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IRON OXIDE SYSTEMS AND BASE METAL MINERALISATION IN NORTHERN SWEDEN

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Abstract - The Lower Proterozoic succession in Northern Sweden, hosts a major iron oxide province with a widespread and diverse base metal sulphide mineralisation. A large amount of geological and exploration data exists, but fundamental questions remain regarding the distribution and relationship of the iron and predominantly copper rich sulphide mineralisation. Detailed field, isotopic, mineralogical, petrological, fluid inclusion and structural observations are now providing new data on this historically important and significant province. Genetic concepts can now be reassessed and specific deposits re-evaluated to investigate the inter-relationship of base metal mineralisation, iron oxide deposits, rock alteration, metamorphism, orogenic cycles, structural development and igneous activity.

Iron mineralisation occurs in predominantly four forms: (1) Banded, stratiform, siliceous, 'quartz-banded' iron oxide formations; (2) Calc-silicate 'skarn' and carbonate hosted, stratabound, iron formations; (3) Concordant to discordant, massive, brecciated and vein style, magnetite-actinolite, magnetite-apatite and magnetite-haematite-apatite ores; and (4) Disseminated, massive, vein and replacement iron oxides with silica and carbonate.

Base metal (Cu-Zn-Pb-Ag-Co) mineralisation, often with Au, occurs as: (1) Disseminated sulphides within pelitic, siliceous, carbonate and calc-silicate metasediments; (2) Hydrothermal veins within massive and brecciated magnetite (-haematite) and replacement bodies within mixed siliciclastics, metavolcanites and metacarbonates; and (3) Veinlet and disseminated sulphides within iron formations, iron bearing calc-silicates and chemical sediments, and with magnetite within metavolcanites and intrusive bodies.

Regional and locally developed rock alteration, spatially associated with mineralisation, occurs as scapolite, albite, K-spar, sericite, biotite, chlorite, actinolite, epidote, carbonates, fluorite, tourmaline and silica. Mineralisation is multistage, and apparently focussed and hosted by specific lithological hosts, lithostratigraphic units and brittle-ductile tectonic zones.

Introduction

A 2.5 to 1.85 Ga Palaeoproterozoic terrane in Sweden is represented by a ~1000 km wide belt of mixed 'greenstone', siliciclastic and pelitic metasedimentary and acid to basic metavolcanic sequences deposited in an inferred extensional or trans-tensional environment on the edge of the Archaean continent (Fig. 1).

Two iron bearing provinces with subordinate base metals occur in the northern and central parts of Sweden. The northern province, lies within Norrbotten, Swedish Lappland, and the central province forms the historic mining district of Bergslagen, (Fig. 1). The Norrbotten Province, which currently produces over 30 Mtpa of iron ore and processed pellets from Europe's largest magnetite deposits, and ~62 000 tpa of copper from one of Europe's largest mines, is the subject of this paper.

Extensive iron mineralisation is developed in Palaeoproterozoic metavolcanics and metasediments in both Norrbotten and Bergslagen, as apparently stratiform-stratabound quartz, carbonate and calc-silicate haematite (-magnetite) banded iron formations, and the volumetrically significant, but problematical magnetite-actinolite, magnetite-apatite and magnetite-haematite-apatite iron ores.

Disseminated, schlieren, massive and vein type magnetite is a common accessory in a range of base metal deposits and occurrences in both regions, suggesting a common origin for iron oxides and Cu, Zn, Pb sulphides with Au and Ag. The inter-relationship of the various styles of iron and the often spatially coincident Cu, Cu-Au, and Zn-Pb mineralisation, the phases of mineralisation, alteration patterns, the degree of structural control, and structural, metamorphic and plutonic igneous relationships to mineralisation are not yet well documented nor understood. This paper seeks to address these issues.

