*Current Research (1992) Newfoundland Department of Mines and Energy,
Geological Survey Branch, Report 92-1, pages 331-366*

THE RELEVANCE OF BALTIC SHIELD METALLOGENY TO MINERAL EXPLORATION IN LABRADOR

C.F. Gower
Labrador Mapping Section

ABSTRACT

The hypothesis that Laurentia and Baltica evolved together as a single continental landmass during the mid-Proterozoic is now well established, and has important implications with respect to mineral exploration in Labrador. In Baltica, mining has a 2000-year history, mineral prospecting has been carried out for 500 years, and the geological database has been steadily accumulating over the last 150 years. This vast wealth of accumulated knowledge is thus available for application to mineral exploration in Labrador.

In this article, correlations are restricted to regions south of the Archean cratonic nuclei. The Kalevian Group (ca. 2.10 to 1.94 Ga), which was deposited as a continental marginal prism on the flank of the Karelian cratonic nucleus, and Cu−Zn−Co−(Ni) mineralization within it (e.g., Outokumpu), is compared with rocks deposited on the northwest margin of the Makkovik Province, known to host similar mineralization.

The Svecofennian orogen (1.91 to 1.82 Ga) is equated with the Makkovik−Ketilidian orogen. Inasmuch as only the fringe of the Makkovikian−Ketilidian orogen flanking the Archean cratonic nucleus is preserved in Labrador, only the northernmost section of the Svecofennian orogen is deemed relevant to metallogeny in Labrador. From a metallogenic standpoint, however, this region is the most important part of Baltica. The marginal part of the Archean microcontinent that was reworked during Svecofennian orogenesis is host to Mo−U−(W−Sn) mineralization, south of which are the arc-related Cu−Zn−Au massive sulphide deposits and Cu−Mo−(Au) porphyry-type mineralization of the Skellefte district and then a zone of Ni mineralization. In the Makkovik orogen, Mo−U mineralization is flanked on its eastern side by a concentration of Cu−Pb−(Au) showings, suggesting an analogous situation. In both Baltica and Labrador, at least some of the Mo−U mineralization has been linked with post-orogenic 1.81 to 1.77 Ga granitoid rocks.

The next major accretionary event took place between 1.71 and 1.60 Ga, resulting in the Gothian−Kongsberg orogen in Baltica and the Labrador orogen in Laurentia. Pre-orogenic pelitic and psammitic schists in Baltica (ca. 1.76 Ga) are host to stratiform Cu−(Co) deposits, which have been compared to Besshi-type ores. Similar, but barely prospected, sulphide-impregnated, locally Cu-mineralized zones, are common in parts of southern Labrador. The later, syn-orogenic Gothian−Kongsbergian rocks appear devoid of related mineralization, except in felsic volcanic rocks deposited on older crust at the eastern fringe of the orogen, hence the only Laurentian counterparts judged to hold prospecting potential are analogous felsic volcanic rocks at the northern margin of the Labrador orogen. Coeval (1.64 Ga) rapakivi granitoid rocks in Finland host Sn−Be−W−Pb−Zn deposits, however, and comparable mineralization could exist in the southern part of the poorly known 1.64 Ga Mealy Mountains Intrusive Suite in Labrador, if uppermost intrusive levels are preserved.

Following crustal stabilization between 1.59 and 1.51 Ga, both Baltica and Laurentia experienced anorogenic conditions, lasting until 1.27 Ga. Apart from V−Ti deposits associated with mafic intrusions, mineralizing activity during this period appears to have been meagre in Baltica. Such need not be true of Labrador, where there is sufficient contrast in structural setting of a wide range of younger anorogenic rocks to allow considerable promise for both Sn−Be−W−Pb−Zn granophile mineralization and Ti−V mafic-intrusion-related mineralization.

The final stage in the evolution of mid-Proterozoic Laurentia−Baltica was the 1.27 to 0.95 Ga Sveconorwegian−Grenvillian orogenic cycle, which embraced several separate tectonic events. Related mineral deposits include Cu−Mo−Au mineralization hosted by rift-related supracrustal rocks, Mo mineralization linked with syn- to late-tectonic granites, Au -Cu−(Pb−Zn−Ag) mineralization associated with late- to posttectonic veins, and Ti−Fe−Ni mineralization in anorthosite. Magmatic Ti−Fe−Ni segregation deposits in anorthosite have obvious analogues in eastern Laurentia (e.g., Lac Tio, Quebec), but the potential for Grenvillian analogues for the other types of mineralization remains poorly known. Much of the Cu−Mo−Au, Mo, and Au−Cu mineralization has been linked to late Sveconorwegian granitoid rocks. The existence of comparable granitic rocks has only been recognized in recent years in Labrador, and most are likely to occur in yet-to-be-mapped areas in southernmost Labrador. These granites offer a promising and completely untested target for mineralization, and, following the completion of mapping in the next few years, an up-to-date geological database will be available for focussed exploration.

INTRODUCTION

From 1500 onwards there has been systematic prospecting in Sweden; undertaken by the state, private individuals and companies. (Grip, 1978).

Relatively little mineral exploration has been carried out in Labrador ... and large tracts remain virtually unexplored. (Swinden *et al.*, 1991).

Laurentia and Baltica formed a single continental landmass during Proterozoic times, following the amalgamation of Archean continental nuclei between 1.90 and 1.80 Ga (cf. Gower *et al.*, 1990). This hypothesis is now well established and is used in this article as a basis for examining the Proterozoic metallogenic history of the Baltic Shield in an attempt to gain insights regarding how such knowledge could be applied to mineral exploration in Labrador. Conversely, it is also hoped that the Laurentian perspective presented here will be of use to future metallogenic studies in Baltica.

Why study the Baltic Shield at all? Surely, metallogenic comparisons between Labrador and other parts of Laurentia are more pertinent, especially as geological continuity can be demonstrated much more easily. Certainly, rock units do not stop at provincial borders (despite the way their distribution is commonly depicted on many geological maps), and it is obviously important to pay attention to ongoing research and exploration in immediately neighbouring regions. Nevertheless, there are several advantages to be gained by considering metallogenesis in the Baltic Shield that cannot be gained within Canada. Baltica has very long traditions of mining, mineral exploration and geological study. Mining in Baltica has a history extending back over 2,000 years, serious mineral exploration has been carried out for over 400 years, and systematic geological mapping has been in progress for 150 years. This has resulted in the accumulation of a very large metallogenic data base, unequalled in most of Laurentia.

The major theme that underlies this report is that, given the validity of tectonic correlations between Baltica and Labrador, then the huge metallogenic data base for Baltica can be used as a tool for the identification of analogous metallogenic environments in Labrador. The secondary theme is that, despite investigations over such a long period (or perhaps because of them?), new metallogenic environments are still being discovered in the Nordic countries. Apart from demonstrating that success does not come easily, it raises the question, 'what might a region such as Labrador, which is almost totally unexplored by comparison, have to offer?'.

A SUMMARY OF LAURENTIA–BALTICA CORRELATIONS

The Baltic Shield occupies about 1,000,000 km² in Sweden, Finland, Norway, the Baltic states and westernmost Russia (Figure 1). It can be broadly divided into three major regions, namely the Archean and associated provinces in the north, the Early Proterozoic Svecofennian orogen in the centre, and the Middle and Late Proterozoic Southwest Scandinavian Province in the southwest. Baltica also extends under Paleozoic platform rocks southeast of the Baltic Sea, and, in the west, forms the basement to the Paleozoic Caledonian orogen.

Although correlations between Laurentia and Baltica exist both north and south of the Archean cratonic nucleus of the North Atlantic–Karelia cratons, attention here is restricted to the regions south of the cratonic nuclei (Figure 1). The major correlations are as listed below. In subsequent sections, key metallogenic features are outlined below for each of the major tectonic groupings in Baltica and potential correlative environments in Laurentia are proposed.

(i) Pre-Svecofennian, Karelian continental margin prism rocks of the 2.10 to 1.94 Ga Kalevian Group are correlated with similar rocks at the northwest margin of the Makkovik–Ketilidian orogen of Laurentia.

(ii) The 1.91 to 1.82 Ga rocks of the Svecofennian orogen are correlated with rocks of similar age within the Makkovik–Ketilidian orogen.

(iii) The 1.81 to 1.77 Ga late- to post-Svecofennian units are correlated with late- to post-Makkovikian–Ketilidian rocks in southern Greenland and Labrador.

(iv) The pre-Gothian–Kongsbergian Stora Le-Marstrand Formation and correlative rocks (ca. 1.76 Ga) are equated with pre-Labradorian sedimentary rocks in the Grenville Province.

(v) The 1.71 to 1.50 Ga Gothian–Kongsbergian orogen is equated with the Labrador orogen that transects southern Labrador.

(vi) Various anorogenic AMCG (anorthosite–mangerite–charnockite–granite) suites having ages between 1.65 and 1.27 Ga in Baltica are compared with similar rocks emplaced within the same time interval in eastern Laurentia.

(vii) Pre-Sveconorwegian and Sveconorwegian rocks having ages between 1.27 and 0.95 Ga are equated with broadly coeval pre-Grenvillian and Grenvillian rocks in eastern Laurentia.

KALEVIAN–MAKKOVIKIAN MARGIN

GEOLOGICAL SETTING

The boundary between the Archean craton and the northern margin of the Svecofennian orogen cannot be drawn precisely, as the Archean rocks to the northeast were remobilized during Svecofennian orogenesis. The Archean margin can be identified, however, on the basis of Sm–Nd isotopic evidence and also by contrasting rock types present north and south of the Raahe–Ladoga zone, with which the isotopic boundary is approximately coincident (Figure 2). The Raahe–Ladoga zone, characterized by wrench faults and an associated negative gravity anomaly, has a movement history spanning 1.90 to 1.75 Ga (Park, 1991). It is, undoubtedly, in economic terms, the most important lineament in the Baltic Shield.

The region north of the Archean–Proterozoic crustal boundary is underlain by Lower Proterozoic supracrustal formations deposited on, and adjacent to, the Archean microcontinent (Karelian continent). Stratigraphic relationships between the various supracrustal suites are complex (Park, 1991), but a key event near the end of this period, from the perspective of this article, was the injection of northwest-trending mafic dykes associated with rifting between 2.2 and 2.0 Ga (Skiöld, 1986: Gaál and Gorbatschev, 1987). Following this event, a passive continental margin developed and a continental marginal prism (Kalevian Group; 2.1 to 1.94 Ga) was deposited. The Kalevian Group grades from proximal, shelf clastic sediments in the northeast to deep-water, distal turbiditic sediments associated with 1.96 Ga slices of ophiolite farther southwest (Gaál and Gorbatschev, 1987; Pharaoh and Brewer, 1990).

METALLOGENY

The most important metallogenic aspect of the Lower Proterozoic rocks immediately north of the Svecofennian orogen is rift-related Cu–Zn–Co–(Ni) mineralization hosted by Kalevian supracrustal rocks. The most famous example is the Outokumpu district, which includes the Keretti, Vuonos, Luikonlahti and Kylylahti deposits (these are not separately indicated on Figure 2). To date, 40 million tonnes of ore have been mined in the district, of which 28 million tonnes have come from the Keretti mine (Parkkinen, 1986). Several additional prospects are known in the Outokumpu district, and in the Kainuu schist belt to the northwest (e.g., Jormua). These are associated with a metal-rich black shale containing 0.14 percent Cu and 0.53 percent Zn (Loukola-Ruskeeniemi *et al.*, 1991).

The mineralization occurs as massive sulphide deposits in a rock association consisting of serpentinite, dolomite, calc-silicate rocks, quartzite, graphitic schist and mica schists. The mineralization is associated with black schists and cherts that were deposited as marine argillaceous sediments between 2.10 Ga and 1.96 Ga. The ore minerals are pyrrhotite, pyrite, chalcopyrite, sphalerite and pentlandite. The average grade of the Keretti deposit is 3.8 percent Cu, 1.0 percent Zn, 0.24 percent Co and 0.12 percent Ni. The ore and its carbon-bearing chemically precipitated host rocks are interpreted to have formed as a result of marine exhalative processes, probably in a rifted continental-margin basin environment (cf. Parkkinen, 1986; Kontinen, 1987; Pharoah and Brewer, 1990).

LAURENTIAN ANALOGUES (2.20 to 1.95 Ga)

The Laurentian analogues of the Kalevian Group are the Moran Lake and Lower Aillik groups in Labrador (Figure 3) and the Vallen and Sortis groups (Allaart, 1976) in southern Greenland. Although none of these rocks is yet precisely dated, it is likely that the rocks formed on the flank of a marginal basin during a ca. 2.20 to 2.00 Ga rifting event. Summaries of the Moran Lake and Lower Aillik groups are given by Wardle and Bailey (1981) and Ryan (1984), and aspects of the metallogeny of the Moran Lake Group have been addressed by Wilton *et al.* (1988) and North and Wilton (1988). The latter two publications identify two types of mineralization in the Moran Lake Group, namely epigenetic Pb–Zn–Cu occurrences at the basal unconformity with Archean rocks, and syngenetic massive Zn–Cu sulphide occurrences within shales of the Warren Creek Formation (cf. also North and Wilton, *in press*). The distribution of mineral occurrences in the Moran Lake Group in Figure 3 is based on Ryan (1984); although Cu mineralization seems to be most ubiquitous, Pb–Zn mineralization dominates at all the major showings.

The shale-hosted mineralization is clearly a close analogue of that found in the Kalevian Group, not only in terms of overall tectonic setting, but also in the nature of the host rocks and the type of mineralization. Some differences between the two areas are that the Outokumpu deposits occur in allochthonous thrust slices, have some associated Ni mineralization, and have been conceptually linked with ophiolites (Kontinen, 1987). Although a simple ophiolite interpretation is not without problems (Gaál and Gorbatschev, 1987), the overall differences suggest a somewhat more distal (from craton) environment than that of the Moran Lake Group. The Lower Aillik Group, farther east, may provide a better analogue, and is known to host sulphide mineralization in graphitic black shales within a dominantly mafic volcanic sequence (cf. Swinden *et al.*, 1991).

SVECOFENNIAN–MAKKOVIKIAN

'... it was not until the eighteenth century that exploration activity was reported in the area, now called the Skellefte district. However, it took another 200 years before prospecting was successful.' (Weihed *et al.*, *in press*).

GEOLOGICAL SETTING

The Svecofennian orogen is divided into three parts (Gaál and Gorbatschev, 1987). These are a northern magmatic arc (Skellefte district), a central intra-arc basin (Bothnian Basin) and a southern magmatic arc (Bergslagen district). Only the northern magmatic arc is deemed here to be of relevance to correlations with eastern Laurentia. The base-metal deposits associated with felsic volcanic rocks in the Bothnian Basin (Hallberg, 1989), and those related to supracrustal rocks in the famous Bergslagen mining district and southern Finland (Lundström and Papunen, 1986; Baker and Hellingwerf, 1988) in the southern Svecofennian will not be reviewed.

The magmatic arc south of the Archean–Proterozoic crustal boundary formed between 1.91 and 1.86 Ga. In the Skellefte district (Figure 4), it consists of a lower submarine,

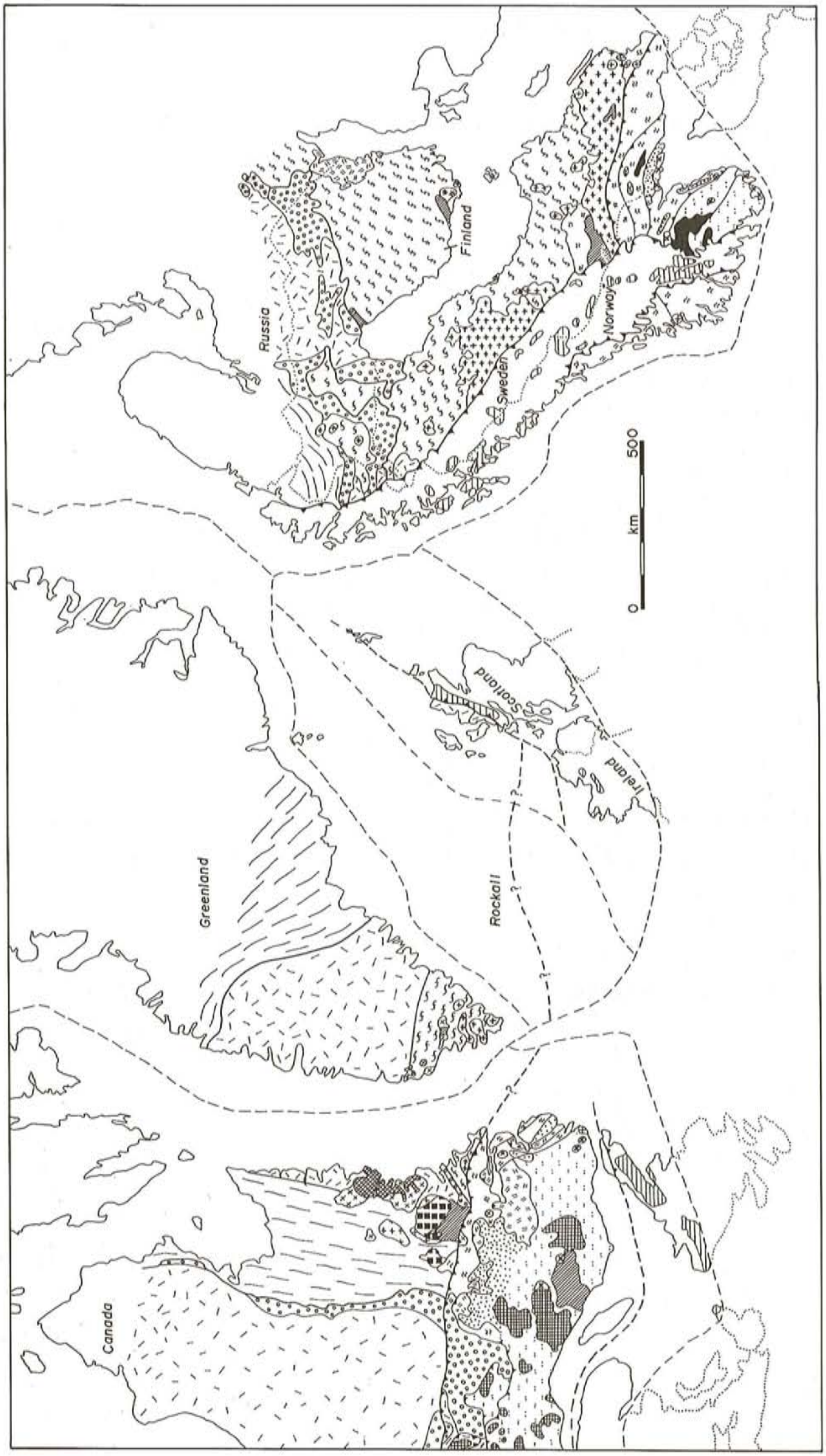

Figure 1. *Simplified geological map of Baltica and eastern Laurentia. Modified from Gower et al. (1990).*

Legend (for Figure 1)

Other Units

Mid-Proterozoic inliers in Caledonian–Appalachian orogen

Undivided Grenvillian–Sveconorwegian orogen

Magmatism and orogeny (1.09 to 0.90 Ga)

Granitic, syenitic and anorthositic intrusions (Grenvillian and late Sveconorwegian orogenies)

Extensional tectonism (1.20 to 1.09 Ga)

Anorthosite–mangerite–charnockite–granite (AMCG) suites

Mafic and mafic–felsic supracrustal sequences

Accretion and orogenesis (1.27 to 1.20 Ga)

Units formed during this period are not distinguished on map. They are within the Grenville–Sveconorwegian orogen

Crustal stability, phase II (1.43 to 1.27 Ga)

Rift-related sedimentation and bimodal volcanism

Granite–rhyolite suite / anorthositic–gabbroic intrusions

Crustal stability, phase I (1.51 to 1.43 Ga)

Granite plutons / anorthositic–gabbroic intrusions

Crustal stabilization (1.59 to 1.51 Ga)

Later rapakivi granite massifs (including Åland, Vehmaa and Laitila massifs)

Granitoid rocks (e.g., southwest Sweden)

Accretionary and non-accretionary events (1.71 to 1.59 Ga)

Anorthositic, rapakivi granite and gabbronorite massifs (including Wiborg and Mealy Mountains massifs)

Accretionary volcanic and plutonic rocks (Labradorian, Gothian–Kongsbergian orogenies)

Accretionary, post-orogenic/anorogenic and rifting environments (1.81 to 1.71 Ga)

Sedimentary sequences (continental margin / rift-related)

