-Pb ages in the 1.56-1.44 Ga range, yielding a maximum depositional age of 1.48 Ga. One ca. 1.88 Ga old grain was found which indicates a pre-Gothian provenance not known today in the Gothian orogen of SW Sweden.

Together the presence of pre-1.65 Ga crust in the core of SW Norway (cf. Ragnhildstveit et al. 1994) and the new ages for SLM and Bamble depositions require reassessment of previous models of westward growth in Baltica and earlier correlations between the Gothian and Kongsbergian histories. A ca. 1.58 Ga collision of an SW Norwegian craton and proto-Baltica is consistent with available data from the crustal segment east of the Oslo Rift, but lacks support from the still poorly constrained evolution in the Kongsberg-Bamble Sector to the west.

East of the Oslo Rift, anorogenic magmatism included 1.51-1.50 Ga gabbro-dolerite-granite associations and 1.46 Ga N-S trending mafic dyke swarms. It is argued that the 1.46 Ga E-W extension did not lead to continental break-up, and thus can be correlated with the failed rift of eastern Laurentia expressed by coeval anorthosite-granite associations and Shabogamo and Michael gabbros (cf. Gower and Tucker 1994, and references therein).

A broad correlation between the Bamble and lowermost Telemark supracrustals in southern Norway and the Skagerrak Formation in SW Sweden is suggested. The analysed Bamble and Skagerrak samples formed after 1.50 Ga and none of their detrital zircons was proven younger than the 1.46 Ga N-S rifting. The age constraints, rock types and distribution of the Skagerrak Formation, are consistent with its deposition in N-S trending troughs associated with the 1.46 Ga E-W extensional event. A similar setting is also possible for the Bamble metasupracrustal rocks.

The Sveconorwegian Oslofjorden Shear Zone (Berthelsen 1980; Hageskov 1980) and the Permian Oslo Rift are thus thought to have developed along a major Mesoproterozoic tectonic boundary representing a ca. 1.58 Ga suture zone and a 1.46 Ga rift zone.

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CORRELATIONS BETWEEN LATE PALEOPROTEROZOIC BALTICA AND LAURENTIA FROM CRITICAL EXAMINATION OF GOTHIAN AND LABRADORIAN TECTONIC SETTINGS

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It has been widely accepted that western Baltica and eastern Laurentia were part of a common accretionary Laurentia-Baltica margin during the late Paleoproterozoic. The resulting Gothian and Labradorian orogens do not show identical tectonic histories, however.

The voluminous pre-Gothian magmatism in Baltica, as manifested by 1.81-1.77 and ca. 1.70 Ga Transscandinavian Igneous Belt (TIB) rocks, lacks counterpart in eastern Laurentia although coeval intrusions are known from the Makkovik Province. Conversely, late Paleoproterozoic supracrustal precursors are sparse in Baltica but abundant in eastern Laurentia. In Baltica, the relative lack of supracrustal rocks and abundance of granitoid rocks support an continental-margin setting, whereas in Laurentia, the reverse proportions are in accordance with the development of a marginal basin at ca. 1.71 Ga.

The period of largely coeval growth in western Baltica and eastern Laurentia embodies both an important comparison and an important contrast. The comparison is that calc-alkaline magmatism extended from 1.69 to 1.65 Ga in Baltica and from 1.68 to 1.65 Ga in Laurentia, thus providing strong evidence for subduction-related growth along the Laurentia-Baltica margin.

The contrast is in the direction of proposed subduction polarity. In Baltica, the progressive eastward change in magmatic character (from calc-alkaline west of the TIB, through coeval alkali-calcic TIB 3 rocks, to rapakivi intrusions in Finland) strongly supports (shallow?) subduction under Baltica. The lack of a similar magmatic zonation, coupled with the abrupt boundary between the 1.65 Ga Trans-Labrador batholith and pre-Labradorian Laurentia, equally strongly argues for a different tectonic regime in eastern Laurentia. Oceanward (southward) subduction under early Labradorian arcs being built on a detached fragment of pre-Labradorian crust has therefore been suggested (Gower 1996). Subduction toward Baltica and away from Laurentia would satisfy balancing whatever global vectors existed at the time for oceanic consumption, but it would be interesting to know where on the Baltica-Laurentia margin the switch-over in subduction direction occurred.

A change in style of tectonism occurred at 1.65 Ga in both regions, although not to a common orogenic regime. The collision of the outboard calc-alkaline arcs with cratonic Laurentia is taken to be the cause of the 1.65 Ga Trans-Labradorian magmatism. The lack of a comparable collision explains the absence of an analogous granitoid belt in Baltica. Integrated structural, geochemical and isotopical studies in SW Sweden, have provided strong indications for continued calc-alkaline magmatism and arc accretion between 1.62 and 1.58 Ga in western Baltica (Connelly and Åhäll 1996; Åhäll et al. in press; Brewer et al. in press). No such activity has been recognised in eastern Laurentia, where, following generation of the 1.65 Ga Trans-Labrador batholith, magmatism declined, became bimodal and appears to have ceased prior to 1.60 Ga. It cannot be ruled out, however, that continental-margin activity did not jumped further south to the still poorly known southeasternmost Laurentia.

Present data show significant geological activity continuing in Baltica after ca. 1.58 Ga orogenic deformation, but very little to match it in Laurentia. In Baltica, two tectonic scenarios are currently viable for the early Mesoproterozoic; continent-continent collision occurred at ca. 1.58 Ga, and eastward subduction was renewed. Although different, these scenarios could also have operated sequentially since a ca. 1.58 Ga docking of proto-SW Norway may have forced subduction to jump further west (cf. Berthelsen 1980), thus allowing continued eastward subduction in the early Mesoproterozoic.

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