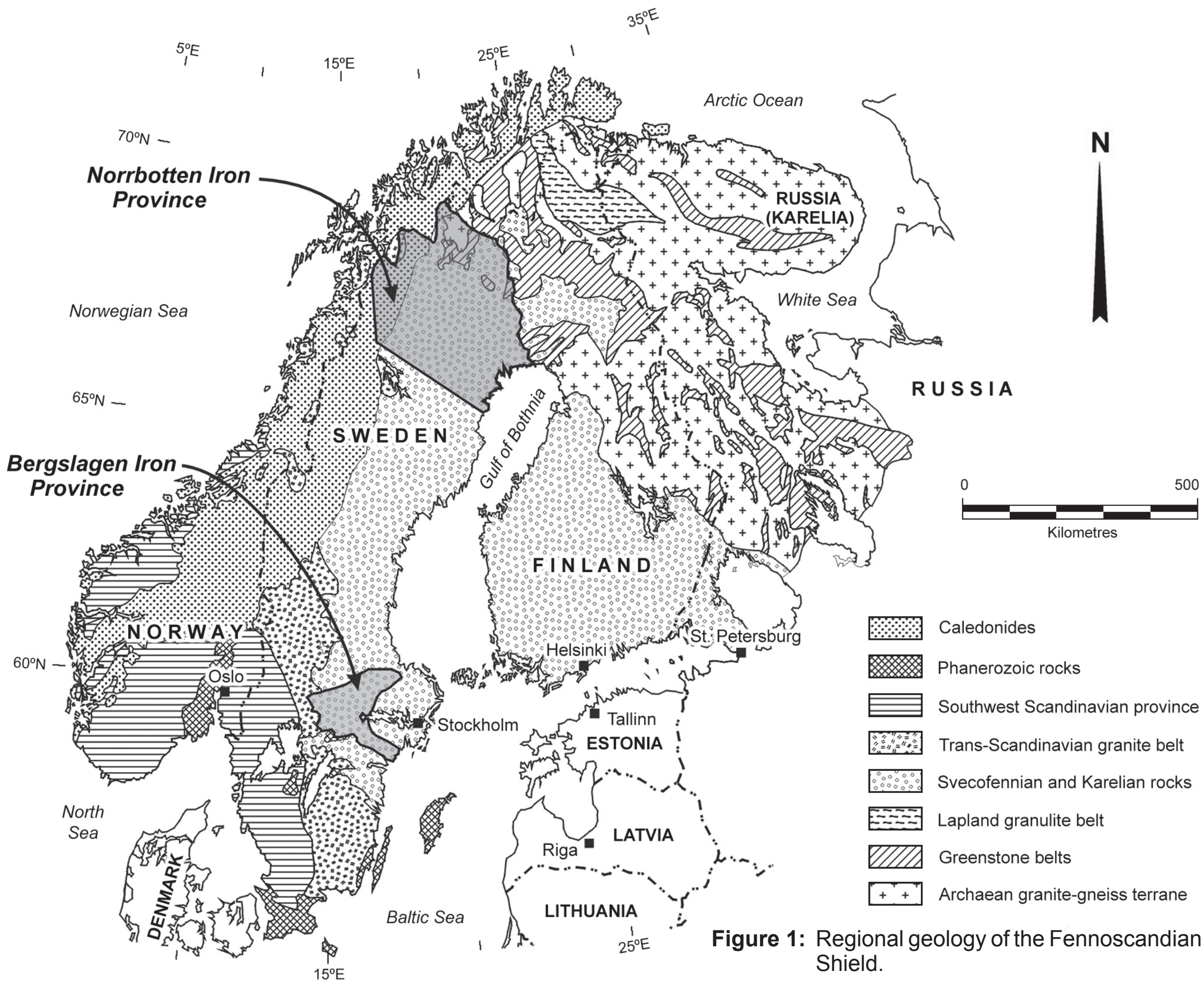

Figure 1: Regional geology of the Fennoscandian Shield.

Regional Geology of the Swedish Fennoscandian Shield

The Palaeoproterozoic successions were deposited in a structurally complex extensional environment on the edge of the Archaean continent between 2.5 to 1.85 Ga (Gorbatschev and Bogdanova 1993). The geotectonic environment is interpreted as a series of volcanic arcs, back arc basins and rifts along the Archaean continent above a series of variously active northwest dipping subduction zones in an oceanic – continental collision zone. Accretion of Proterozoic juvenile crust along the Archaean continental boundary was followed and partly accompanied by closure and deformation creating the Svecokarelian-Svecofennian Orogenic cycles (Gorbatschev and Bogdanova 1993, Skiöld *et al.*, 1993).