Late- and post-Svecofennian/Makkovikian/Ketilidian rocks

Magmatic arc accretion (1.90 to 1.81 Ga)

Early Proterozoic arcs south of Archean cratonic nuclei (Svecofennian, Makkovikian, Ketilidian)

Reworked Archean and Early Proterozoic crust north of, and between Archean cratonic nuclei

Pre- 1.90 Ga rocks

Continental margin supracrustal sequences

Archean cratonic nuclei

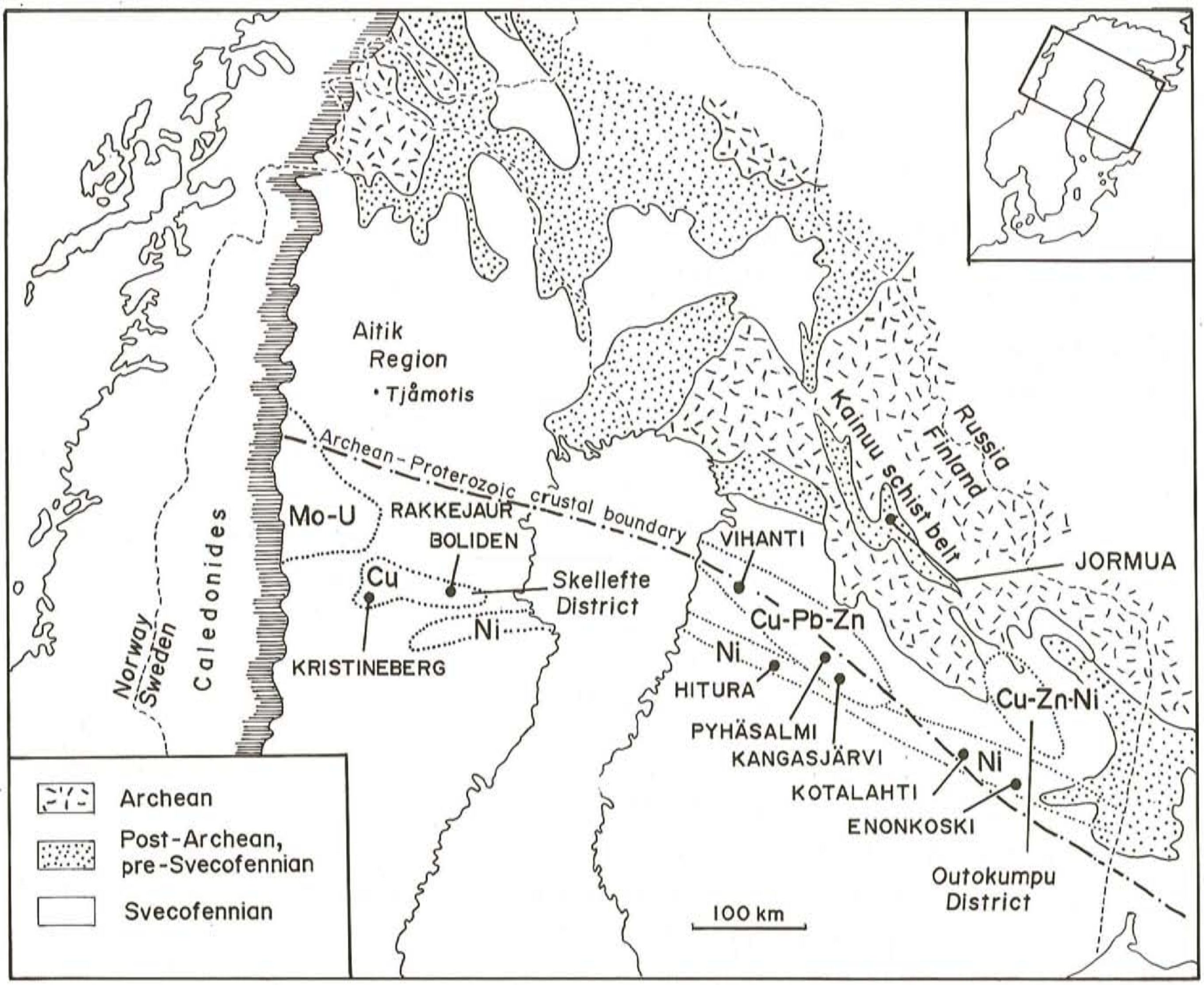

Figure 2. *An outline of the major metallogenic provinces associated with the cryptic margin of the Archean microcontinent and the Lower Proterozoic Svecofennian orogen. Based on maps by Adamek and Wilson (1979) and Gaál (1986).*

calc-alkaline volcanic sequence interbedded with carbonate rocks and epiclastic sediments (Skellefte Group), succeeded by a dominantly greywacke formation, which is comparable to the turbiditic sediments of the Bothnian Basin. These units are intruded by syn-kinematic granitoid rocks and both supracrustal and plutonic units are unconformably overlain by the dominantly fluvial Vargfors Group. Granitoid rock emplacement postdating the time of arc formation occurred at 1.84 Ga (e.g., Avaviken granite; Wilson *et al.*, 1985) and during late- to post-Sveconfennian events (discussed later). The volcanic rocks in the lower part of the Skellefte Group have island-arc affinities, whereas the upper part of the Skellefte Group has a bimodal rift-related character (Vivallo, 1987; Weihed *et al.*, *in press*). The volcanic arc is succeeded southward by turbiditic sediments of the Bothnian Basin, accompanied by subordinate 1.87 Ga (Welin, 1987) volcanic rocks. In the centre of the basin, the sediments achieve a thickness of 10,000 m (Lundqvist, 1987). Correlative island-arc volcanic rocks in Finland are reviewed by Gaál (1986).

It is generally accepted that the magmatic arc is the product of subduction-related processes, but the direction of the subducting slab remains in question (but is a crucial factor in discussing correlations with Laurentia). Majority interpretation has favoured northeastward subduction, but this view has been contested, one argument being that such a model would not provide any reason for closure of an oceanic environment between the arc and the proto-continent to which the arc was later accreted (Weihed *et al.*, *in press*). Southwestward subduction would allow the Ni-mineralized intrusions (see below) to be placed in a back-arc spreading context. Recent seismic results from the Bothnian sea have indicated a series of deep northeastward-dipping conductors that have been taken as indicating remnant oceanic crust and support for subduction having been northeastward (BABEL Working Group, 1990).

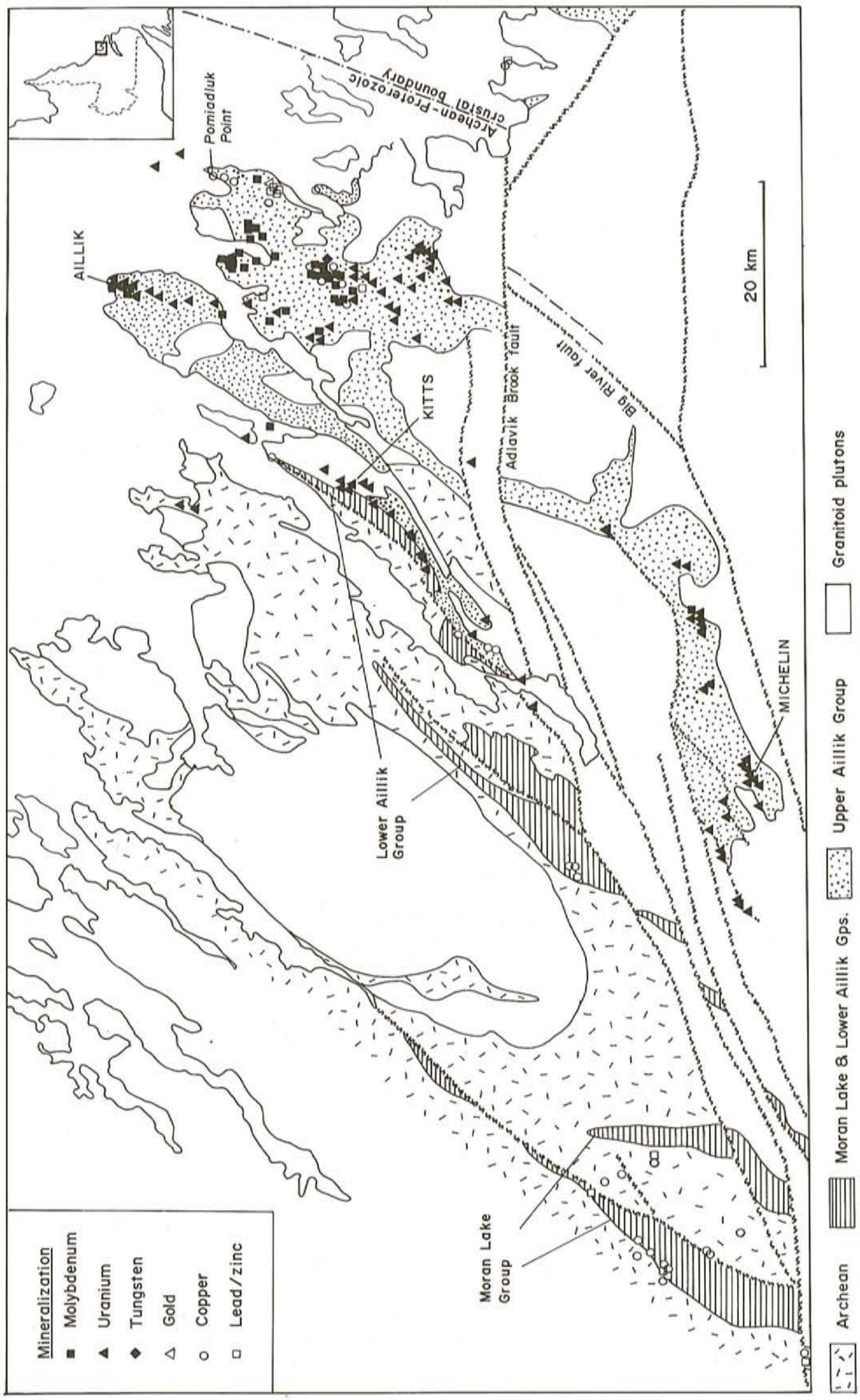

Figure 3. *Western and central parts of the Makkovik Province, Labrador. Simplified from Gower* et al. *(1982a) and Ryan (1984).*

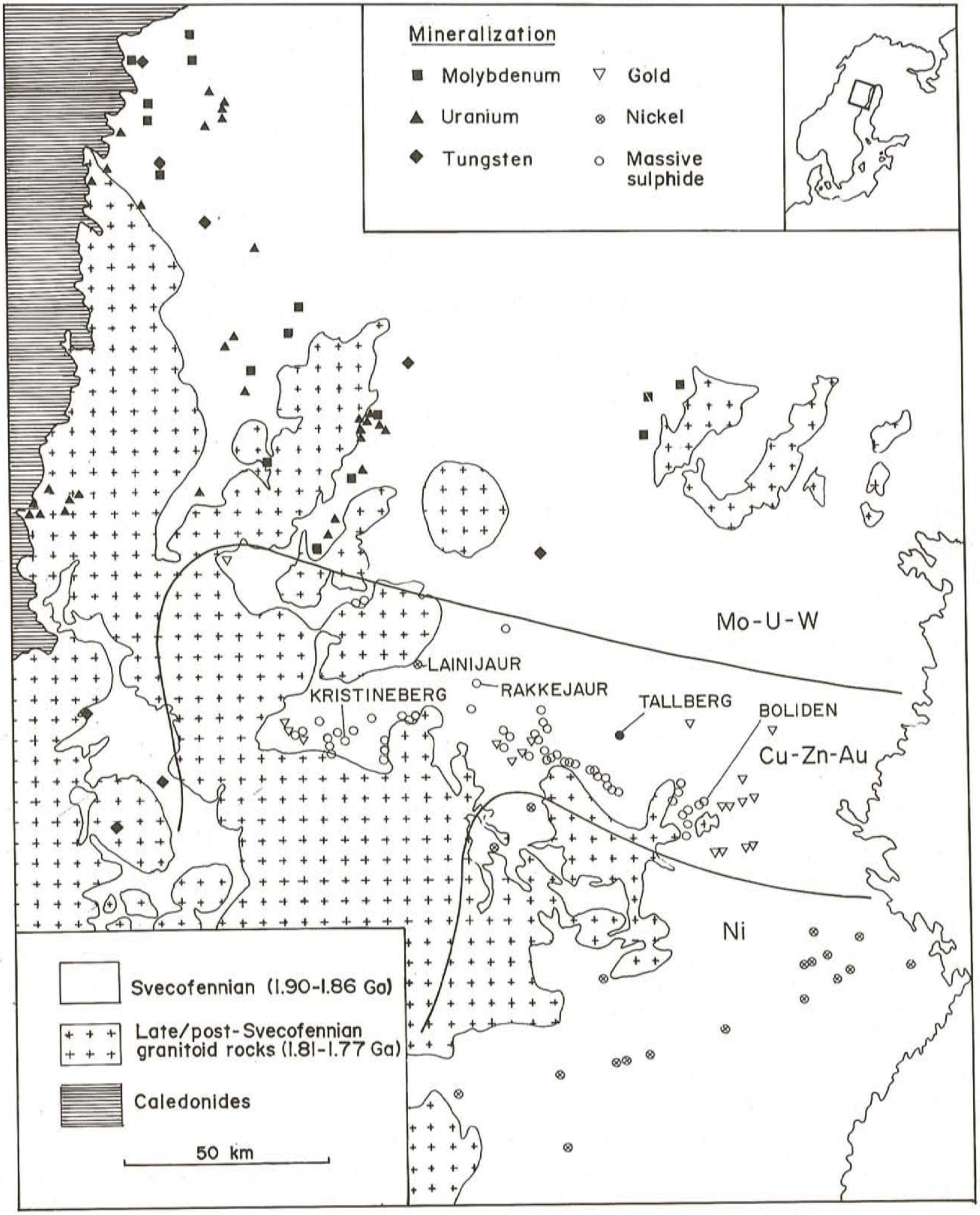

Figure 4. *Distribution of mineralization in the Skellefte district. Based on data from Adamek and Wilson (1979), Walser and Einarsson (1982), Öhlander (1986), Rickard (1986), and Weihed* et al. (in press). *The lines separating metallogenic provinces are for visual emphasis only.*

METALLOGENY

Mineralization in the northern Svecofennian arc can be subdivided into four groups, as follows:

(i) Cu–Zn–Au massive sulphide deposits associated with the northern Svecofennian magmatic arc,

(ii) Cu–Mo–(Au) porphyry-type mineralization in felsic intrusions, syn-kinematic with arc volcanism,

(iii) Mo–W mineralization temporally related to Svecofennian orogenesis, but spatially restricted to the Karelian hinterland, and

(iv) Ni mineralization south of the magmatic arc.

Cu–Zn–Au Volcanogenic Massive Sulphides

The Cu–Zn–Au deposits in the northern magmatic arc include those of the Skellefte district and in possibly tectonically correlative regions in Finland (Figure 2). The Skellefte district is currently the most important ore-producing region in Sweden, supporting 10 mines in volcanogenic massive sulphide deposits and two Au open-pit operations (Weihed *et al.*, *in press*). The major deposits in Finland are at Vihanti, Pyhäsalmi and Kangasjärvi (Gaál, 1986). The largest of these orebodies exceeds 20 million tonnes (Kristineberg and Rakkejaur (Skellefte district), and Pyhäsalmi), but most are less than 10 million tonnes, and several less than 1 million tonnes.

In the Skellefte district (Figure 4), the deposits are mostly concentrated at the top of the bimodal upper part of the Skellefte Group. They are associated with felsic pyroclastic rocks, quartz porphyries and minor mafic volcanic rocks in the footwall, and calcareous or graphitic reworked volcanoclastic rocks in the hanging wall. The deposits are typically stratabound and massive, but stringer and disseminated ores are also found. Chalcopyrite and sphalerite are the main ore minerals, and are associated with pyrite (the dominant sulphide), arsenopyrite, galena and pyrrhotite. Gold is an important component of the Skellefte ores and silver is a significant by-product from many deposits (Rickard, 1986; Weihed *et al.*, *in press*). The Skellefte ore bodies are widely interpreted to be volcanogenic massive sulphide deposits (Weihed *et al.*, *in press;* Rickard, 1986; Vivallo, 1987). Rickard (*op. cit.*) envisages a deep marine, hydrothermally dominated process with accumulation of the ore on the seafloor close to volcanic vents.

The deposits in Finland have some similar characteristics, including an association with bimodal volcanic rocks and a Au-rich signature (Gaál, 1986); however, there are differences. The Skellefte district is situated southwest of the cryptic Archean craton margin, whereas the Finnish deposits are situated at the Archean–Proterozoic crustal boundary. Also, the stratigraphic sequence of the Skellefte district is not easily compared with that of the Vihanti-Pyhäsalmi deposits. The latter are better correlated with the Tjåmotis area (Figure 2), 180 km north of the Skellefte district (K. Sundblad, personal communication, 1992). Finally, the Pb isotopic signatures of the Skellefte and Vihanti–Pyhäsalmi districts differ (Sundblad, 1991a).

Cu–Mo–(Au) Mineralization

The Cu–Mo–(Au) mineralization, interpreted to be of porphyry type, is best documented from the Tallberg area (Figure 4) in the 1.89 Ga Jörn batholith (Wilson *et al.*, 1987) in the Skellefte district (Weihed *et al.*, 1987). Other, similar occurrences in the Skellefte district have been interpreted to be porphyry type (Walser and Einarsson, 1982), and comparable mineralization has been reported in Finland (Nurmi and Haapala, 1986). The Tallberg mineralization, first discovered in 1979, has not been exploited, although a large tonnage (45 million tonnes; Weihed *et al.*, *in press*) has been outlined.

The mineralization is hosted by subvolcanic quartz-feldspar stocks (dated at 1886^{+15}_{-9} Ma; Weihed and Schöberg, 1991) belonging to the oldest phase of the intrusion, and is accompanied by strong propylitic and phyllic alteration. The minerals present include chalcopyrite, pyrite, molybdenite, sphalerite and magnetite concentrated in veins, with or without quartz, calcite and chlorite. The mineralization is low grade (0.27 percent Cu) and of disseminated stockwork type (Claesson and Weihed, 1986; Weihed *et al.*, *in press*). Auriferous quartz ± tourmaline veins are closely associated with the base-metal mineralization. Similar veins are also known in other 1.89 Ga granitoid intrusions (Gaál and Sundblad, 1990). The relatively high Au and low Mo, together with the primitive I-type compositional characteristics of the host rocks, are indicative of an island-arc setting for the Skellefte porphyry mineralization (Weihed *et al.*, *in press*).

Possibly broadly correlative to the porphyry occurrences, are Cu–Au deposits in the Aitik region (Figure 2), hosted by 1.91 Ga sedimentary and felsic volcanic rocks. The deposits are large and low grade, containing disseminated chalcopyrite, gold, bornite, chalcocite, sphalerite, and bismuth- and silver-tellurides (Gaál and Sundblad, 1990).

Mo–(W) Mineralization

Mo–(W) mineralization is widely scattered throughout the Karelian continental domain north of the Skellefte district. Most occurrences are minor and there is no current production of Mo, although some attempts have been made to mine it in the past. The main host rocks are aplite and pegmatite, but mineralization also occurs as impregnations and veins within granite, or in faults transecting altered and metamorphosed volcanic rocks. In addition to molybdenite, some occurrences also have associated chalcopyrite, pyrite, scheelite and fluorite (Öhlander, 1985, 1986). The host granitoid intrusions display within-plate geochemical characteristics, but this does not mean that they are tectonically divorced from the magmatic arc. As Weihed *et al. (in press)* point out, it is common to find such granites on the continental side of arc systems.

Ni Mineralization

Ni mineralization is mostly situated south of the Skellefte district, although a few occurrences are located within it. Many of the occurrences have been known for several decades, but only a few, including the Lainijaur deposit in Sweden (Figure 4) and the Hitura, Kotalahti and Enonkoski deposits in Finland (Figure 2), have progressed to the production stage. The mineralization is associated with ultramafic and mafic rocks intruded into migmatized greywackes and pelites of turbidite affinity. The ultramafic rocks include peridotite, pyroxenite and picrite and the mafic rocks comprise gabbro and norite. Compositionally these rocks range from komatiitic to tholeiitic, and have MORB to island-arc petrotectonic affinity. Massive, vein, breccia and disseminated mineralization is found, containing pentlandite, pyrrhotite and chalcopyrite. The deposits are the product of fractionation of synorogenic tholeiitic intrusions. Gaál (1986) has noted a spatial linkage between the Finnish deposits and dextral transcurrent faults at the edge of the Karelian continent.

LAURENTIAN ANALOGUES (1.91 to 1.84 Ga)

The central part of the Makkovik Province (Figure 3) appears to the closest Laurentian analogue of the Svecofennian northern magmatic arc. Large areas of this region are underlain by the Upper Aillik Group, which consists of felsic volcanic and volcanoclastic rocks associated with cogenetic high-level intrusions and minor mafic volcanic rocks. The contact between the Lower and Upper Aillik groups is highly tectonized, obscuring original (unconformable?) relationships. Dating of the Upper Aillik Group has demonstrated that there were at least two pulses of volcanism, at 1.86 and 1.81 Ga (Schärer *et al.*, 1988). The 1.81 Ga felsic volcanic rocks are the extrusive equivalents of 1.81 to 1.80 Ga granitoid rocks, which are discussed in the next section. Similar dates from granites have been reported from Greenland by van Breemen *et al.* (1974), who obtained ages of 1,845 ± 15 Ma and 1,805 ± 25 Ma.

Granitoid plutonic rocks of several ages are spatially associated with the supracrustal sequences. Two pre-1.80-Ga groups of granitoid rock have been identified in the Makkovik Province and have ages of ca. 1.90 and 1.84 Ga (Kerr *et al.*, *in press*). The latter age group is defined by one date from an intrusion in the eastern part of the Makkovik Province. In terms of correlations between the Makkovik Province and the Svecofennian orogen, the 1.86 Ga age from felsic volcanic rocks of the Upper Aillik Group and the 1.90 and 1.84 Ga ages from granitoid rocks indicate that comparable activity was taking place in both regions simultaneously.

The metallogenic picture for the Upper Aillik Group and associated granitoid rocks is not yet clear. In terms of searching for analogues of the metallogenic styles described above, however, it would seem that the Upper Aillik Group provides a possible analogue for the Skellefte Group, and should be prospected for comparable Cu–Zn–(Au) massive sulphide mineralization. It should be emphasized that, in drawing analogues with the Skellefte Group, only rocks having 1.86 Ga ages should be considered. In the Makkovik Province, these rocks have been only partially distinguished from those having 1.81 Ga ages. Another point is that the Upper Aillik Group appears to be situated above Archean crust, whereas the Skellefte magmatic arc is situated southwest of Archean crust. Given that the Finnish deposits are situated at the Archean–Proterozoic crustal boundary, however, they provide an alternative analogue.

The Cu–Pb–(Au) occurrences that are spatially associated with the Upper Aillik Group, and which might be comparable to either the Skellefte or Vihanti–Pyhäsalmi districts, are situated in easterly areas of the Makkovik district (i.e., south of Pomiadluk Point, Figure 3). Although some of these occurrences are demonstrably post-Makkovikian, their distribution could still be influenced by a Makkovikian or older basement control. It may be significant that they are close to the concealed margin of Archean crust as defined from Nd–Sm and Pb–Pb isotopic evidence (Kerr and Fryer, 1990; Wilton, 1991). Does this mean that Skellefte-type massive sulphides should be sought farther east in the Makkovik Province? If it does, then this is indeed unfortunate because most of the eastern Makkovik Province is underlain by younger granitoid rocks.

On the other hand, a hypothetical location for such a belt allows positioning of other northern Svecofennian metallogenic elements in a Makkovikian context. The Mo–W occurrences that are situated in the Karelian continental domain would equate with Mo occurrences that are mostly present west of a north–south line through Pomiadluk Point, and any search for mafic/ultramafic-hosted Ni deposits would have to focus on the Archean–Proterozoic cryptic crustal boundary. Note that this boundary is displaced dextrally by the Adlavik Brook fault and the location of the Big River fault may be controlled by the margin of the Archean craton. Scope for 1.89 Ga Cu–Mo–(Au) porphyry-type mineralization would seem to be restricted to granitoid rocks in the southwest and western parts of the Makkovik Province on the basis of present geochronological data.

LATE/POST- SVECOFENNIAN–LATE/POST- MAKKOVIKIAN

Until recently, very few occurrence of Li and Sn mineralizations were known in Sweden... (Lundqvist *et al.*, 1986).

GEOLOGICAL SETTING

As used in this report, late- and post-Svecofennian rocks refer to those emplaced between 1.81 and 1.77 Ga. Included, therefore, are the granites within and north of the Skellefte district, the 'Revsund-type' granitoid rocks in the central Svecofennian orogen south of the Skellefte district (Lundqvist, 1990), much of the Transscandinavian Igneous Belt, and scattered intrusions in eastern Baltica. The term 'Transscandinavian Igneous Belt' is used in this report for 1.81 to 1.77 Ga granitoid rocks distributed along the western flank of the Svecofennian orogen, extending from southeastern Sweden, northward under the Caledonides, to the Lofoten Islands in Norway (Gorbatschev, 1985; Gaál and Gorbatschev, 1987). As defined in Scandinavia, the Transscandinavian Igneous Belt includes the 1.71 to 1.65 Ga Dala volcanic rocks and associated granitoid intrusions. The present author, however, has chosen to exclude the Dala region from the Transscandinavian Igneous belt (see page 345).

The Revsund intrusions consist mostly of massive granite, but minor granodioritic to quartz-monzonitic rock types are also present (Lundqvist, 1990). The intrusions within and north of the Skellefte district have bulk compositions similar to the 'Revsund-type' granites and have been compared closely with them. The granitoid rocks emplaced through pre-Svecofennian crust north of the Skellefte district commonly have late-stage minor intrusions and mineralization (see below), and are interpreted to have been derived from an underlying Archean crustal source (Öhlander, 1986). Similarly, the 'Revsund-type' granites in the Proterozoic Bothnian Basin are considered to have been derived largely from sedimentary rocks.

The 1.81 to 1.77 Ga granitoid rocks of the Transscandinavian Igneous Belt have, predominantly, granite to quartz-monzonite compositions, but monzodioritic and dioritic phases are present in places (Gaál and Gorbatschev, 1987). Traditionally, the rocks have been divided into textural types—the K-feldspar megacrystic 'Filipstad' type, and the coarse-grained, even-grained 'Växjö' type. The Växjö type is generally closer to granite *sensu stricto,* and is commonly the younger type. The Transscandinavian Igneous Belt granitoid rocks lack pegmatite or other minor intrusions. Volatile deficiency, coupled with compositional characteristics, is interpreted to indicate derivation from deep crustal sources (Lindh and Persson, 1990). A deep crustal source interpretation is consistent with other features, such as having structures conformable with their host rocks and showing common evidence of mafic-felsic magma interaction (cf. Andersson, 1991).

METALLOGENY

It should be stressed at the outset that the late- and post-Svecofennian granites in the north are of most interest in a metallogenic context. In contrast, the Transscandinavian Igneous Belt is generally barren. Mineralization in the northern late- and post-Svecofennian 1.81 to 1.77 Ga granitoid rocks is typically granophile. All of the occurrences are fairly small, but some are potentially large enough to be economically viable. The types of mineralization reflect the variation in the source rocks from which the host granites were derived. The following metallogenic groupings can be recognized:

(i) Mo–U–(W)–(Sn) mineralization associated with granitoid rocks emplaced into Karelian crust, and

(ii) W–Sn and Sn–Li mineralization in granitoid rocks in the Bothnian Basin and farther south.

Although the focus here is on granitoid rocks emplaced between 1.81 and 1.77 Ga, it should be noted that not all the mineralization is confined to granites of this age. Öhlander and Billström (1989) have investigated two granites, both of which host Mo-mineralized aplites, and found them to have ages of 1.89 and 1.77 Ga, respectively. The Mo-mineralized aplite in the 1.89 Ga granite grades into its host, and hence cannot be a later dyke. Despite this example, Öhlander and Billström (1989) concluded that most of the Mo- and W-occurrences are associated with the younger 1.81 to 1.77 Ga granites. This judgement is supported by Wilson and Åkerblom (1982), who summarized data demonstrating that the age of associated U mineralization was ca. 1.75 Ga.

Mo–U–(W)–(Sn) Mineralization

Difficulties in discriminating between the 1.89 and 1.86 Ga and 1.81 to 1.77 Ga Mo–W occurrences are a consequence of the morphological similarities between the two age groups, hence the reader is referred back to the previous section for descriptive details. Information regarding the U mineralization is given here, however – heeding the geochronological data for its younger age.

The major Mo deposits (Figure 5) include Björntjärn (1 million tonnes at ca. 0.15 to 20 percent Mo) and Munka (1.5 million tonnes at 0.10 to 0.15 percent Mo), both of which have been genetically related to the younger granites (Walser and Einarsson, 1982).

The most important U mineralization (Figure 5) includes the Pleutajokk deposit (6,000 tonnes U) and the Björklund and Rävaberget occurrences (Öhlander, 1986). The mineralization occurs as epigenetic fracture fillings and in disseminated form within Na-metasomatized rhyolitic volcanic rocks or granites. The generally thin veins occur singly and in stockworks. Uraninite, the ore mineral, is associated with calcite, fluorite, hematite and uranotitanite. The W occurrences are spatially related to the U and Mo mineralization.

Although geochronological linkage to the younger granites is recognized, most workers consider that the mineralization is the result of a multi-stage process. This process involved scavenging of granophile elements from pre-Svecofennian sialic crust into the 1.89 to 1.86 Ga granitoid rocks and then mobilization of the same elements during later 1.81 to 1.77 Ga granitoid activity (Öhlander, 1986). Thus, from the prospecting point of view, although the earlier stage of scavenging could lead directly to concentrations of economic interest, the younger intrusions are the better targets.

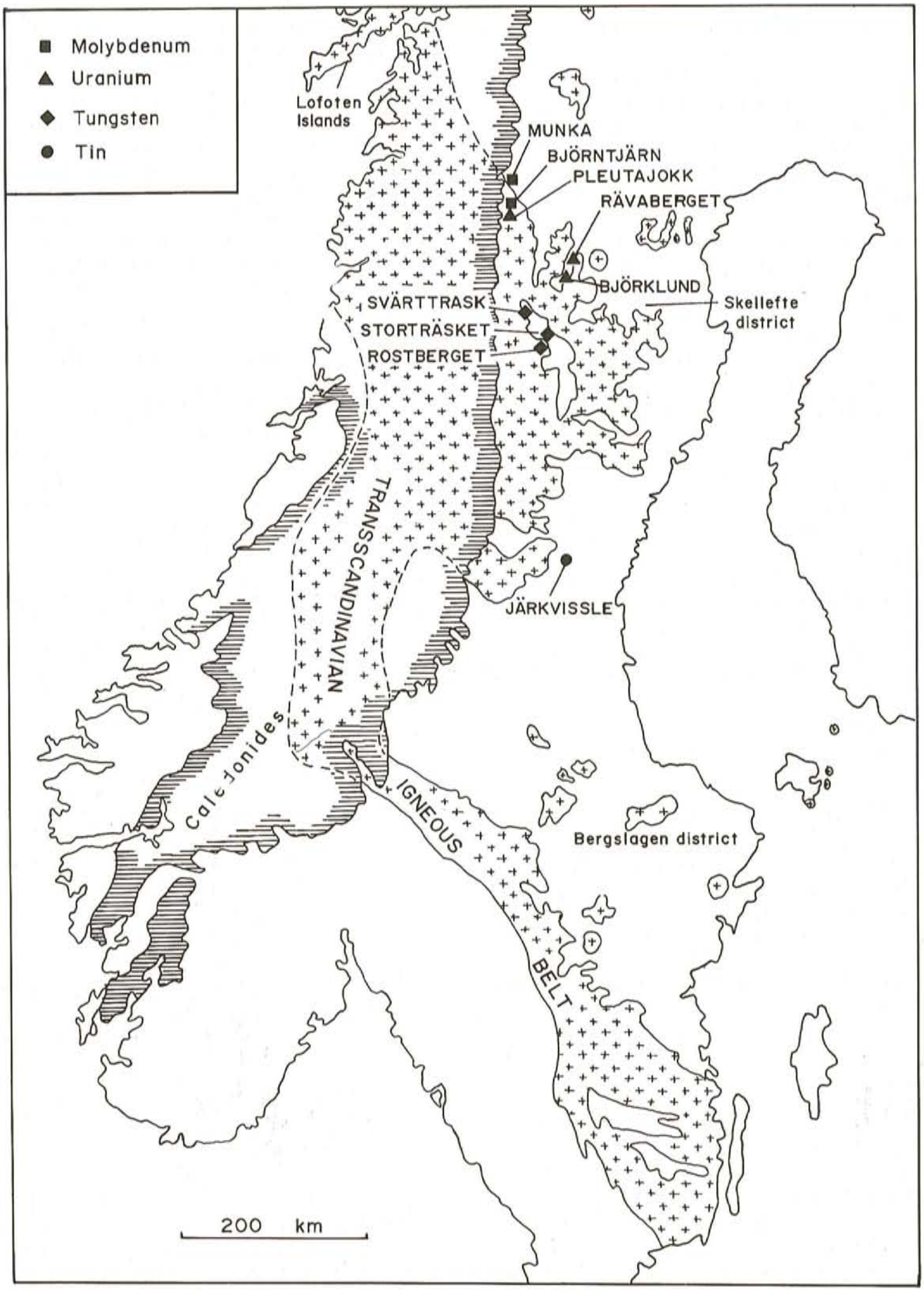

Figure 5. *Distribution of late- and post-Svecofennian rocks in the Baltic Shield and associated major mineral deposits.*

W–(Sn) and Sn–Li Mineralization

The association of W–(Sn) mineralization with 1.81 to 1.77 Ga granitoid rocks is well established. Outside the Bergslagen district, the best described areas of mineralization are south of the Skellefte district (Öhlander, 1986). Some of the deposits have been explored in detail, including extensive diamond drilling, but none have been developed.

The typical mode of occurrence is greisen and quartz veins in granite (Rostberget, Storträsket; Figure 5) and in country rocks close to granite. Wolframite is typically the most important W ore mineral, but scheelite dominates at Svärtträsk. Associated minerals in some occurrences include arsenopyrite, molybdenite, pyrite, pyrrhotite, chalcopyrite and galena. Fluorite, allanite, epidote, apatite and ilmenite are common accessory minerals and tourmaline, xenotime and topaz have also been reported.

Another closely allied metallogenic association is Sn–Li mineralization, which has been recently discovered in 1.82 Ga (late-Svecofennian) granitoid rocks in central Sweden (Lundqvist *et al.*, 1986). Some of the mineralization is potentially of economic interest (e.g., Järkvissle; Figure 5), although no development work has been carried out. The mineralization occurs in muscovite pegmatites intruded into metagreywacke in the Bothnian Basin. The economically interesting minerals include spodumene, petalite, cassiterite and columbite–tantalite.

LAURENTIAN ANALOGUES (1.81 to 1.77 Ga)

The Makkovik Province (Figure 3) offers the closest tectonic analogue for the late-Svecofennian and Transscandinavian 1.81 to 1.77 Ga rocks. Granitoid rocks having ages of 1.80 Ga are now known to be widespread in the central Makkovik Province (Kerr and Krogh, 1990; Kerr *et al.*, *in press*), and a sub-volcanic quartz–feldspar porphyry of the Upper Aillik Group has yielded a similar age (1.81 Ga) (Schärer *et al.*, 1988). Like their late-Svecofennian counterparts, these granitoid rocks are generally undeformed and have dominantly granite compositions, associated with lesser syenite, monzonite, quartz monzonite and monzogranite. The rocks have transitional calc-alkaline to alkaline character.

The Makkovik area is well known for its Mo–U mineralization, with which less well-known W–Cu–Zn–Pb mineralization is also associated (Gower *et al.*, 1982a; MacDougall and Wilton, 1987, 1988; Wilton and Wardle, 1987). The mineralization is hosted by metasedimentary rocks in the Lower Aillik Group (U + pyrite) and by felsic volcanic or volcanoclastic rocks in the Upper Aillik Group. Locally, some occurrences are hosted by pegmatite, granite and amphibolite. The most important deposits are Kitts (207 000 tonnes at 0.73 percent U_2O_8), Michelin (7 million tonnes at 0.13 percent U_2O_8), and Aillik (2 million tonnes at 0.25 percent Mo) (Gower *et al.*, 1982a). The locations of these deposits are shown in Figure 3 and details of other deposits in the region are given by Gower *et al.* (1982a).

Earlier interpretations that envisaged syngenetic mineralization by hydrothermal leaching of volcanic glasses have lost support in favour of models emphasizing the role of fluids associated with later granitoid rocks. The along-strike continuity within a particular supracrustal unit for several of the deposits remains an argument in favour of the syngenetic model, but metallogenic zonation around a high-level granite (MacDougall and Wilton, 1987) demonstrates a linkage with (post-1.80 Ga) plutonism (MacKenzie and Wilton, 1987; Wilton and Wardle, 1987). The role of granitoid rocks received little attention during earlier exploration and, as a result, many targets may have been underrated, or overlooked entirely.

There may be elements of validity to both the syngenetic and epigenetic models. Scavenging of granophile elements from the Archean basement could have led to Mo–U-enriched 1.91 to 1.86 Ga felsic volcanic and granitic rocks, with further mobilization and redistribution during later magmatic events. The key factor is a multistage process. In this regard, the Makkovik area must be regarded very favourably, as there were periods of magmatism at 1.91 to 1.89 Ga, 1.86 Ga, 1.84 Ga, 1.80 Ga, 1.72 Ga and 1.65 Ga (Kerr *et al.*, *in press;* Schärer *et al.*, 1988). Although granitoid magmatism having ages of 1.72 Ga and 1.65 Ga goes beyond the temporal realm discussed here, it is mentioned because it provided concentration opportunities for metal concentration that were not available in areas of Baltica having Archean crust as its foundation. The Makkovik Province, therefore, may well have greater potential than Baltica for this type of deposit.

STORA LE-MARSTRAND FORMATION– PRE-LABRADORIAN SEDIMENTS

The Modum cobalt deposits were discovered in 1772 and mined until 1898... (Bugge, 1978).

GEOLOGICAL SETTING

Supracrustal rocks of the Stora Le-Marstrand Formation and approximately temporally correlative rocks in the Bamble–Kongsberg sectors (Figure 6) were deposited either coeval with, or shortly after, the formation of the Transscandinavian Igneous Belt and related rocks, but prior to the onset of the Gothian–Kongsbergian orogeny (Åhäll *et al.*, 1990).