The western edge of the Svecofennian terrane is largely hidden beneath the easterly thrusted Palaeozoics of the Caledonian Orogen along the Swedish-Norwegian border, and non-residual glacial detritus from Quaternary Ice sheets covers around 98% of the Palaeoproterozoic bedrock.

Northern Sweden - Stratigraphy

The 2.8 Ga Archaean basement of the Fennoscandian Shield is overlain by over 10 km of Palaeoproterozoic formations. These comprise siliciclastics, mixed basic volcanics and sediments of the Greenstone Group, and intermediate to acid felsic volcanic, volcanoclastic and epiclastic sediments of the overlying Porphyry Group (Witschard 1984, Welin 1987). The sequences are preserved in a series of deformed supracrustal belts stretching 250 km across northern Sweden and into Finland, (Fig. 2).

Martinsson (1997) describes the detailed lithostratigraphy of the Greenstone Group in the Kiruna area. This 2.5 to 2.1 Ga sequence (Skiöld and Cliff 1984; Skiöld 1986) is part of a larger tholeiitic province, related to rifting of the Archaean craton across northern Fennoscandia (Ekdahl 1993).

Overlying the Greenstone Group are quartzites, conglomerates and mica schists of Witschard's (1984) 'Middle Sediment Group' (Fig. 3).

These formations are overlain by the Porphyry Group, a volcanic and sub-volcanic complex, marking the rise of alkaline basalt-andesite and calc-alkaline acidic magmas around 1.91 to 1.88 Ga. (Skiöld and Cliff 1984; Skiöld 1987; Welin 1987). Basalts, andesites, dacites, rhyolites and volcaniclastic tuffaceous sediments are subdivided into the dominantly andesitic Porphyrite Group and the syenite and quartz-syenite Kiruna Porphyries. To the west and northwest the Porphyry Group is bimodal and mildly alkaline to alkaline and trachytic, while to the E and in central Norrbotten it is predominantly calc-alkaline, interpreted as back arc extension and continental margin volcanic arc settings respectively, (Pharaoh and Pearce, 1984; Frietsch and Perdahl, 1989). Alkaline volcanic and sub-volcanic units, sodic trachytes, trachyandesites and trachybasalts, albite (leuco) gabbros and sodic microsyenite, are well developed in spatial association with the magnetite-apatitic iron ores in the Kiruna and Gällivare districts (Figs. 2 and 4).

The coeval 1.89 to 1.86 Ga (Skiöld 1987) Haparanda and Jorn Granite suites, form plutonic-infracrustal, differentiated, gabbroic to granitoid intrusives, generated during an early phase of the Svecofennian Orogeny. The 1.91 to 1.88 Ga plutono-volcanic cycles ended with the deposition of thick molasse-type or turbiditic, arkosic-siliceous clastics, locally derived from the volcanites, and deposited in reactivated graben structures (Witschard 1984).

Potassic rocks (5 to 9% K_2O) occurring in the Rappen-Tjåmotis -Ultevis areas appear to relate to a NNE-SSW rift zone in which the volcanites are overlain by a >5 km thick pile of clastic sediments (Ödman, 1947; Carlon, 1984).

Regional Metamorphism, Deformation and Igneous Activity

A close temporal relationship exists between the extensional depositional environments of the Greenstone Group, the Porphyry Group and the overlying sediments, and the compressional phases of the orogen which occurred in the 1.9 to 1.8 Ga interval. The detailed tectonic and chronological development of the Svecofennian Orogeny is still not fully resolved (Nironen, 1997; Ekdahl, 1993). Regional structural data from the European Geotraverse (Berthelsen and Marker 1986), and more detailed mapping and structural interpretation in the Kiruna area (Vollmer *et al.*, 1984, Wright 1988, Talbot and Koyi 1995) indicates a complex ductile-brittle evolution.