The Stora Le-Marstrand Formation consists of migmatized greywacke-dominated sedimentary rocks, associated with banded amphibolites derived from pillowed mafic lavas and volcanoclastic rocks. These rocks are intruded by mafic sills, dykes and small ultramafic to gabbroic bodies. The supracrustal rocks in the Bamble–Kongsberg sectors consist of a lower sequence of quartzite and sillimanite-bearing rocks and an upper division of variable gneisses made up of biotite-, graphite- and sulphide-bearing schist, quartzite and quartz-rich gneiss, with calc-silicate and marble layers (Starmer, 1990, 1991). The age of the Stora Le-Marstrand Formation is poorly constrained by a 1758 ± 58 Ma Sm–Nd

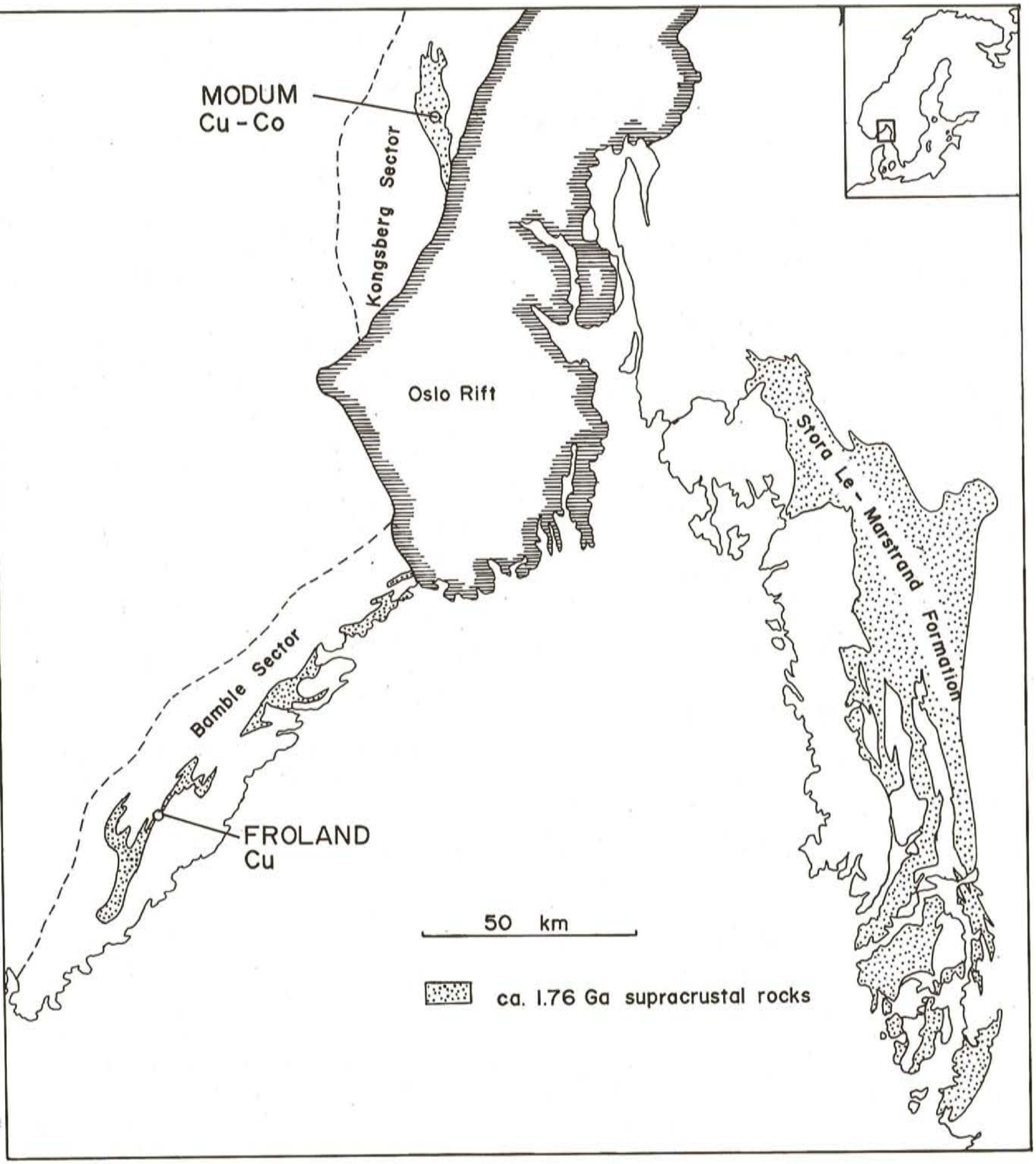

Figure 6. *Distribution of the Stora Le-Marstrand Formation and approximately coeval supracrustal rocks in the Bamble–Kongsberg Sector, and the location of the past-producing Modum and Froland Cu–(Co) deposits.*

errorchron for interstratified mafic volcanic rocks (Åhäll and Daly, 1989). The possibly younger supracrustal rocks in the Bamble–Kongsberg sectors are considered to have been deposited prior to 1680 Ma (Starmer, 1990).

Åhäll and Daly (1989) suggest that the Stora Le-Marstrand Formation had an oceanic-arc or back-arc tectonic setting, but in close proximity to proto-Baltica. The higher proportion of more mature quartz-rich sediments and a dearth of mafic volcanic units in the supracrustal rocks of the Bamble–Kongsberg sectors indicate a somewhat different depositional setting, but one that also involved derivation of material from a nearby sialic source, which is considered by Starmer (1990) to be proto-Baltica.

METALLOGENY

Mineralization linked to the ca. 1760 to 1700 Ma clastic supracrustal rocks in southwest Scandinavia is of one type only, namely stratabound Cu–Co deposits. Deposits located at Modum in the Kongsberg Sector and at Froland in the Bamble Sector were mined in the past. The deposits occur in fahlbands, which are schistose, sulphide-impregnated zones that may extend for several kilometres along strike and be several hundreds of metres thick. The host rocks are sillimanite–cordierite-bearing mica schist, quartzite and amphibolite. The dominant sulphides are pyrite and pyrrhotite, but chalcopyrite, sphalerite, galena, cobaltite, skutterudite, and native bismuth, copper and molybdenite have also been found. The deposits are low grade; the ore at Modum averaged 0.15 percent Cu and 0.1 percent Co. The deposits are believed to have formed from volcanic exhalative or biogenic processes (Bugge, 1978). In current nomenclature, the mineralization could be interpreted as Besshi-type or sedimentary exhalative, depending on the metal associations and extent of volcanic activity.

LAURENTIAN ANALOGUES (1.76 to 1.70 Ga)

The pre- or syn-Labradorian metasedimentary gneisses within the eastern Grenville Province are remarkably similar to their pre-Gothian–Kongsbergian temporal equivalents in Baltica. The Laurentian analogues underlie large tracts of southern Labrador and comprise mainly pelitic to semipelitic gneiss, with minor associated calc-silicate rocks, amphibolite and quartzite. The amphibolite is derived, in part, from mafic volcanic rocks and at least some of the quartzite probably originated as chert (Gower *et al.*, 1987).

In terms of known occurrences of sulphides, the Paradise metasedimentary gneiss belt in southeast Labrador (Figure 7) seems to be one of the best candidates for economic mineralization of the type described above. Spectacular, ochreous-weathering, sulphide-rich (mainly pyrite) zones extending up to 3 km in length are abundant in the Dead Islands and Occasional Harbour areas, and similar occurrences are also known in the vicinity of southern Sandwich Bay. It is worth emphasizing that the number of occurrences correlates directly with the quality of exposure, which deteriorates rapidly away from the coast. The regional continuity of rock types provides a good reason to believe that sulphide-rich zones are present throughout the entire belt (Gower and Swinden, 1991). Although Fe-sulphides are most abundant, traces of Cu are known locally (Gower *et al.*, 1982b, 1987), and Co anomalies are seen in lake-sediment geochemical data. Shallow drilling was carried out at Eagle River (Bradley, 1966), where a surface sample averaged 2.8 percent Cu (Douglas, 1953).

Thought should be given to the possibility that two separate sedimentary environments, possibly having different ages, are present in both the Gothian–Kongsbergian and Labrador orogens. Perhaps the supracrustal rocks in both the Bamble and Kongsberg sectors and the Paradise River metasedimentary gneiss were deposited in rift-related settings (the zones of crustal weakness so formed being subsequently utilized and disguised by later tectonism), whereas the Stora Le-Marstrand Formation and areas outside the Paradise metasedimentary gneiss belt may have had an intra-arc or continental margin setting. Such a distinction could offer an explanation for the presence of sulphide-rich sediments in the Paradise metasedimentary gneiss belt and the Bamble and Kongsberg sectors, but their apparent dearth elsewhere. If there is any validity to this suggestion, it should also be kept in mind that the Paradise metasedimentary gneiss belt is geologically simpler and has a much larger prospective area than the Bamble–Kongsberg sectors.

GOTHIAN–KONGSBERGIAN–LABRADORIAN

GEOLOGICAL SETTING

The Gothian–Kongsbergian orogeny extended from 1.71 to 1.57 Ga and resulted in the accretion of a large area of juvenile crust to the western margin of proto-Baltica (Figure 8). The main area is in southwest Sweden and southeast Norway, but this area probably links up, under the Caledonides, with coeval rocks of the Western Gneiss Region in western Norway. The accreted crust consists dominantly of calc-alkaline plutonic rocks, that, typically, are now orthogneisses. These range from tonalite to granite and include minor anorthositic to gabbroic intrusions. Felsic volcanic rocks and associated sediments are also present (Gaál and Gorbatschev, 1987). Several cycles of plutonism occurred, perhaps at ca. 1.71, 1.66 and 1.60 Ga, but the duration and areal extent of these remains uncertain (cf. Åhäll *et al.*, 1990: Åhäll and Persson, *in press;* Larson *et al.*, 1990, Tucker *et al.*, 1990).

Inboard of the main calc-alkaline belt, partially within the older Svecofennian orogen, is a separate assemblage of felsic volcanic rocks and coeval granitoid intrusions (Figure 8). The felsic extrusive rocks include the Dala porphyries, deposited unconformably on rocks of the Svecofennian orogen (Lundqvist, 1968), and the associated granite intrusions include the Siljan and Garberg plutons. Some of the granites have rapakivi textures (Sundblad, 1991b). The rocks are usually grouped with the Transscandinavian Igneous Belt and, although many Scandinavian workers will accept that they are distinct from the 1.81 to 1.77 Ga parts of the Transscandinavian Igneous Belt (cf. Sundblad, 1991b), not all would agree with grouping them, as has been done here, with rocks of contrasting character west of the Protogine zone.

METALLOGENY

The principal metallogenic feature of the 1.71 to 1.57 Ga Gothian–Kongsbergian orogenic period is an almost complete

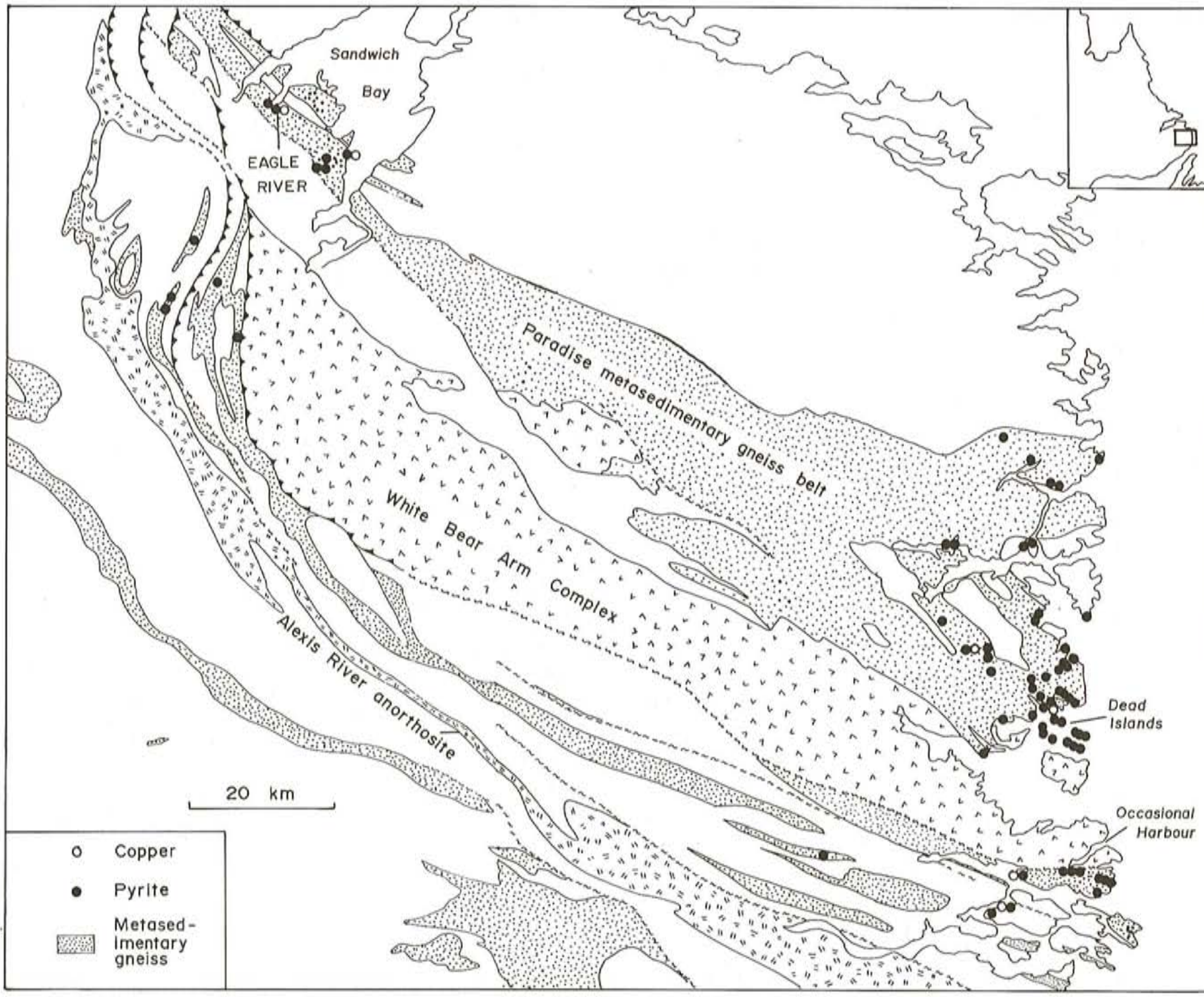

Figure 7. *Paradise metasedimentary gneiss belt and other nearby major units, including the distribution of pyritic gossans.*

lack of contemporaneous mineralization. There are two noteworthy exceptions, both east of the Protogine zone:

(i) Sn-, Pb-, Zn- and Be-bearing greisen veins in Siljan granite (Figure 8), and

(ii) minor Cu–Zn–Pb deposits hosted by the Dala volcanic rocks.

Sn–Pb–Zn–Be Mineralization

Sn–Pb–Zn–Be mineralization in greisen veins has received only brief mention in the Scandinavian literature (Sundblad, 1991b; Ahl, 1991). The occurrences are found in the Siljan granite, which has an age of ca. 1.70 Ga. Sundblad (1991b) has suggested a linkage with similar mineralization found in younger (less than 1.65 Ga) rapakivi granitoid intrusions in Finland.

Cu–Zn–Pb Mineralization

The Cu–Zn–Pb occurrences include Börningsberget, Rotendal and Storharn in the Dala volcanic rocks and Van and Öradtjärn in the closely related Siljan granite (Johansson and Rickard, 1985). The deposits in the Dala volcanic rocks have been locally exploited for their Cu content (Lundqvist, 1968). Most of the mineralization occurs in the matrix of volcanic breccias and in irregular veins, the latter typically quartz-filled and locally brecciated. It consists of chalcopyrite, chalcocite, sphalerite, galena and pyrite, with associated fluorite, carbonate, epidote, feldspar and quartz. The mineralization and accompanying wall-rock alteration, are interpreted as products of hydrothermal activity. The Pb isotopic studies indicate that the metals were derived from both Svecofennian crustal rocks and post-Svecofennian mantle sources (Johansson and Rickard, 1985).

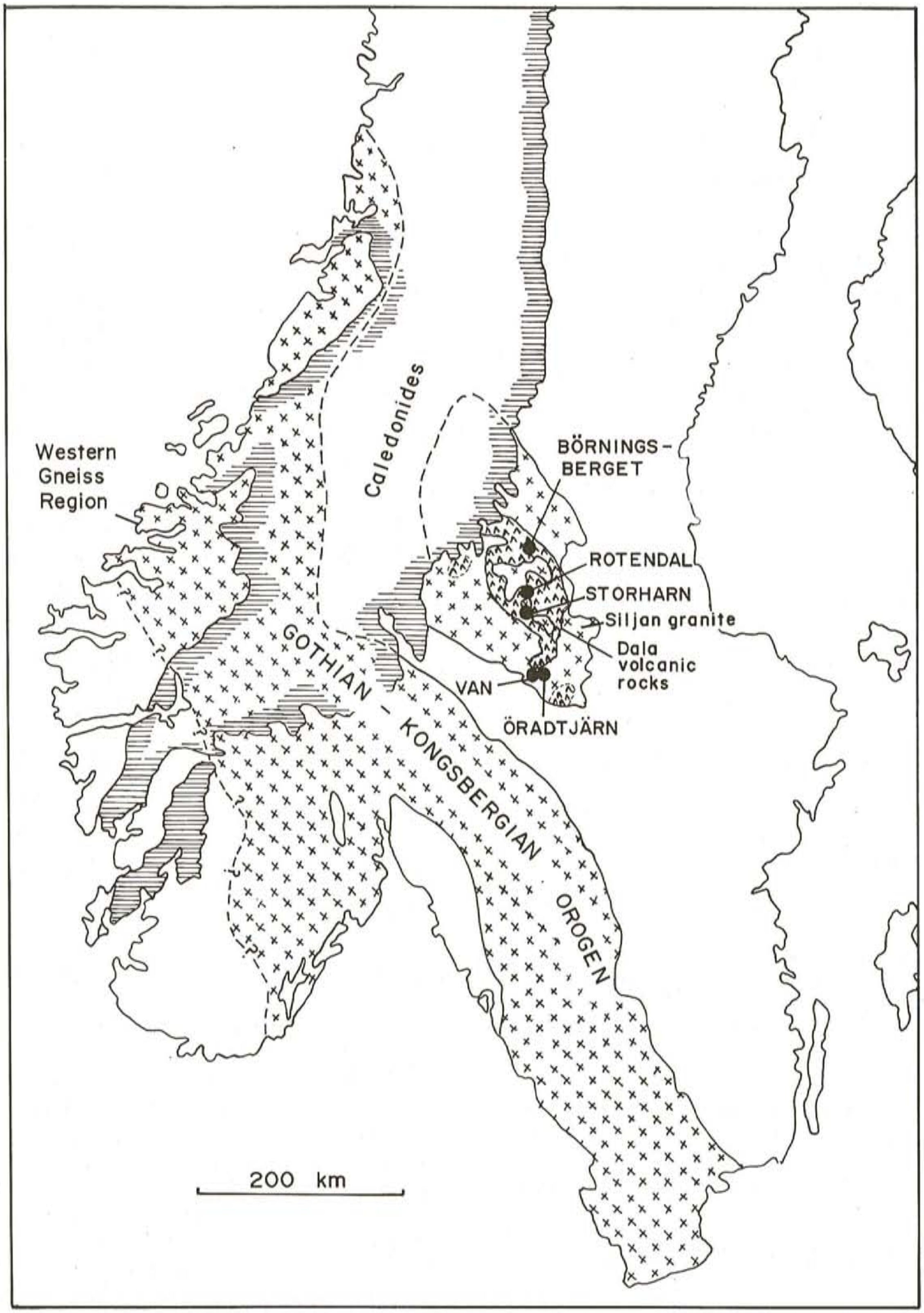

Figure 8. *Distribution of Gothian–Kongsbergian crust in Baltica and the location of minor Cu–Zn–Pb deposits in the coeval Dala volcanic rocks.*

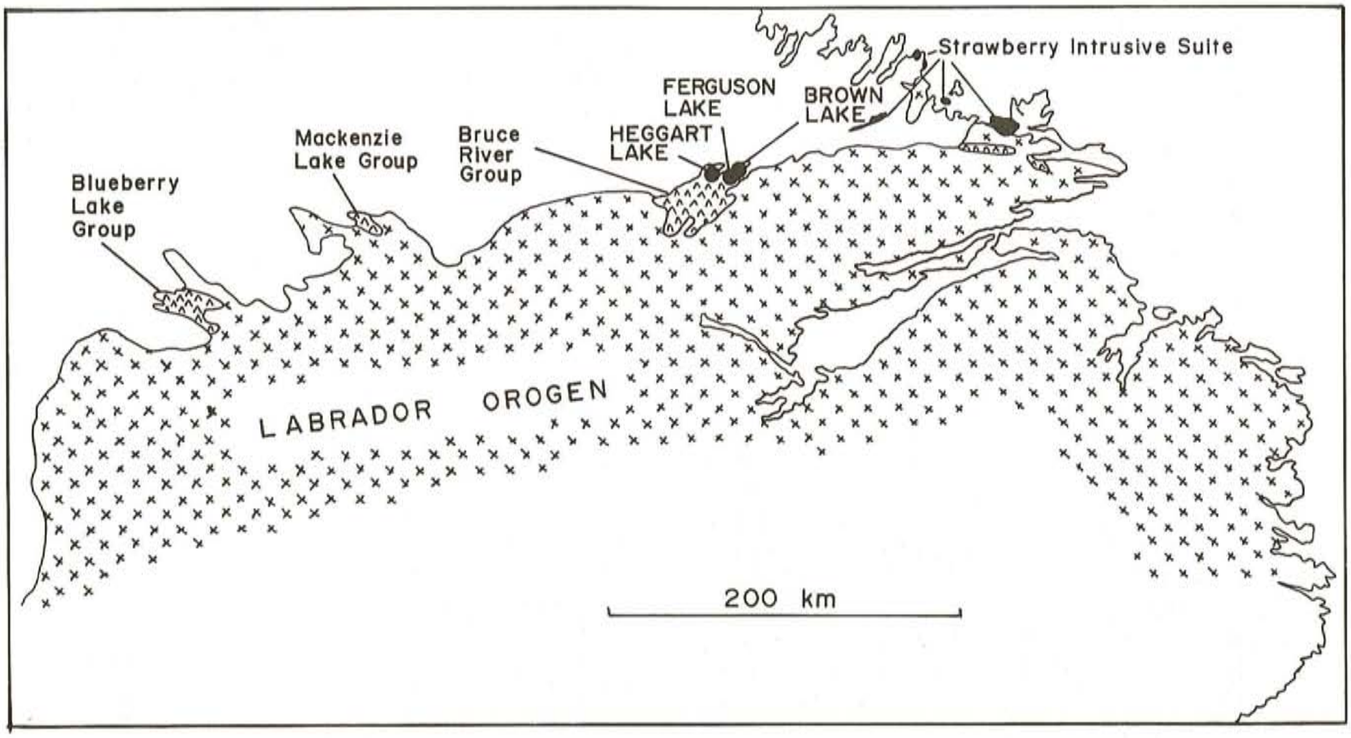

Figure 9. *The distribution of Labradorian crust in Labrador. The locations of the Strawberry Intrusive Suite and felsic volcanic rocks at the northern margin of the Trans-Labrador batholith are also shown, and major mineral occurrences in the Bruce River Group indicated.*

LAURENTIAN ANALOGUES (1.71 to 1.62 Ga)

Rocks formed during the 1.71 to 1.62 Ga Labradorian orogeny (Figure 9) are a close analogue to those of the Gothian–Kongsbergian orogenic belt. Like their Scandinavian plutonic counterparts, they, too, seem to be remarkably devoid of mineralization. Based on the proposed correlations, mineral exploration of Labradorian-age plutonic rocks does not appear promising (this conclusion does not extend to post-Labradorian rocks in the Labrador orogen, however; see below).