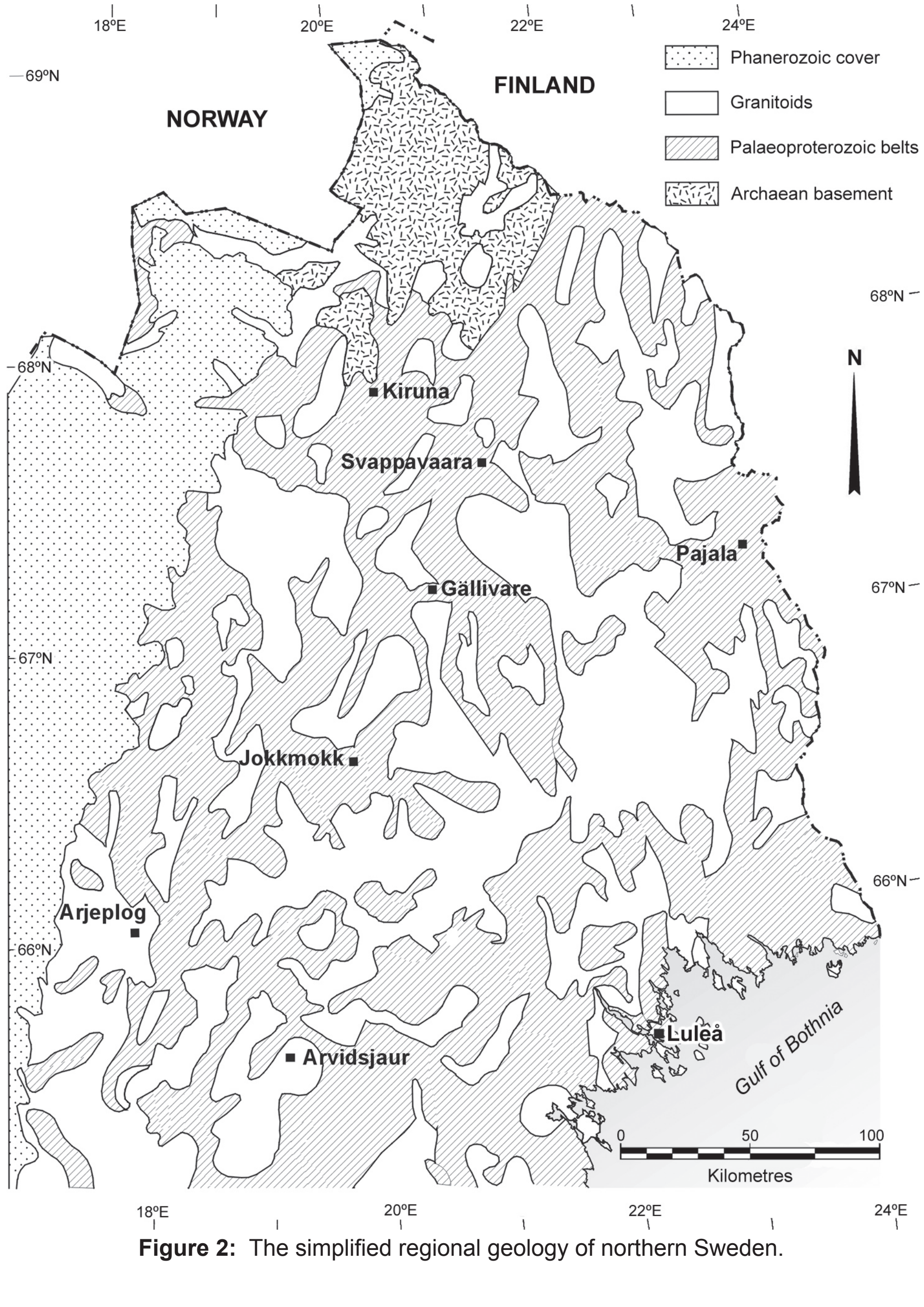

Figure 2: The simplified regional geology of northern Sweden.