An explanation for the dearth of mineralization in rocks of these orogenic belts is not difficult to find, noting that scavenging from older into younger crustal rocks seems to have been an important mechanism in the control of earlier granophile-type mineralization, as discussed earlier. In both Baltica (Lindh and Persson, 1990) and Laurentia (Schärer, 1991), the rocks have been interpreted as juvenile. The only opportunities for a scavenging mechanism to have been operative would have been at the margin of the 1.71 to 1.62 Ga orogenic belts, where magmas passed through older crust. In Scandinavia, the mineralized Dala volcanic rocks and associated granitoid intrusions occupy such a tectonic setting.

In Labrador, two groups of rocks occur in a similar setting and have potential economic significance. These are (i) the Strawberry Intrusive Suite and related rocks in the Makkovik Province and (ii) felsic volcanic rocks of the Bruce River, Mackenzie Lake and Blueberry groups, on the foreland side of the Trans-Labrador batholith.

Like the Siljan granite, the tectonic status of the Strawberry Intrusive Suite is still under discussion. Linkage with Labradorian orogenesis is not necessarily implied here, despite including it in this section. It should be kept in mind, however, that the earliest rocks belonging to the Labrador orogen (1.71 Ga) are not much younger. The 1.72 Ga Strawberry Intrusive Suite has been identified as part of a group of specialized granites and potential for Mo, Cu, Pb and Zn mineralization has already been established (Kerr, 1988). The Strawberry Intrusive Suite is not known to have Sn mineralization, but the Cape Strawberry granite does have anomalously high background Sn concentrations.

Of the felsic volcanic rocks on the foreland side of the Trans-Labrador batholith, only in the Bruce River Group has there been any serious prospecting. This resulted in the discovery of numerous Cu–Zn–Pb–U showings–see summaries by Ryan (1984), Ryan *et al.* (1987) and Wilton (1988). The most significant showings are at Heggart Lake, Ferguson Lake and Brown Lake (Figure 9). The mineralization has been modelled by Wilton (1988) as epigenetic and the product of Grenvillian tectonism. The role of older source rocks and processes should not be dismissed, however, especially as similar mineralization is not ubiquitous throughout the Grenville orogen.

1.65 to 1.27 Ga ANOROGENIC SUITES

... in general, the rapakivi granites have been regarded as the most barren rocks of Finland. However, the exploration work carried out ... since 1967 has shown that tin and related beryllium, tungsten, zinc and copper mineralizations often occur in ... the rapakivi massifs. (Haapala, 1977).

GEOLOGICAL SETTING

1.65 to 1.51 Ga

Contemporaneously with calc-alkaline plutonism at the western margin of Baltica, magmatism of an anorogenic anorthosite–mangerite–charnockite–granite (AMCG) character was taking place within it, about 700 km farther east (Figure 10). The products of this plutonism included the Wiborg rapakivi massif and associated satellite bodies surrounding it (Bodom, Ahvenisto, Suomenniemi, Obbnäs, Onas). The Wiborg massif was emplaced between 1.65 and 1.63 Ga, but some porphyries were emplaced as late as 1.615 Ga (Vaasjoki *et al.*, 1991). Classic rapakivi granite makes up about 80 percent of the body, the remainder being a variety of granite types. This range of rock types is also seen in the satellite intrusions, together with gabbroic, anorthositic and monzodioritic rocks. Remnants of a volcanic carapace to the Wiborg massif are preserved near its southern margin (cf. Rämö and Haapala, 1990). Associated with the Wiborg massif are the northwest-trending Häme diabase and quartz porphyry dykes, dated at 1.64 Ga.

An essentially compositionally identical group of rocks were emplaced farther west about 50 million years later. Included here are the large Åland, Vehmaa, Laitila massifs and the smaller Kökar, Fjälskär, Eurajoki, Kokemäki and Siipyy intrusions in Finland. The Nordsjö, Ragunda, Nordingrå, Rödön and Gävle bodies in Sweden are provisionally included here, although only the Nordingrå body has been dated so far (Figure 10). The age range of the dated intrusions is 1.59 to 1.54 Ga. Temporally part of this group, but emplaced east of the Wiborg massif, are the Salmi and Sotjärvi plutons.

All the 1.65 to 1.54 Ga AMCG intrusions were emplaced into Svecofennian crust with the exception of the Salmi and Sotjärvi bodies, which are located in Proterozoic-reworked Archean crust.

1.51 to 1.43 Ga

Between 1.51 and 1.43 Ga, the focus of activity shifted farther west, and included widely scattered felsic, and locally mafic, magmatism. Included here are granite plutons in southeast Sweden (Åberg, 1988), gabbroic intrusions in southwest Sweden (Åhäll *et al.*, 1990), alkaline intrusions in the Bamble Sector (Starmer, 1990), felsic volcanic rocks in the Telemark Sector (Dahlgren and Heaman, 1991) and granitic and gabbroic intrusions in the Western Gneiss Region (Tucker *et al.*, 1990). A period of high-grade metamorphism at this time has been identified in southwesternmost Norway (Corfu, 1980), and it is possible that many of the intrusions farther east are inboard magmatic effects linked with that event. Mafic intrusive activity at 1.43 Ga, which was apparently widespread in both Laurentia and Baltica, terminates these events.

1.43 to 1.27 Ga

Following the 1.43 Ga mafic magmatism referred to above, sporadic and scattered granite emplacement continued across southern Scandinavia, especially in southeast and southwest Sweden, southeast Norway and in the Bamble Sector in southern Norway. This stage of crustal evolution in Baltica and Laurentia also ended with widespread mafic intrusive activity, which occurred at 1.27 Ga (cf. Gower *et al.*, 1990).

METALLOGENY

Mineralization related to the anorogenic suites can be divided into in two groups:

(i) Sn–Be–W–Pb–Zn mineralization associated with specialized granites, and

(ii) Ti–V mineralization associated with fractionated mafic intrusions.

Sn–Be–W–Pb–Zn Mineralization

This metallogenic type is associated with the 1.65 to 1.54 Ga rapakivi massifs. Mineralization occurs in the Wiborg, Vehmaa, Åland and Salmi massifs and in the Eurajoki, Suomenniemi and Ahvenisto satellite intrusions. The only economic deposits are at Pitkäranta in the Salmi massif, where mining started in 1842 (Haapala, 1977).

The mineralization is associated with the youngest equigranular or porphyritic rapakivi granite types. It is concentrated in pegmatitic veins and pockets, and in greisen and quartz veins. The ore minerals include cassiterite, beryllium minerals (beryl, genthelvite, bertandite), wolframite, sphalerite, chalcopyrite, galena, molybdenite, arsenopyrite and gahnite. These are associated with a wide range of accessory phases, such as topaz, tourmaline, fluorite, monazite and bastnaesite, in addition to more common silicate phases such as quartz, mica and chlorite (Haapala, 1988). The Pitkäranta deposits are somewhat different, in that they occur in limestone–dolomite-skarn layers in the exocontact zone of the Salmi massif, parts of which are probably situated below and very close to the deposits, although the main massif is up to 4 km away on the surface. Despite the mineralization not being in the massif, there seems little reason to doubt a genetic link between the mineralization and the rapakivi intrusion (Haapala, 1977) and, like similar mineralization elsewhere, to interpret the ore minerals as having been precipitated from late-stage residual fluids. An important

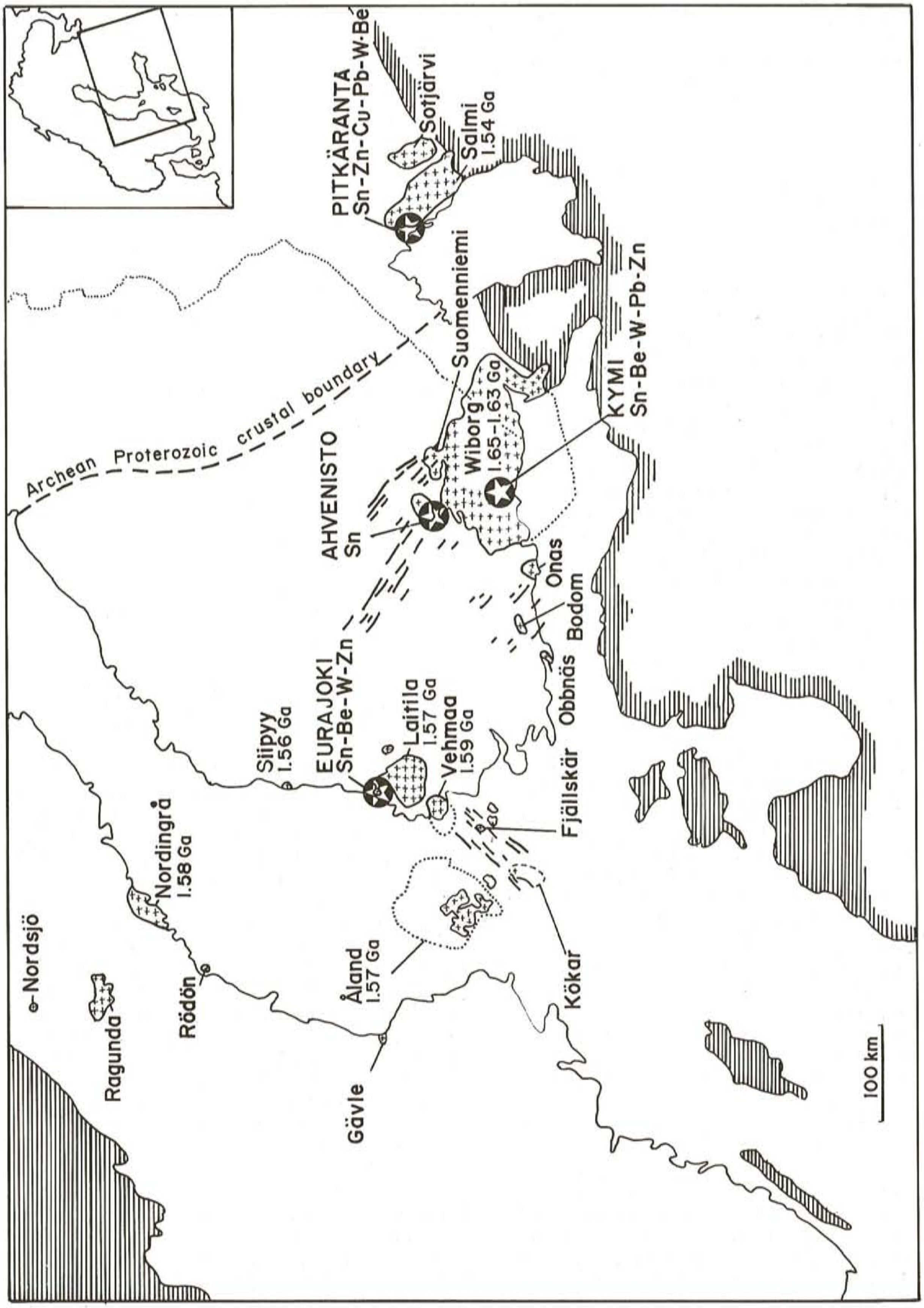

Figure 10. *Distribution of 1.65 to 1.54 Ga rapakivi massifs and major mineral occurrences in eastern Baltica. Based on Rämö (1991) and Lundqvist (1990). Lined pattern represents Paleozoic rocks.*

difference between the Pitkäranta deposits and those of other rapakivi massifs is that the metals source for the Pitkäranta deposits was Archean rather than Svecofennian (Sundblad, 1991b, Rämö, 1991).

Ti–V Mineralization

The Ti–V deposits occur in various places in Baltica associated with mafic intrusions emplaced during the anorogenic period. The only two of major importance are those at Smålands Taberg in southern Sweden and at Ulvön in central east Sweden (Figure 11). The mineralization in the Smålands Taberg deposit consists of rich concentrations in an olivine-bearing metagabbro emplaced between 1550 and 1500 Ma. It comprises titanomagnetite, with which minor pyrite, pyrrhotite, pentlandite and chalcopyrite are associated. Although large (150 million tonnes), the grade of 6 percent TiO_2 and 0.3 percent V_2O_5, is too low for the deposit to be economic (Grip, 1978). The Ulvön Ti–V deposit is much younger, being part of the widespread ca. 1270 Ma magmatic event that affected both Baltica and Laurentia. The ore minerals are titanomagnetite with ilmenite and ulvöspinel and they occur at several levels in an olivine dolerite intrusion (Larson and Magnusson, 1976). As the layers are rarely thicker than 2 m (6 m thick including disseminated zones) and the deposit is relatively small (20 million tonnes), it is not currently economic. The grade is slightly higher than that at Smålands Taberg, achieving 8 percent TiO_2 and 0.35 percent V_2O_5 (Grip, 1978).

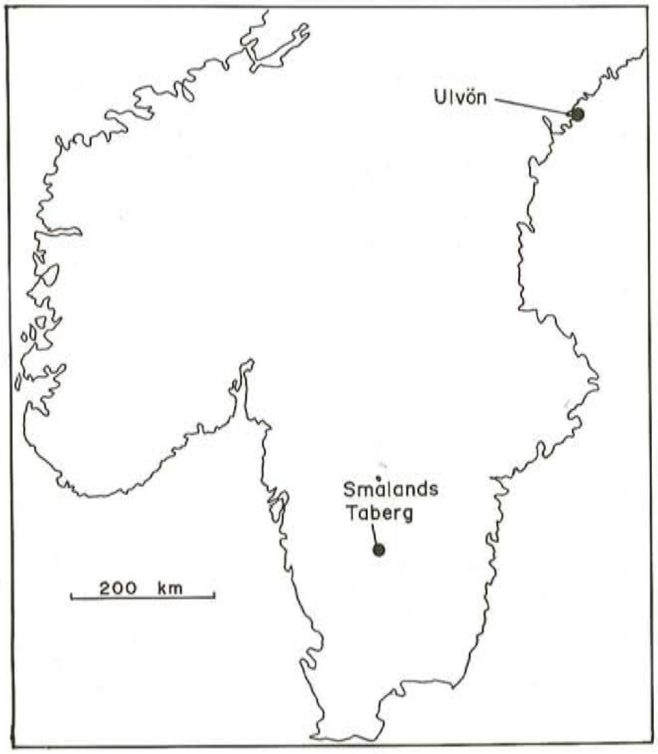

Figure 11. *Locations of the Smålands Taberg and Ulvön Ti–V deposits (Grip, 1978).*

LAURENTIAN ANALOGUES (1.65 to 1.27 Ga)

Labrador is well known for its mid-Proterozoic anorogenic intrusive and associated volcanic rocks. These include the 1.64 Ga Mealy Mountains Intrusive Suite, the ca. 1.48 Ga Pinware terrane granites, the 1.45 Ga Harp Lake, Michicamau, and Mistastin intrusions, the 1.43 Ga Michael–Shabogamo gabbros, the 1.33 to 1.27 Ga Nain Plutonic Suite, the 1.33 Ga Red Wine Intrusive Suite and genetically related Letitia Lake Group and the 1.27 Ga Flowers River Suite (Figure 12).

The spectrum of ages for the Labrador intrusions closely matches that of Baltica and it would be possible to make direct chronological comparisons with their Baltica analogues. A much more important metallogenic factor than precise time of emplacement within the anorogenic period, however, is the exposed structural level. The Sn–Be–W–Pb–Zn mineralization occurs in the uppermost levels of granitoid intrusions emplaced at high crustal levels, whereas Ti–V mineralization is found near the base of mafic intrusions.

Some of the highest level granitoid intrusions must have been near surface because some of the magma escaped to produce volcanic rocks still present in the region. Thus the Middle Proterozoic (at ca. 1.30 Ga) and present-day surfaces are essentially identical in some parts of Labrador. Examples in Labrador include the Red Wine Intrusive Suite (together with the spatially and genetically associated Letitia Lake Group), the Flowers River Suite, and the Strange Lake intrusion (cf. Hill and Miller, 1990). All of these units host mineralization resembling that found in the Finnish rapakivi granites (cf. Miller, 1988, 1990). Larger felsic bodies that ascended to high crustal levels include the Notakwanon, Makhavinekh and Umiakovik intrusions, which all form part of the Nain Plutonic Suite. These are not known to be mineralized, but their close similarity to ore-mineral-bearing rapakivi granites in Baltica has been emphasized by Ryan (1991). Compositionally similar, but somewhat older rocks include the 1.44 Ga Mistastin intrusion, fringes of the 1.45 Ga Harp Lake and Michicamau bodies and part of the Mealy Mountains Intrusive Suite. The Mealy Mountains intrusion is easily overlooked as having any potential for granophile mineralization, particularly as it occurs in the Grenville Province, and the best-known northern part is dominantly anorthositic and probably represents an upthrust, deeper level of the intrusion. It seems likely that higher intrusive levels will be identified south of the areas mapped at present. Despite the region being in the Grenville Province, there is good evidence that the Mealy Mountains Intrusive Suite was never deeply buried during Grenvillian orogenesis (Emslie *et al.*, 1984).

Two further points are worth making. First, although the largest bodies provide the biggest tracts of prospective terrain, they may not represent the best targets. Given that mineralization is concentrated near the roof of intrusions, better prospects would be granites that did not quite reach the earth's surface, and did not vent to it. If exposed, such granites would appear quite small and seemingly insignificant (e.g., Strange Lake). Second, in Baltica, the best

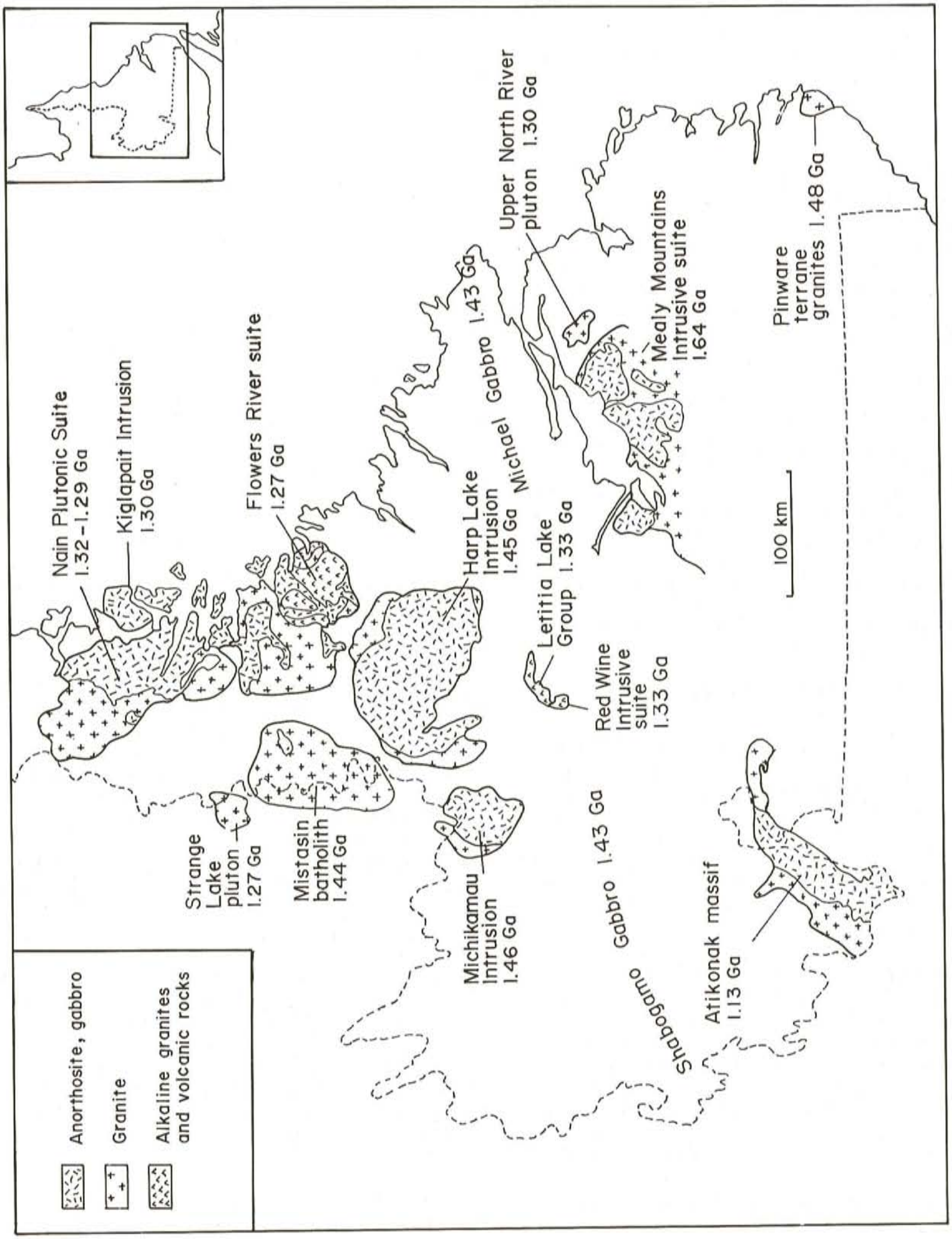

Figure 12. *Distribution of major 1.65 to 1.27 Ga anorogenic intrusions in Labrador. Location of individual intrusions of Shabogamo and Michael gabbros are not shown. The 1.13 Ga Atikonak massif (mentioned later in the text) is also shown.*

mineralization is associated with an intrusion (Salmi) that was emplaced into crust having a long and active earlier history; by analogy, the best prospects in Laurentia should be associated with anorogenic intrusions emplaced into Archean crust reworked during (repeated) Proterozoic orogenesis.