Detailed structural studies do not exist for most of the supracrustal belts in Norrbotten and the complex interaction of deformation phases, metamorphism and plutonism is still largely unknown. Vollmer *et al.* (1984), Wright (1988) and Talbot and Koyi (1995) interpret the Kiruna regional geology in terms of an easterly dipping and younging homoclinal sequence which has suffered an early cycle of westward directed thrust-nappe stacking, crustal shortening (>46 km) isoclinal folding and imbrication (Svecokarelian?). This is overprinted by peak ductile deformation and prograde metamorphism to upper greenschist or amphibolite facies within stress fields generated by sagging between rising diapiric granitoids during the ~1.84 Ga Svecofennian orogeny.

Deformation and strain is highly heterogeneous, and focussed along zones of competency contrast. Massive magnetite bodies in the Kiruna area have high strain zones focussed around their contacts. The sulphide bodies at Viscaria are elongate and plunging down possible low to high angled, thrust-shear structures, and the Malmberget magnetite-apatite bodies are sheared, refolded, highly strained, plunging shoot-like bodies, long recognised as recrystallised deposits.

Low and high angled ductile-brittle thrusting and shear is a significant feature of the tectonic development. Wright (1988) mapped late stage east-west trending, sub-vertical dextral shears, and NNW trending sinistral shears in the Kiruna area. Shear deformation can be demonstrated in the regional airborne magnetic data indicating a number of major NNE-SSW to north-south, and northwest-southeast ductile to brittle shear zones. Berthelsen and Marker (1986) define a major NNE-SSW structure (the Baltic-Bothnian Megashear) passing through east Norrbotten (Pajala) with sub-parallel branches to the west. Henkel (1991) notes this as the Bothnian-Seiland Fault Zone, and the main northwest trending structure as the Bothnian-Senja Fault Zone. Frietsch *et al.* (1990), Wikstrom *et al.* (1996) and Billström and Martinsson (2000) all refer to the major NNE, north-south and northwest trending structural lineaments, the northwest trending Luleå-Malmberget structural zone lying parallel and close to the buried edge of the Archaean craton (Fig. 5; Mellqvist *et al.*, 1999).

The supracrustal belts are preserved within and between extensive granitoids displaying early strain fabrics and later non-strained diapiric forms. These features defined at least three granite suites: the 1.89 to 1.86 Ga Haparanda-Jorn

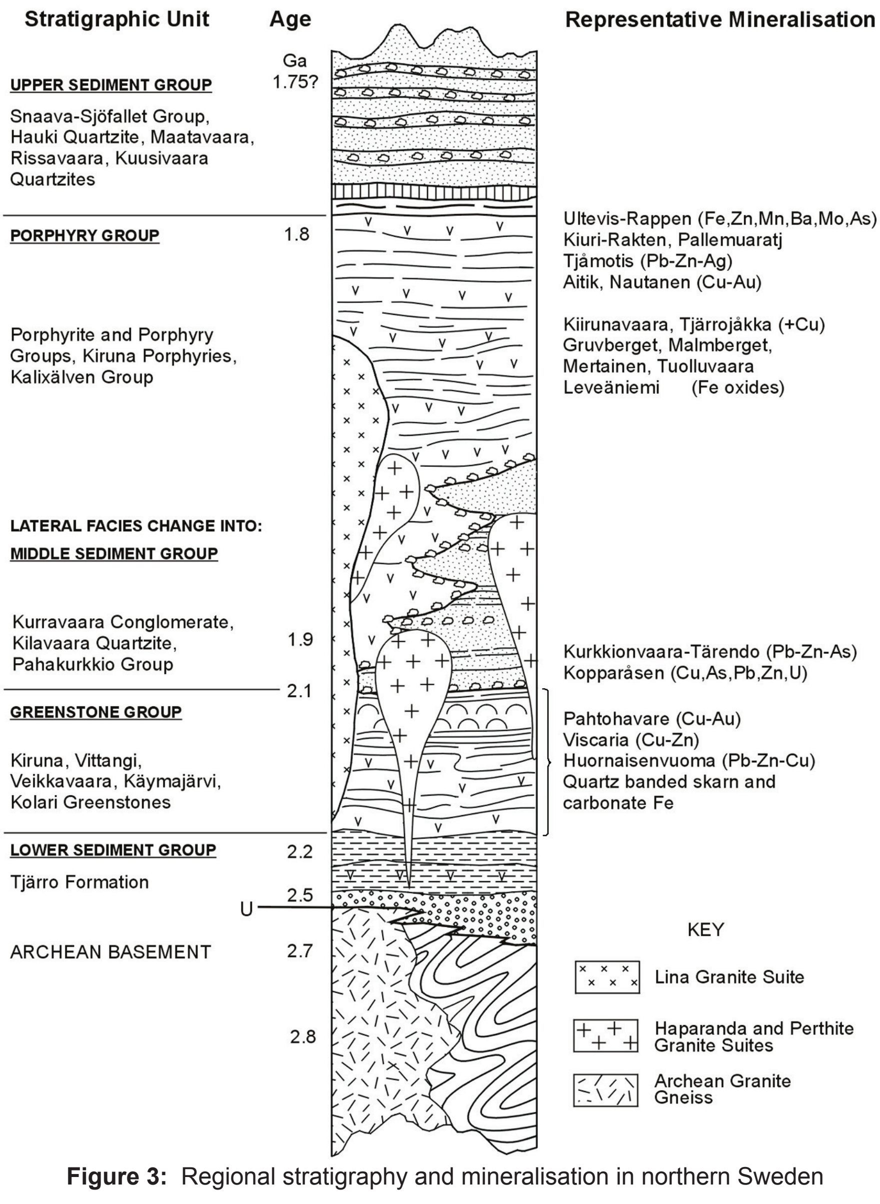

Figure 3: Regional stratigraphy and mineralisation in northern Sweden

differentiated granite-gabbro suite; the 1.86 to 1.82 Ga Perthite Granite Suite; and the 1.80 to 1.78 Ga Lina-TIB post-orogenic, monzonite-granite suite.

Talbot and Koyi (1995) present evidence for a two staged emplacement of the Haparanda-Perthite Granite suites; as syn-volcanic (Kiruna Porphyry), crustal melts (~1.90 to 1.86 Ga) and a later, post-thrusting, syn-orogenic, solid-state ductile event (~1.86 to 1.82 Ga) forming a series of mushroom shaped diapirs now exposed at different erosional levels. This process continued with the subsequent rise of the post-orogenic Lina Granites.

Iron Oxide Mineralisation

Iron oxides occur in northern Sweden in four main associations:

1. Banded, stratiform, siliceous, 'quartz-banded' iron oxide formations.
2. Calc-silicate 'skarn' and carbonate hosted, stratabound, iron oxides.
3. Concordant to discordant, massive, brecciated and vein style, magnetite-actinolite, magnetite-apatite and magnetite-haematite-apatite ores (the *'magnetite-apatite'* ores).
4. Disseminated, massive, vein and replacement iron oxides with silica and carbonate.

Quartz-banded, skarn and carbonate hosted iron formations are sheet-like to lensoid masses, generally parallel to the host rock banding or layering. The quartz-banded iron mineralisation occurs principally within the upper sequence of the Greenstone Group in Norrbotten, and in the Jokkmokk-Arjeplog region to the southwest, it is apparently higher in the sequence, near the top of the Porphyry Group (Figs. 3 and 4).

Quartz-banded, iron silicate - magnetite bearing quartzites and metacherts, are typically low in Mn (1 to 2%) and P (<0.1%). They often pass laterally and vertically into clean carbonate or actinolite-diopside-hornblende-chlorite-biotite, calc-silicate hosted, 'skarn iron ores'. These form lenses and layers, concordant with host marbles, dolomites and banded cherts, up to 1 to 2 km long, 10 to 100 m thick with 30 to 40% Fe. The reserve estimate is 500 Mt @ 36% Fe (Grip and Frietsch, 1973) with individual deposits ranging in size from 5 to 80 Mt. Stora Sahavaara (82 Mt @ 41% Fe) in the Pajala district, is the largest known deposit Fig. 4. Syn-sedimentary deposition of iron oxides across a wide spectrum of siliceous to carbonate environments and subsequent regional metamorphism appears to be the origin of this mineralisation. The Greenstone hosted skarn iron ores often contain minor pyrite, pyrrhotite and chalcopyrite, apatite and associated scapolite-diopside-biotite alteration possibly indicative of some hydrothermal input.