Where there is potential for high-level Sn–Be–W–Pb–Zn mineralization, then, at first thought, it would seem fortuitous to expect Ti–V mineralization in rocks of similar age, remembering that such mineralization is most probable in the lower level of mafic intrusions. If, however, the mafic magmas reached moderately high levels prior to fractionation, then both types of mineralization might conceivably be found in the same area. Also, it can only be established that the earth's surface at ca. 1.30 Ga (and north of the Grenville front) was the same as the present earth's surface; pre-1.30-Ga intrusions were uplifted and deeper levels exposed (Hill, 1991). Such a situation, admittedly, diminishes prospects for Sn–Be–W–Pb–Zn mineralization in the older intrusions, but it might improve their chances for hosting near-surface Ti–V ore bodies. In any case, Ti–V mineralization is known in several of the above listed mafic intrusions, although, like their Baltica counterparts, the occurrences are too small and(or) low grade to be exploited.

PRE-SVECONORWEGIAN/ SVECONORWEGIAN–PRE-GRENVILLIAN/ GRENVILLIAN

The recognition of large amounts of auriferous quartz veins in southwestern Scandinavia has been one of the pleasant suprises of this work. (Gaál and Sundblad, 1990).

GEOLOGICAL SETTING

The period between 1.27 and 0.95 Ga in both Baltica and Laurentia can be subdivided into two orogenic events separated by an anorogenic stage that lasted from ca. 1.20 to 1.10 Ga (cf. Gower *et al.*, 1990). In southwest Baltica, between 1.27 and 1.20 Ga, there was widespread granitoid plutonism accompanied by high-grade metamorphism. This event is best documented in southwest Sweden, where several crustally derived granite intrusions were emplaced at about 1.25 Ga (Lindh and Holme, 1989). In southeast Sweden, syenite to granite intrusions were emplaced between 1.23 and 1.20 Ga (Johansson, 1990; Hansen and Lindh, 1991). In southern Norway, although the timing of similar granitoid plutonism and metamorphism is not so precisely constrained, the pattern of events appears to be somewhat similar and the events are grouped together as early Sveconorwegian (Falkum, 1985; Smalley *et al.*, 1988; Starmer, 1990, 1991).

Following early Sveconorwegian orogenesis, there was widespread mafic extrusive and intrusive activity and some sedimentation, probably in a rift-related setting (cf. Atkin and Brewer, 1990). The focus of this activity in Norway was the Telemark Sector where clastic sediments of the Seljord Group were deposited, and were overlain by bimodal volcanic rocks (1.16 Ga; Dahlgren and Heaman, 1991) and associated sediments of the Bandak Group. At the same time, the Seljord Group was intruded by mafic sills. Similar mafic intrusive activity also occurred in the adjacent Bamble Sector. In southwest Sweden, the (probably rift-controlled) Dalsland Group was deposited, and the 1.18 Ga Protogine Zone dykes were emplaced (cf. Johansson, 1990). Some granitic intrusive activity also took place, peaking at ca. 1.14 Ga in both southern Norway and southwest Sweden (cf. Persson *et al.*, 1987).

The renewed orogenesis that started at ca. 1.10 Ga resulted in widespread deformation and high-grade metamorphism and was accompanied by the emplacement of a wide range of syn- to post-kinematic high-K calc-alkaline to alkali-calcic granitoid rocks (Eliasson and Schöberg, 1991), mafic intrusions, and, at the end of the period in southwest Norway, the Rogaland AMCG suite (Duchesne and Michot, 1987).

The anorogenic stage can be linked with rifting of Baltica away from easternmost Laurentia (probably east Greenland). The final orogenesis is interpreted here to correlate with collision between Baltica and southeastern Laurentia (southern Labrador and eastern Quebec), after its rotation through about 90° (Gower, 1990). The rotation is dated between 1.10 and 1.00 Ga from paleomagnetic evidence (Stearn and Piper, 1984). After ca. 1.05 Ga, therefore, southwest Baltica would have been juxtaposed against southeastern Laurentia, and they should have directly complementary histories.

METALLOGENY

The following metallogenic environments are represented in the Sveconorwegian Province:

(i) Cu–Mo–Au mineralization hosted by rift-related supracrustal rocks of the Telemark Supergroup,

(ii) Mo mineralization linked with syn- to late-tectonic granitoid rocks,

(iii) Au–Cu–(Pb–Zn–Ag) mineralization associated with late- to posttectonic veins, and

(iv) Ti–Fe–Ni mineralization in the Rogaland anorthosite massif.

Recent information concerning the first two of these metallogenic environments is rather sparse, and most of the information presented here for them is summarized from Bugge (1978).

Cu–Mo–Au Mineralization

This type of mineralization is found in an area measuring roughly 150 by 50 km in the Telemark Sector in southern Norway (Figure 13). Probably similar, but commercially

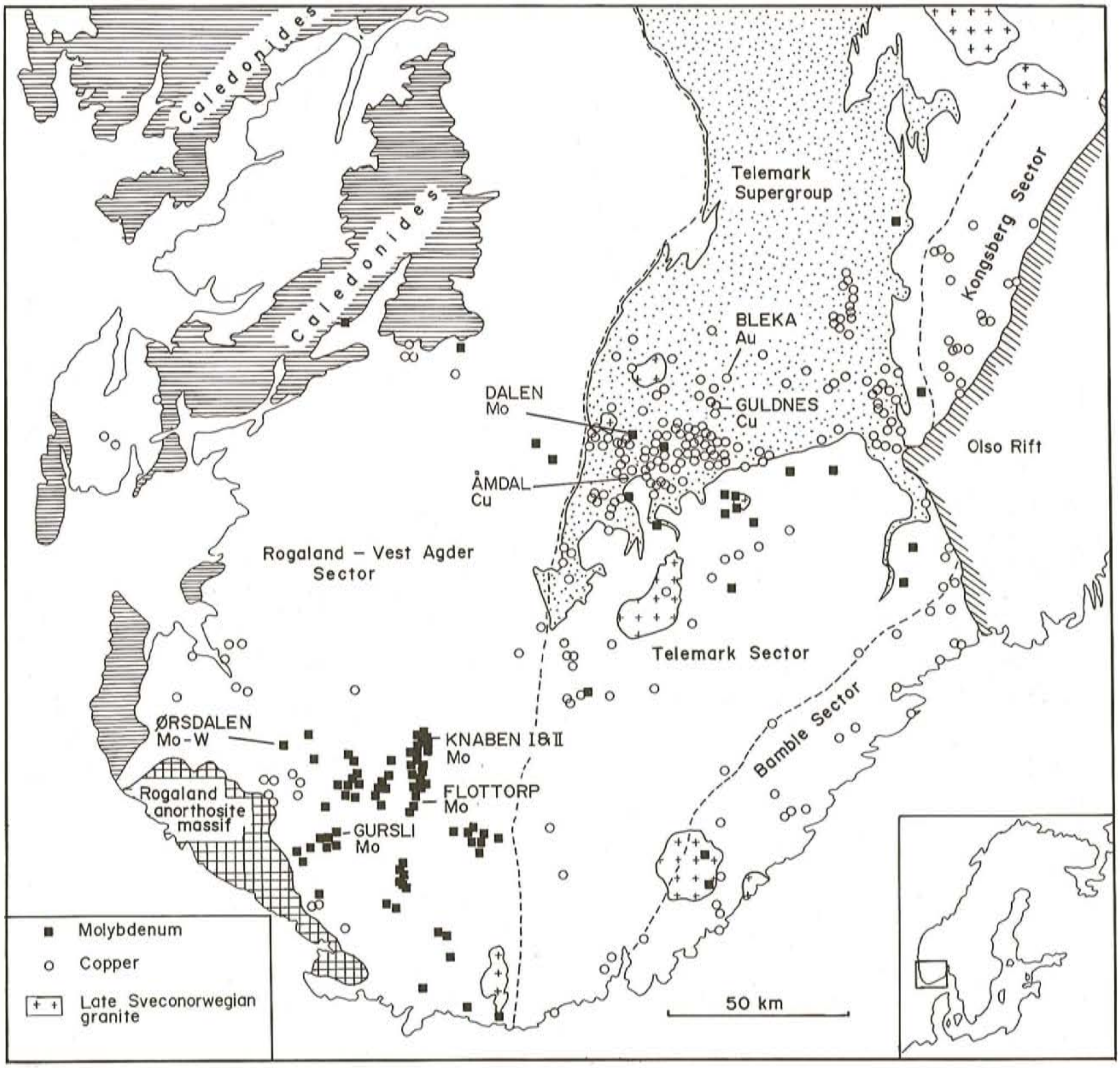

Figure 13. *Distribution of Cu and Mo mineralization in the Sveconorwegian Province in southwest Norway. Based on data compiled by Torske (1976) and Sigmond (1985).*

insignificant mineralization is known within the Dalsland Group in southwest Sweden. The deposits in the Telemark Sector supported several mining operations from the beginning of the sixteenth century until 1945. The principal commodity exploited was Cu, but mining was also carried out for Mo, As, Au and Bi.

The deposits are hosted by rocks of the Telemark Supergroup, especially the Seljord and Bandak groups. The deposits occur in irregular pods and lenses in quartz veins, that may be up to a few metres wide and several hundred metres long. A wide variety of minerals have been found, but the most important, economically, are chalcopyrite, bornite, digenite, chalcocite, molybdenite, galena, sphalerite, arsenopyrite and electrum. Silver and bismuth minerals are found in most of the Cu deposits. The ore minerals are associated with quartz, calcite, micas, feldspars, chlorite, fluorite and tourmaline. Pyrite is only found as an accessory mineral in chalcopyrite-bearing deposits and pyrrhotite is rare.

The mineralization in the Dalsland Group (Figure 14) consists of stratabound Cu impregnations in a calcareous phyllite sandwiched between two quartzite beds (Grip, 1978; Johansson, 1985).

The Telemark deposits were originally interpreted as hydrothermal fissure fillings genetically related to granite emplacement or to mobilization during high-grade

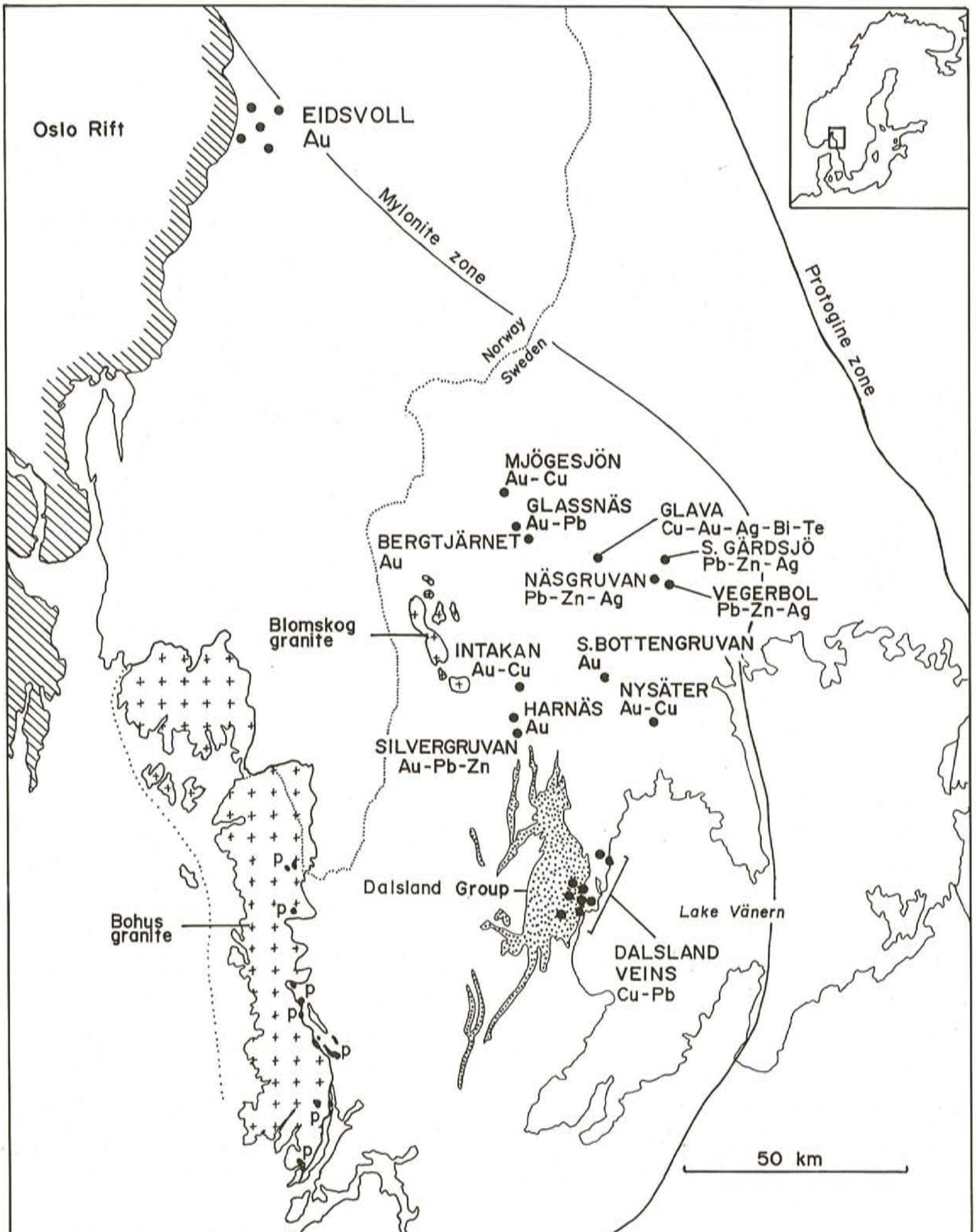

Figure 14. *Distribution of vein-type mineralization in southeast Norway and southwest Sweden. Compiled from Alm (1991) and Johansson (1985), p—pegmatite at the eastern margin of the Bohus granite.*

metamorphism. The spatial association with the supracrustal rocks cannot be denied, however, and it has been more recently suggested that the mineralization was originally syngenetic, and that the epigenetic imprint was subsequently stamped onto the deposits during metamorphism and granitoid emplacement.

Mo Mineralization

In contrast to the Cu-dominant mineralization of the Telemark Sector, Mo mineralization is mainly found farther west, in the Rogaland–Vest Agder Sectors (Sigmond, 1985). The Knaben deposits are the most important in this region and were mined over a period of nearly 100 years. The largest was the Knaben II deposit from which 8.6 million tonnes of ore was extracted, averaging 0.21 percent MoS_2. The mine is no longer in production, but proved reserves of 2.5 million tonnes of ore, averaging 0.15 percent MoS_2 remain. Smaller exploited deposits include the Ørsdalen Mo-W mine, and the Flottorp and Gursli mines (Figure 13).

Mo mineralization occurs in amphibolitic gneiss, albitized granite, aplite, pegmatite, and quartz veins and lenses. Most of the dykes and veins are small, but production from the Knaben II deposit exploited a quartz vein 30 to 80 m wide and 1500 m long. In the minor granitoid intrusions and quartz veins, the grade is commonly high, but drops off rapidly in disseminated zones in granite and amphibolitic gneiss. In addition to molybdenite, pyrite, chalcopyrite, pyrrhotite, scheelite, sphalerite and bismuth minerals may be present. Associated minerals include quartz, muscovite, calcite and fluorite.

The deposits have been compared to Cu–Mo porphyry deposits elsewhere (Torske, 1976; Bugge, 1978), although there are differences, particularly in the Norwegian examples being smaller and lacking associated volcanic rocks. The granitoid intrusions with which the late-stage dykes and veins are linked, are interpreted to be of deep crustal origin.

Au–Cu–(Pb–Zn–Ag) Mineralization

In contrast to the dearth of up-to-date information available on polymetallic mineralization in the Norwegian part of the Sveconorwegian Province, there has been sustained recent interest in vein-type mineralization (Figure 14) in southwest Sweden (Johansson, 1985; Lundegårdh, 1989; Gaál and Sundblad, 1990; Alm, 1991). Some of the larger veins have been mined intermittently over the last 200 years, but none is being exploited at present. The most important past producers were at Eidsvoll in southeast Norway (for Au), and at Glava in southwest Sweden (for Cu).

The veins occur in a broad belt west of the mylonite zone (Ihlen, 1986), a region representing a shallower level of Sveconorwegian orogenesis than the rocks immediately east of the mylonite zone. In addition to the veins located in Figure 14, Au has been discovered in Halland, south of Gothenburg (Arbetet newspaper, 16 May 1991). Although in a rather different tectonic setting, the Bleka Au mine in the Telemark Sector (Figure 13) may also belong to this metallogenic group.

Most of the mineralization is hosted by felsic to intermediate gneisses, mafic rocks and porphyries of Gothian–Kongsbergian age (see earlier), but some of the southerly veins are located within rocks of the Dalsland Group, which constrains their age to less than ca. 1200 Ma. A better indication of age is provided by Johansson (1985), who concluded from Pb isotopic data that the best estimate for the time of mineralization was 1010 $\pm$ 90 Ma for the veins from both Dalsland and Värmland.

The veins are typically small (rarely wider than 1 to 2 m and rarely longer than 100 m), steeply dipping, and are probably fault controlled. A wide range of minerals is present, but the most common are pyrite, chalcopyrite, bornite, covellite, galena and sphalerite (Johansson, 1985; Alm, 1991). Alm also concluded that the Cu-rich, Au-bearing veins preferentially carried Te-, Se- and Bi-bearing phases.

Johansson (1985) suggested that the veins could have formed during either Dalslandian (1000 Ma) metamorphism or associated with the emplacement of the Bohus (0.92 Ga) and Blomskog granites (located on Figure 14). The metals were introduced along with hydrothermal fluids, and isotopic data indicate that they probably originated in rocks formed during Gothian–Kongsbergian orogenesis.

Ti–Fe–Ni Mineralization

The Ti–Fe–Ni mineralization in the Sveconorwegian Province can be divided into two groups, (i) currently uneconomic deposits associated with various host rocks and scattered throughout the Sveconorwegian Province, but mainly concentrated in the Bamble Sector, and (ii) large deposits associated with the Rogaland anorthosite massif in southwest Norway.

Deposits of the first group include ilmenite deposits in layered gabbros and amphibolite, skarn-type ores associated with calcareous metasedimentary gneisses, apatite-bearing ores associated with quartzofeldspathic gneisses and fissure vein deposits in olivine gabbros consisting of magnetite with quartz, rutile and hematite. The host rocks have ages between ca. 1.70 and 1.10 Ga, and the deposits, although mined in the past, are generally too small and low grade to attract current interest.

In contrast, the deposits associated with the Rogaland anorthosite massif (Figure 15) are among the largest and most important of their kind in Europe. Production started in the late 19th century from the Blåfjell and Koldal-Anker mines, and in 1918 from the Storgangen deposit. Most important at the moment, however, is the huge Tellnes deposit, which, although in the same district, was not discovered until 1954. This deposit, from which production commenced in 1960, has reserves of over 300 million tonnes averaging 18 percent TiO_2 (Bugge, 1978), and currently accounts for more that 13

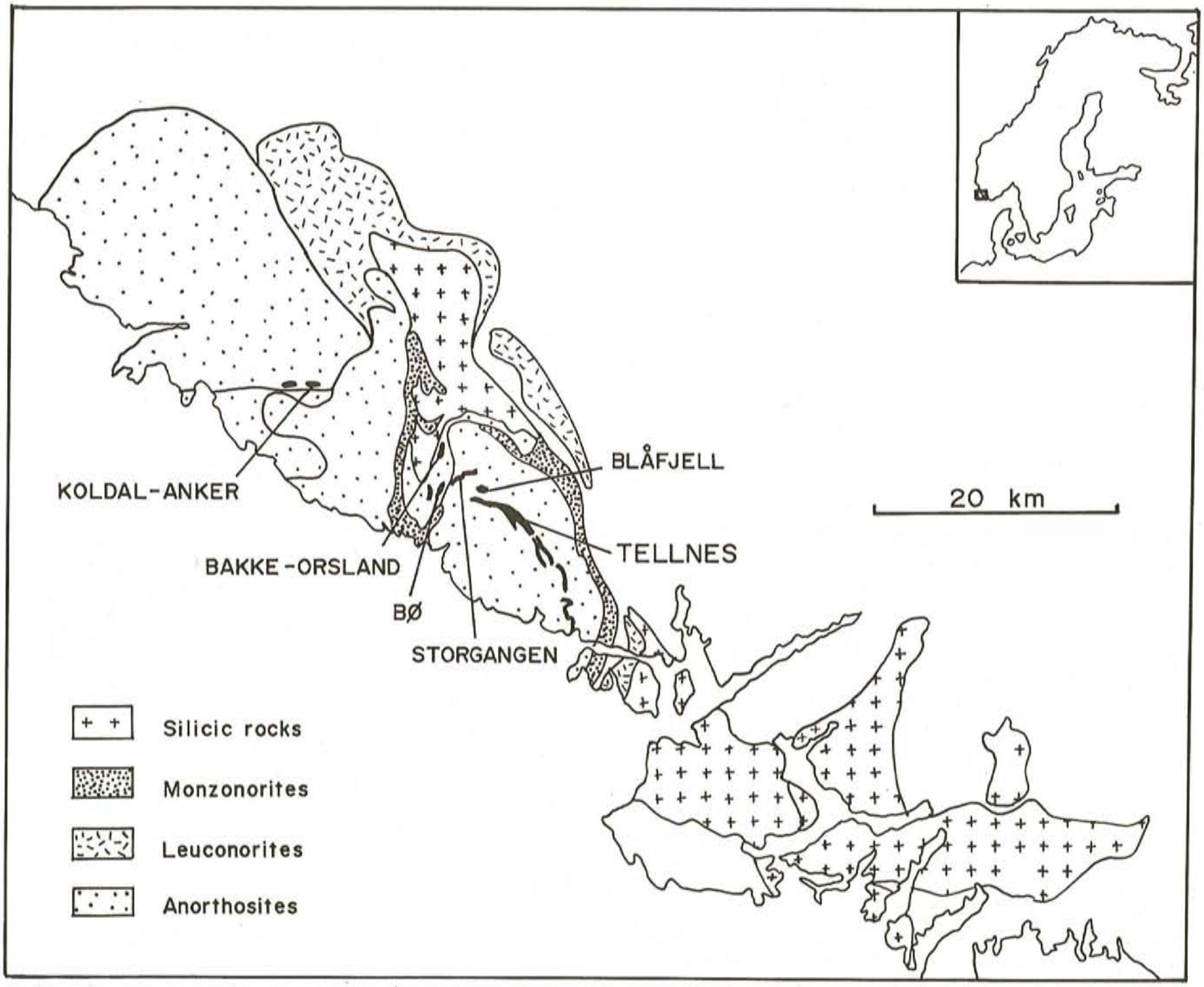

Figure 15. *Major rock units and location of Ti–Fe–Ni deposits in the Rogaland anorthosite massif (after Bugge, 1978).*

percent of the world supply of TiO_2 pigment (Wilmart *et al.*, 1989).

The Tellnes orebody is an ilmenite norite lens intruded into the surrounding anorthosite. The deposit is 400 m thick and 2.5 km long and extends at both ends as a 5- to 10-m-thick dyke that can be traced for 4 km and 10 km in northwest and southeast directions, respectively. In addition to ilmenite, the ore contains plagioclase, bronzite and olivine, together with lesser clinopyroxene, apatite, biotite, magnetite, and complex Fe–Ni–(Co)–Cu sulphides. The ilmenite norite and more evolved felsic units in the same region are interpreted to be the product of fractional crystallization (Wilmart *et al.*, 1989).

LAURENTIAN ANALOGUES (1.27 to 0.95 Ga)

The most obvious analogue to the Telemark Supergroup would seem to be the Seal Lake Group as both sequences formed in similar tectonic settings and show similar mineralization styles. The two sequences cannot be strictly compared, however, because the Seal Lake Group was probably deposited at least 70 million years earlier (and is better equated with Jotnian rocks). Nevertheless, in view of the fact that, in both regions, the mineralization has been interpreted to be epigenetic (cf. Wilton, 1989 for the Seal Lake Group) and related to Grenvillian–Sveconorwegian orogenesis, comparison may be justified.

An alternative Laurentian analogue to the Telemark Supergroup is the Wakeham Supergroup in eastern Quebec (Figure 16). The lower Aguanus River Group has an age of 1.27 Ga, but the overlying Davy Lake Group has not been dated (Bourne, 1991). The Davy Lake Group is a good analogue for the Telemark Supergroup, as the Wakeham Supergroup is situated well within the Grenville Province (as is the Telemark Supergroup in the Sveconorwegian Province) and the Davy Lake Group (which must be older than 1.11 Ga; Bourne, 1991), could easily have the same 1.16 Ga age

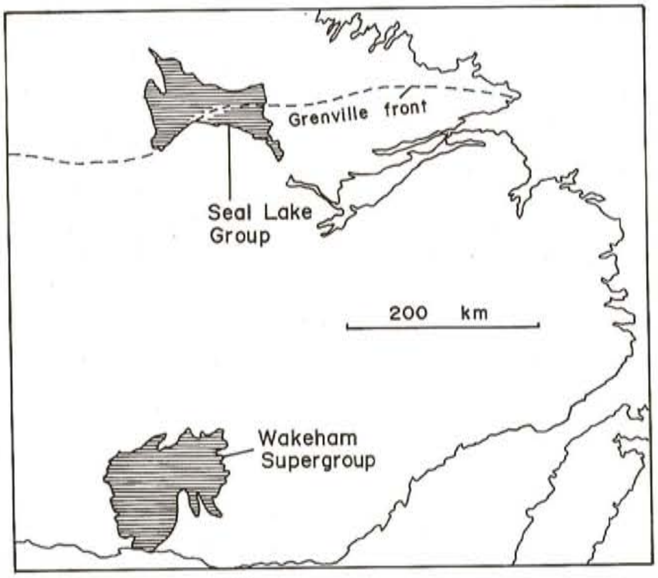

Figure 16. *Locations of Seal Lake Group and Wakeham Group in eastern Laurentia.*

as the Bandak Group. Of particular interest to mineral exploration in Labrador is the tectonic relationship between the Seal Lake Group and the lower part of the Wakeham Supergroup, and whether similar rocks (or mineralized linking structures) remain undiscovered in the poorly mapped intervening area in southernmost Labrador.

There are no known examples in Labrador comparable to either the Mo mineralization in the western Sveconorwegian Province or the Au–Cu–(Pb–Zn–Ag) mineralization in the eastern Sveconorwegian Province. Rather than this demonstrating a weakness in the Baltica–Laurentia correlative approach, given all the other geological correlations that exist, lack of documented mineralization offers tantalizing mineral-exploration possibilities for southern Labrador. It is not difficult to understand why mineralization might have escaped detection–large areas of southernmost Labrador are poorly exposed and unmapped, even at 1:250 000 reconnaissance scale.

Mineralization in the Sveconorwegian Province is interpreted to be an integral part of Sveconorwegian orogenesis and associated late- to posttectonic granite emplacement. It is only in recent years that it has been recognized that similar granites (Figure 17) are widespread in southern Labrador (Gower *et al.*, 1991). They are not presently known to contain Mo or Au mineralization. The granites locally contain U mineralization (Hauseux, 1977), they are generally enriched in large ion lithophile (LIL) elements, and they have radio-element and lake-sediment granophile anomalies (e.g., Gower *et al.*, 1985). The link between radio-element enrichment and other mineralization is important as, in the Sveconorwegian Province, radio-element-anomalous granitoid rocks clearly correlate with the distribution of Mo mineralization in the Rogaland–Vest Agder Sector (Sigmond, 1985) and vein mineralization in southwestern Sweden has been temporally linked to the anomalously radioactive Bohus and Blomskog granites (Gaál and Sundblad, 1990).

There are no direct temporal Laurentian analogues for the Rogaland anorthosite massif in Labrador, and it seems unlikely that any will be found. As noted earlier, however, temporal correlation is probably less important than tectonic setting in the case of Ti–Fe–V mineralization in anorthosites. The commercial Lac Tio deposits in the Allard Lake anorthosite and the unexploited Magpie Mountain deposit in eastern Quebec are examples of similar deposits in slightly older (1.13 Ga) anorthosite massifs in the eastern Grenville Province (Sangster *et al.*, *in press*). The Atikonak massif, in southwest Labrador, is a temporal equivalent of the Lac Allard massif.

A final word of caution is necessary with respect to Sveconorwegian–Grenvillian metallogenic correlations. Although various metallogenic provinces seem to be fairly clearly outlined in the Sveconorwegian Province, the identification of similar regions in southern Labrador is not straightforward, given that the orientation of Baltica changed considerably during this period. Thus the pattern, from east to west, of 'Sveconorwegian front–Au metallogenic zone–Mo metallogenic zone', need not be matched by a similar north-to-south progression from the Grenville front. Such a comparison might be justified if these metallogenic characteristics were acquired prior to rotation, and simply modified during subsequent collision, but if the metallogenic signatures postdate ca. 1.00 Ga, then they will be a product of the collision and the above correlation would be invalid.

FINAL COMMENTS

This article has examined mineral occurrences in Baltica formed during a 1-billion-year period when Laurentia and Baltica experienced a common geological history. Geological comparisons have been made largely on a temporal basis, although it is recognized that the identification of appropriate tectonic environments, irrespective of their age, is the most widely established predictive metallogenic strategy. Nevertheless, by adopting a temporal correlation approach (incorporating tectonic comparisons), several new exploration possibilities have emerged. Some of these are in line with established thinking, but some have not been previously considered and, hopefully, will develop into new and successful exploration models for the region.

This article has also emphasized, for rocks of several different ages, the importance of multistage reconcentration of metals in the crust. Such a process is heavily dependent on either superimposed orogenesis or anorogenic magmatism within pre-existing crust. In this regard, it is vital to know when the crust separated from the mantle, and to understand its subsequent geological history. Such information can be obtained by combining Sm–Nd and U–Pb isotopic techniques, and these investigations should routinely complement every regional mapping or regional mineral-exploration project.

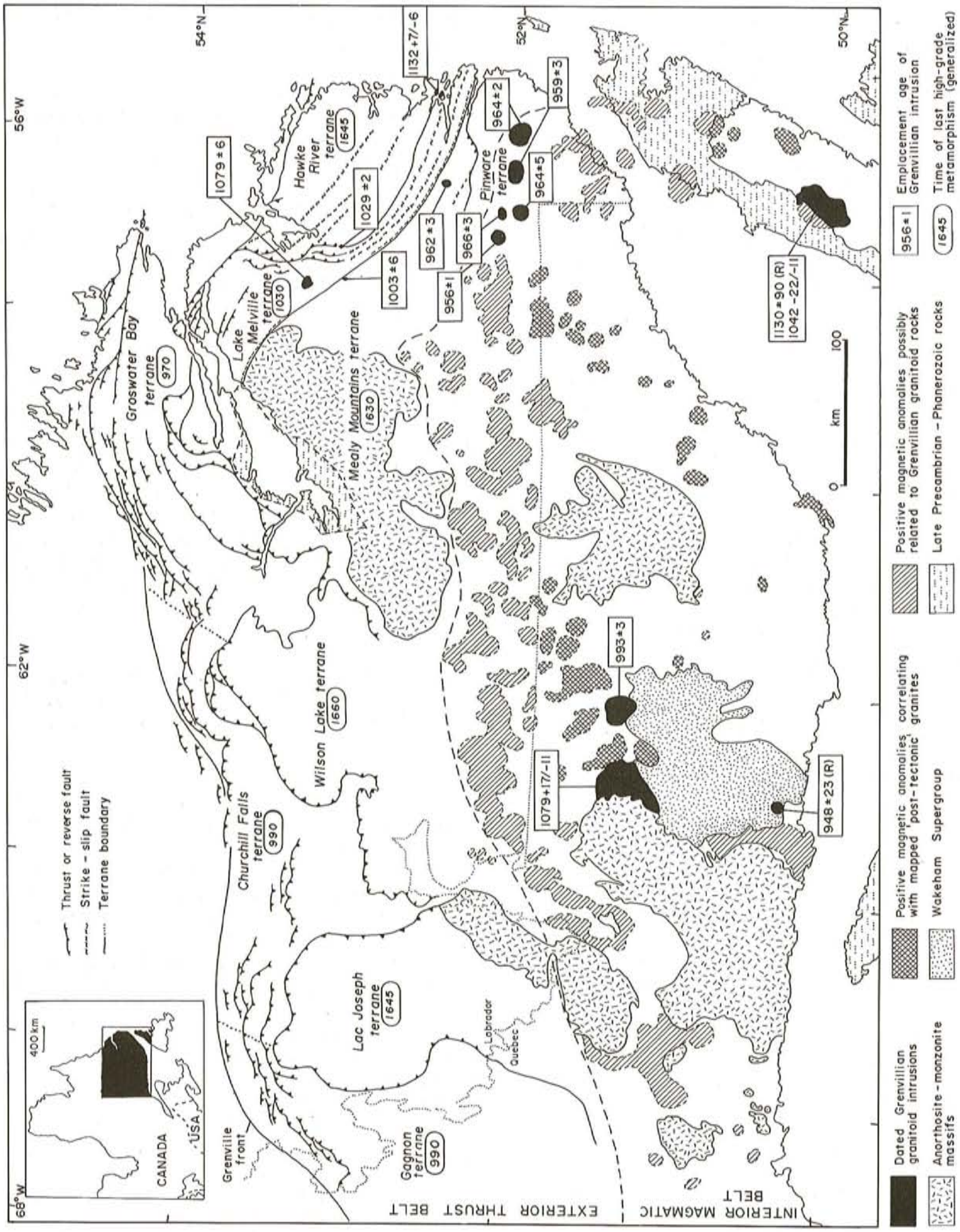

Figure 17. *Distribution of Grenvillian granitoid intrusions in the eastern Grenville Province. Modified from Gower et al. (1991).*

Apart from straightforward comparative metallogeny, there are other underlying themes in this article. First, the long history of mineral exploration and geological research in Baltica offers a wealth of information, with which geologists involved in mineral exploration in eastern Laurentia would do well to become familiar. Second, the Scandinavian experience emphasizes that success does not come easily—the fact that economic deposits were not discovered during an earlier exploration phase does not mean they do not exist (the discovery of the Tellnes deposit is a good example). Third, despite exploration extending over decades, or even centuries, new types of deposits are still being discovered, in some cases in regions where mineralization was previously unknown. Finally, it must be stressed that Baltica and Laurentia are not identical. Marginally suitable tectonic environments containing only non-commercial mineralization in one region may well correlate with ideal settings hosting major deposits in the other.

ACKNOWLEDGMENTS

The faculty and research students at Gothenburg University and geologists working with the Swedish Geological Survey in Gothenburg are thanked for providing me with a wealth of information on various aspects of Baltic Shield geology. Particular thanks are due to Sven-Åke Larson (University of Gothenburg) and Lennart Samuelsson (Geological Survey of Sweden) for overwhelming kindness and hospitality during my stay in Sweden. Thanks are also due to the many excursion leaders who have familiarized me with so much of Fennoscandian geology. They remain unnamed, for fear of omission, but they are not unappreciated. I am greatly indebted to the following for reading and suggesting substantial improvements to various parts of the preliminary manuscript; Ulf Bergström, Andy Kerr, Sven-Åke Larson, Thomas Lundqvist, Bruce Ryan, Krister Sundblad, Scott Swinden and Derek Wilton.

REFERENCES

Åberg, G.
1988: Middle Proterozoic anorogenic magmatism in Sweden and worldwide. Lithos, Volume 21, pages 279-289.

Adamek, P.M. and Wilson, M.R.
1979: The evolution of a uranium province in northern Sweden. Philosophical Transactions of the Royal Society of London, Volume A291, pages 355-368.

Åhäll, K.I. and Daly, J.S.
1989: Age, tectonic setting and provenance of Östfold-Marstrand belt supracrustals: westward crustal growth of the Baltic Shield at 1760 Ma. Precambrian Research, Volume 45, pages 45-61.

Åhäll, K.I., Daly, J.S. and Schöberg, H.
1990: Geochronological constraints on mid-Proterozoic magmatism in the Östfold-Marstrand belt; implications for crustal evolution in southwest Sweden. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 97-115.

Åhäll, K.I. and Persson, P.-O.
In press: Westward accretion of the Baltic Shield; evidence from the ca. 1.60 Ga Åmål-Horred belt, SW Sweden. Precambrian Research.

Ahl, M.
1991: Geological and geochemical control of Sn-Pb-Zn-Be-greisen bearing granitoids in the Dala region, central Sweden. Abstract volume, Symposium on Rapakivi Granites and Related Rocks, Helsinki. Geological Survey of Finland, Opas 34, page 3.

Allaart, J.H.
1976: Ketilidian mobile belt of south Greenland. *In* Geology of Greenland. *Edited by* A. Escher and W.S. Watts. Grønlands Geologiske Undersøgelse, pages 120-151.

Alm, E.
1991: En mineralogisk studie av Au-, Ag-, Bi-, Te-, Se- och Ge-förande kvartsgånger i sydvästra Värmland. Examensarbete i malmgeologi, Institutionen för geologi och geokemi, Stockholms Universitet, 44 pages.

Andersson, U.
1991: Granitoid episodes and mafic-felsic magma interaction in the Svecofennian of the Fennoscandian Shield, with main emphasis on the ~ 1.8 Ga plutonics. Precambrian Research, Volume 51, pages 127-149.

Atkin, B.P. and Brewer, T.S.
1990: The tectonic setting of basaltic magmatism in the Kongsberg and Telemark sectors, southern Norway. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 471-483.

BABEL Working Group
1990: Evidence for early Proterozoic plate tectonics from seismic reflection profiles in the Baltic Shield. Nature, Volume 348, pages 34-38.

Baker, J.H. and Hellingwerf, R.H. (editors)
1988: The Bergslagen Province—Central Sweden. Geologie en Mijnbouw Special Issue, Volume 67, Numbers 2-4, 476 pages.

Bourne, J.
1991: The geochemistry of the La Galissonnière pluton: a Middle Proterozoic late-orogenic intrusion from the eastern Grenville Province, Quebec. Canadian Journal of Earth Sciences, Volume 28, pages 37-43.

Bradley, D.A.
1966: Geology of southeastern part of Sandwich Bay—Square Island joint venture area. Brinex, Unpublished Report, 15 pages. [Lab 199]

Bugge, J.A.W.
1978: Norway. *In* Mineral Deposits of Europe. Volume I: Northwest Europe. *Edited by* S.H.U. Bowie, A. Kvalheim and H.W. Haslam. The Institution of Mining and Metallurgy and The Mineralogical Society, London, pages 199-249.

Claesson, L-Å. and Weihed, P.
1986: The early orogenic granitoid complex and associated mineralization. *In* The Skellefte Field. *Edited by* D. Rickard. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 4. Sveriges Geologiska Undersökning, Series Ca, Number 62, 54 pages.

Corfu, F.
1980: U-Pb and Rb-Sr systematics in a polyorogenic segment of the Precambrian shield, central southern Norway. Lithos, Volume 13, pages 305-323.

Dahlgren, S. and Heaman, L.
1991: U-Pb constraints for the timing of Middle Proterozoic magmatism in the Telemark region, southern Norway. Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, Volume 16, page A28.

Douglas, G.V.
1953: Notes on localities visited on the Labrador coast in 1946 and 1957. Geological Survey of Canada, Paper 53-1, 67 pages.

Duchesne, J.C. and Michot, J.
1987: The Rogaland intrusive masses: introduction. *In* The Geology of Southernmost Norway. *Edited by* C. Maijer and P. Padget. Norges Geologiske Undersøkelse Special Publication Number 1, pages 48-59.

Eliasson, T. and Schöberg, H.
1991: U-Pb dating of the post-kinematic Sveconorwegian (Grenvillian) Bohus granite, SW Sweden: evidence of restitic zircon. Precambrian Research, Volume 51, pages 337-350.

Emslie, R.F., Loveridge, W.D. and Stevens, R.D.
1984: The Mealy dykes, Labrador: petrology, age, and tectonic setting. Canadian Journal of Earth Sciences, Volume 21, pages 437-446.

Falkum, T.
1985: Geotectonic evolution of southern Scandinavia in light of a late-Proterozoic plate-collision. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. NATO Advanced Science Institutes Series, Volume 158, pages 309-322.

Gaál, G.
1986: Base metal, chromite, and PGE deposits of central Finland: Metallogeny of an Early Proterozoic continental margin. *In* Proterozoic Mineral Deposits in Central Finland. *Edited by* G. Gaál. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 5. Sveriges Geologiska Undersökning, Series Ca, Number 63, 36 pages.

Gaál, G. and Gorbatschev, R.
1987: An outline of the Precambrian evolution of the Baltic Shield. Precambrian Research, Volume 35, pages 15-52.

Gaál, G. and Sundblad, K.
1990: Metallogeny of gold in the Fennoscandian Shield. Mineralium Deposita, Volume 25 (supplement), pages S104-S114.

Gorbatschev, R.
1985: Precambrian basement of the Scandinavian Caledonides. *In* The Caledonide Orogen–Scandinavia and Related Areas. *Edited by* D.G. Gee and B.A. Sturt. John Wiley and Son Ltd., pages 197-212.

Gower, C.F.
1990: Mid-Proterozoic evolution of the eastern Grenville Province, Canada. Geologiska Föreningens i Stockholm Förhandlingar, Volume 122, pages 127-139.

Gower, C.F., Flanagan, M.J., Kerr, A. and Bailey, D.G.
1982a: The geology of the Kaipokok Bay–Big River area, Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-77, 77 pages.

Gower, C.F., Heaman, L.M., Loveridge, W.D., Schärer, U. and Tucker, R.D.
1991: Grenvillian granitoid plutonism in the eastern Grenville Province, Canada. Precambrian Research, Volume 51, pages 315-336.

Gower, C.F., Neuland, S., Newman, M. and Smyth, J.
1987: Geology of the Port Hope Simpson map region, Grenville Province, eastern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 183-199.

Gower, C.F., Noel, N. and van Nostrand, T.
1985: Geology of the Paradise River region, Grenville Province, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Report 85-1, pages 19-32.

Gower, C.F., Owen, V. and Finn, G.
1982b: The geology of the Cartwright region, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 122-130.

Gower, C.F., Ryan, A.B. and Rivers, T.
1990: Mid-Proterozoic Laurentia-Baltica: an overview of its geological evolution and a summary of the contributions made by this volume. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers, and A.B. Ryan. Geological Association of Canada Special Paper 38, pages 1-20.

Gower, C.F. and Swinden, H.S.
1991: Pillow lavas in the Dead Islands area, Grenville Province, southeast Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 205-215.

Grip, E.
1978: Sweden. *In* Mineral Deposits of Europe. Volume I: Northwest Europe. *Edited by* S.H.U. Bowie, A. Kvalheim and H.W. Haslam. The Institution of Mining and Metallurgy and The Mineralogical Society, London, pages 93-198.

Haapala, I.
1977: The controls of tin and related mineralizations in the rapakivi-granite areas of south-eastern Fennoscandia. Geologiska Föreningens i Stockholm Förhandlingar, Volume 99, pages 130-142.

1988: Metallogeny of Proterozoic rapakivi granites of Finland. *In* Recent Advances in the Geology of Granite-Related Mineral Deposits. *Edited by* R.P. Taylor and D.F. Strong. Canadian Institute of Mining and Metallurgy, Special Volume 39, pages 124-132.

Hallberg, A.
1989: Metal sources in the Early Proterozoic Svecofennian terrain of central Sweden: Pb isotope evidence. Mineralium Deposita, Volume 24, pages 250-257.

Hansen, B.T. and Lindh, A.
1991: U-Pb zircon age of the Görbjörnarp syenite in Skåne, southern Sweden. Geologiska Föreningens i Stockholm Förhandlingar, Volume 113, pages 335-337.

Hauseux, M.A.
1977: Mode of uranium occurrence in a migmatitic granite terrain, Baie Johan Beetz, Quebec. Canadian Mining and Metallurgical Bulletin, Volume 70, pages 110-116.

Hill, J.D.
1991: Emplacement and tectonic implications of the mid-Proterozoic peralkaline Flowers River Igneous Suite, north-central Labrador. Precambrian Research, Volume 49, pages 217-227.

Hill, J.D. and Miller, R.R.
1990: A review of Middle Proterozoic epigenic felsic magmatism in Labrador. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 417-431.

Ihlen, P.
1986: Late Proterozoic gold deposits of the Eidsvoll-Odalen district, southeast Norway (Abstract). Terra Cognita, Volume 6, page 538.

Johansson, Å.
1985: The Dalslandian sulphide-bearing quartz veins of Dalsland and Värmskog southwest Sweden. Sveriges Geologiska Undersökning, Series C, No. 809, 48 pages.

1990: Age of the Önnestad syenite and some gneissic granites along the southern part of the Protogine Zone, southern Sweden. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 131-148.

Johansson, Å. and Rickard, D.
1985: Some new lead isotopic determinations from the Proterozoic sulfide ores of central Sweden. Mineralium Deposita, Volume 20, pages 1-7.

Kerr, A.
1988: Geochemical characteristics and mineral potential of specialized granitoid plutons in the Trans-Labrador batholith, eastern Labrador. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 15-36.

Kerr, A. and Fryer, B.J.
1990: Sources of Early and Middle Proterozoic magmas in the Makkovik Province, Labrador: evidence from Nd isotopic data. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 65-78.

Kerr, A. and Krogh, T.
1990: The Trans-Labrador granitoid belt in the Makkovik Province: new geochronological and isotopic data and their geological implications. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 90-1, pages 237-249.

Kerr, A., Krogh, T.E., Corfu, F., Schärer, U., Gandhi, S.S. and Kwok, Y.Y.
In press: Episodic Early Proterozoic granitoid plutonism in the Makkovik Province, Labrador: U-Pb geochronological data and geological implications. Canadian Journal of Earth Sciences.

Kontinen, A.
1987: An early Proterozoic ophiolite—the Jormua mafic-ultramafic complex, northeastern Finland. Precambrian Research, Volume 35, pages 313-341.

Larson, S.-Å., Berglund, J., Stigh, J. and Tullborg, E.-L.
1990: The Protogine Zone, southwest Sweden: a new model—an old issue. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 317-333.

Larson, S.-Å. and Magnusson, K.-Å.
1976: The magnetic and chemical character of Fe-Ti oxides in the Ulvö dolerite, central Sweden. Sveriges Geologiska Undersökning, Series C, Number 723, 29 pages.

Lindh, A. and Holme, K.
1989: Formation of granitic magmas during repeated orogenic events: an example from the Baltic shield. Precambrian Research, Volume 45, pages 97-109.

Lindh, A. and Persson, P.-O.
1990: Proterozoic granitoid rocks of the Baltic Shield—trends of development. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 23-40.

Loukola-Ruskeeniemi, K., Heino, T., Talvitie, J. and Vanne, J.
1991: Base-metal-rich metamorphosed black shales associated with Proterozoic ophiolites in the Kainuu schist belt, Finland: a genetic link with the Outokumpu rock assemblage. Mineralium Deposita, Volume 26, pages 143-151.

Lundegårdh, P.H.
1989: Leta guld i Värmland. Wermland Guldbrytning AB, 32 pages.

Lundqvist, T.
1968: Precambrian geology of the Los-Hamra region central Sweden. Sveriges Geologiska Undersökning, Series Ba, Number 23, 255 pages.

1987: Early Svecofennian stratigraphy of southern and central Norrland, Sweden, and the possible existence of an Archaean basement west of the Svecokarelides. Precambrian Research, Volume 35, pages 343-352.

1990: Beskrivning till berggrundskartan över Västernorrlands län. Sveriges Geologiska Undersökning, Series Ba, Number 31, 429 pages.

Lundqvist,T., Willdén, M., Kresten, P. and Sundblad, K.
1986: The Enåsen Au deposit and the Alnö alkaline complex. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 9/10. Sveriges Geologiska Undersökning, Series Ca, Number 67, 22 pages.

Lundström, I. and Papunen, H. (editors)
1986: Mineral deposits of southwestern Finland and the Bergslagen Province, Sweden. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 3. Sveriges Geologiska Undersökning, Series Ca, Number 61, 44 pages.

MacDougall, C.S. and Wilton, D.H.C.
1987: Middle Proterozoic granite-related mineralization in the Round Pond area, Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 457-466.

1988: Geology of radioactive zones in the Round Pond area, Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 271-275.

MacKenzie, L.M. and Wilton, D.H.C.
1987: Uranium, molybdenum and base metal sulphide mineralization: three different styles of ore formation in the Burnt Lake area, central Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 467-476.

Miller, R.R.
1988: Yttrium (Y) and other rare metals (Be, Nb, REE, Ta, Zr) in Labrador. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 229-245.

1990: The Strange Lake pegmatite-aplite-hosted rare-metal deposit, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 90-1, pages 171-182.

North, J.W. and Wilton, D.H.C.
1988: Stratigraphy of the Warren Creek Formation, Moran Lake Group, Central Mineral Belt of Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 123-128.

In press: Origins of stratiform and stratabound Fe-Cu-Zn horizons in the Lower Proterozoic Moran Lake Group, Labrador Central Mineral Belt. Canadian Journal of Earth Sciences.

Nurmi, P.A. and Haapala, I.
1986: The Proterozoic granitoids of Finland: granite types, metallogeny and relation to crustal evolution. Bulletin of the Geological Society of Finland, Volume 58, pages 203-233.

Öhlander, B.
1985: Geochemical characteristics of granites associated with Proterozoic molybdenite mineralization in northern Sweden. Chemical Geology, Volume 51, pages 247-263.

1986: Proterozoic mineralizations associated with granitoids in northern Sweden. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 7. Sveriges Geologiska Undersökning, Series Ca, Number 65, 39 pages.

Öhlander, B. and Billström, K.
1989: Regional implications of U-Pb zircon dating of two Proterozoic granites associated with molybdenite mineralized aplites in northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar, Volume 111, pages 229-238.

Park, A.F.
1991: Continental growth by accretion: a tectonostratigraphic terrane analysis of the evolution of the western and central Baltic Shield, 2.50 to 1.75 Ga. Geological Society of America Bulletin, Volume 103, pages 522-537.

Parkkinen, J.
1986: The Outokumpu (Keretti) Mine. *In* Proterozoic Mineral Deposits in Central Finland. *Edited by* G. Gaál. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 5. Sveriges Geologiska Undersökning, Series Ca, Number 63, 36 pages.

Persson, P.-O., Malmström, L. and Hansen, B.T.
1987: Isotopic datings of reddish granitoids in southern Värmland, southwest Sweden. Geologische Rundschau, Volume 76, pages 389-406.

Pharaoh, T.C. and Brewer, T.S.
1990: Spatial and temporal diversity of early Proterozoic volcanic sequences—comparisons between the Baltic and Laurentian shields. Precambrian Research, Volume 47, pages 169-189.

Rämö, O.T.
1991: Petrogenesis of the Proterozoic rapakivi granites and related basic rocks of southeastern Fennoscandia: Nd and Pb isotopic and general geochemical constraints. Geological Survey of Finland, Bulletin 355, 161 pages.

Rämö, O.T. and Haapala, I.
1990: The rapakivi granites of eastern Fennoscandia: a review with insights into their origin in the light of new Sm-Nd isotopic data. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 401-415.

Rickard, D. (editor)
1986: The Skellefte Field. 7th IAGOD Symposium and Nordkalott Project Meeting, Excursion Guide Number 4. Sveriges Geologiska Undersökning, Series Ca, Number 62, 54 pages.

Ryan, B.
1984: Regional geology of the central part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 3, 185 pages.

1991: Makhavinekh Lake pluton, Labrador, Canada: geological setting, subdivisions, mode of emplacement, and a comparison with Finnish rapakivi granites. Precambrian Research, Volume 51, pages 193-225.

Ryan, A.B., Baragar, W.R.A. and Kontak, D.J.
1987: Geochemistry, tectonic setting, and mineralization of high-potassium middle Proterozoic rocks in central Labrador, Canada. *In* Geochemistry and Mineralization of Proterozoic volcanic Suites. *Edited by* T.C. Pharaoh, R.D., Beckinsale and D. Rickard. Geological Society Special Publication No. 33, pages 241-254.

Sangster, A.L., Gauthier, M. and Gower, C.F.
In press: Metallogeny of structural zones, Grenville Province, northeastern North America. Precambrian Research.

Schärer, U.
1991: Rapid continental crust formation at 1.7 Ga from a reservoir with chondritic isotope signatures, eastern Labrador. Earth and Planetary Science Letters, Volume 102, pages 110-133.

Schärer, U., Krogh, T.E., Wardle, R.J., Ryan, B. and Gandhi, S.S.
1988: U-Pb ages of Early and Middle Proterozoic volcanism and metamorphism in the Makkovik Orogen, Labrador. Canadian Journal of Earth Sciences, Volume 25, pages 1098-1107.

Sigmond, E.M.O.
1985: The Mandal—Ustaoset line, a newly discovered major fault zone in south Norway. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. NATO Advanced Science Institutes Series, Volume 158, pages 323-331.

Skiöld, T.
1986: On the age of the Kiruna greenstones, northern Sweden. Precambrian Research, Volume 32, pages 35-44.

Smalley, P.C., Field, D. and Råheim, A.
1988: Rb-Sr systematics of a Gardar-age layered alkaline monzonite suite in southern Norway. Journal of Geology, Volume 96, pages 17-29.

Starmer, I.C.
1990: Mid-Proterozoic evolution of the Kongsberg—Bamble belt and adjacent areas, southern Norway. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada Special Paper 38, pages 279-305.

1991: The Proterozoic evolution of the Bamble Sector shear belt, southern Norway: correlations across southern Scandinavia and the Grenvillian controversy. Precambrian Research, Volume 49, pages 107-139.

Stearn, J.E.F. and Piper, J.D.A.
1984: Palaeomagnetism of the Sveconorwegian mobile belt of the Fennoscandian Shield. Precambrian Research, Volume 23, pages 201-246.

Sundblad, K.
1991a: Svecofennian lead isotope provinces in the Baltic Shield. *In* Source, Transport and Deposition of Metals. *Edited by* M. Pagel and J.L. Leroy. Proceedings of the 25 Years SGA Anniversary Meeting, Balkema, Rotterdam, pages 355-358.

1991b: Lead isotopic evidence for the origin of 1.8−1.4 Ga ores and granitoids in the southeastern part of the Fennoscandian Shield. Precambrian Research, Volume 51, pages 265-281.

Swinden, H.S., Wardle, R.J., Davenport, P.H., Gower, C.F., Kerr, A., Meyer, J.R., Miller, R.R., Nolan, L., Ryan, A.B. and Wilton, D.H.C.
1991: Mineral exploration opportunities in Labrador−a perspective for the 1990's. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 349-390.

Torske, T.
1976: Metal provinces of a Cordilleran-type orogen in the Precambrian of south Norway. *In* Metallogeny and Plate Tectonics. *Edited by* D.F. Strong. Geological Association of Canada Special Paper 14, pages 597-613.

Tucker, R.D., Krogh, T.E. and Råheim, A.
1990: Proterozoic evolution and age-province boundaries in the central part of the Western Gneiss Region, Norway: results of U-Pb dating of accessory minerals from Trondheimsfjord to Geiranger. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers, and B. Ryan. Geological Association of Canada Special Paper 38, pages 149-173.

Vaasjoki, M., Rämö, O.T. and Sakko, M.
1991: New U-Pb ages from the Wiborg rapakivi area: constraints on the temporal evolution of the rapakivi granite-anorthosite-diabase dyke association of southeastern Finland. Precambrian Research, Volume 51, pages 227-243.

van Breemen, O., Aftalion, M. and Allaart, J.H.
1974: Isotopic and geochronologic studies on granites from the Ketilidian mobile belt of south Greenland. Geological Society of America Bulletin, Volume 85, pages 403-412.

Vivallo, W.
1987: Early Proterozoic bimodal volcanism, hydrothermal activity, and massive sulfide deposition in the Boliden-Långdal area, Skellefte district, Sweden. Economic Geology, Volume 82, pages 440-456.

Walser, G. and Einarsson, Ö.
1982: The geological context of molybdenum occurrences in the southern Norrbotten region, northern Sweden. Geologische Rundschau, Volume 71, pages 213-229.

Wardle, R.J. and Bailey, D.G.
1981: Early Proterozoic sequences in Labrador. *In* Proterozoic Basins in Canada, supplement. *Edited by* F.H.A. Campbell. Geological Survey of Canada, Paper 81-10, pages 331-358.

Weihed, P. and Schöberg, H.
1991: Age of porphyry-type deposits in the Skellefte District, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar, Volume 113, pages 273-378.

Weihed, P., Bergman, J. and Bergström, U.
In press: Metallogeny and tectonic evolution of the Early Proterozoic Skellefte district, northern Sweden. Precambrian Research.

Weihed, P., Isaksson, I. and Svenson, S-Å.
1987: The Tallberg porphyry cooper deposit in northern Sweden: a preliminary report. Geologiska Föreningens i Stockholm Förhandlingar. Volume 109, pages 47-53.

Welin, E.
1987: The depositional history of the Svecofennian supracrustal sequence in Finland and Sweden. Precambrian Research, Volume 35, pages 95-113.

Wilmart, E., Demaiffe, D. and Duchesne, J.C.
1989: Geochemical constraints on the genesis of the Tellnes ilmenite deposit. Economic Geology, Volume 84, pages 1047-1056.

Wilson, M.R. and Åkerblom, G.V.
1982: Geological setting and geochemistry of uranium-rich granites in the Proterozoic of Sweden. Mineralogical Magazine, Volume 46, pages 233-245.

Wilson, M.R., Hamilton, P.J., Fallick, A.E., Aftalion, M. and Michard, A.
1985: Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics. Earth and Planetary Science Letters, Volume 72, pages 376-388.

Wilson, M.R., Sehlstedt, S., Claesson, L.-Å., Smellie, J.A.T., Aftalion, M., Hamilton, P.J. and Fallick, A.E.
1987: Jörn: an Early Proterozoic intrusive complex in a volcanic-arc environment, north Sweden. Precambrian Research, Volume 36, pages 201-225.

Wilton, D.H.C.
1988: Copper occurrences in the Bruce River Group, Central Mineral Belt of Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 291-297.

1989: Studies in the Seal Lake Group, central Labrador, Part I: description of copper occurrences. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 89-1, pages 23-33.

1991: Metallogenic and tectonic implications of Pb isotope data for galena separates from the Labrador Central Mineral Belt. Economic Geology, Volume 86, pages 1721-1736.

Wilton, D.H.C., MacDougall, C.S., MacKenzie, L.M. and Pumphrey, C.
1988: Stratigraphic and metallogenic relationships along the unconformity between Archean granite basement and the early Proterozoic Moran Lake Group, central Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 277-282.

Wilton, D.H.C. and Wardle, R.J.
1987: Two contrasting metallogenic styles in the Early Proterozoic Upper Aillik Group, Central Mineral Belt, Labrador, Canada. Mineralium Deposita, Volume 22, pages 198-206.

NOTE: Geological Survey Branch file numbers are included in square brackets.