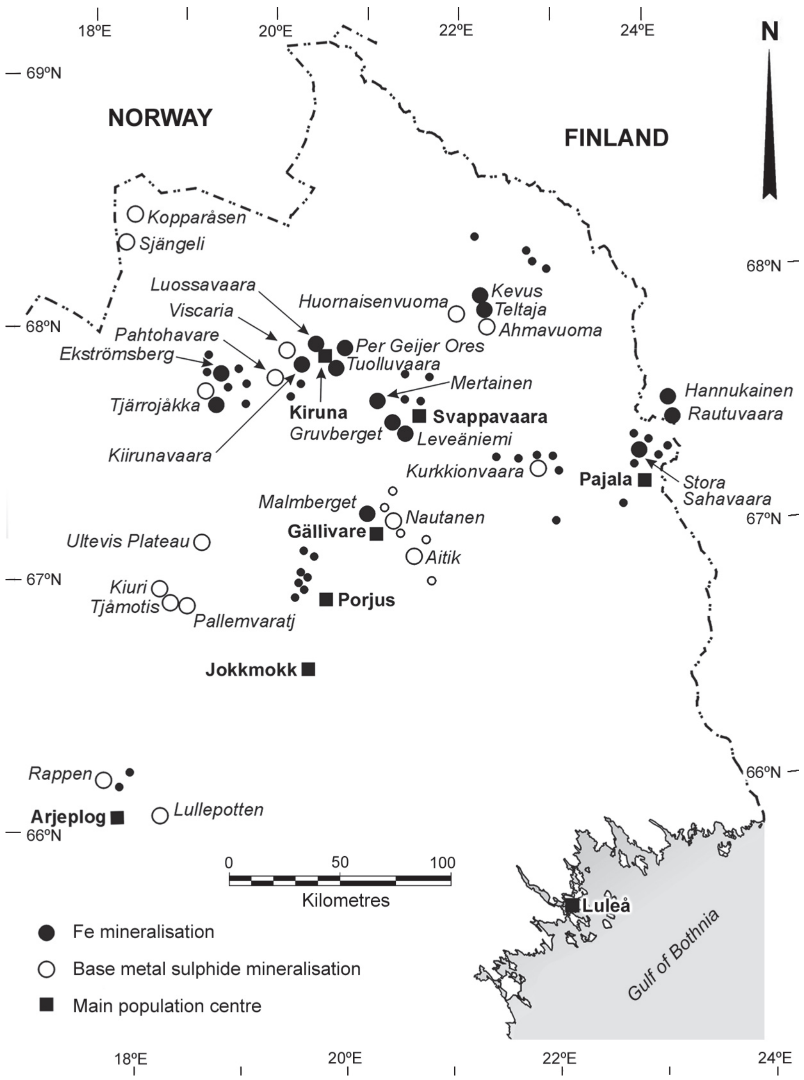

Figure 4: Deposit location plan, northern Sweden

Banded quartz-magnetite mineralisation occurs in the inferred upper stratigraphic sections of the Porphyry Group in the Arjeplog-Porjus district of southwest Norrbotten as a 40 km long, manganiferous (4 to 7% Mn) quartz banded iron formation, very similar in lithology and setting to the 'manganiferous iron formations' in the Bergslagen District, Central Sweden.

The "magnetite-apatite" or "Kiruna-type" iron ores, typified by the Kiirunavaara deposit, are magnetite-apatite, magnetite-actinolite and magnetite-haematite-apatite bodies. They are spatially and genetically associated with alkaline volcanic, sub-volcanic and intrusive rocks within the Porphyry Group. Around 35 to 40 discrete and clustered deposits are known in four main areas (Fig. 4), around Kiruna, W and SW of Kiruna, around Svappavaara, and in the Gällivare district.

Much has been written about their form and origin, particularly with regard to Kiirunavaara, notably by Blake (1992); Cliff and Rickard (1992); Cliff *et al.*(1990); Fleischer (1983); Frietsch (1978, 1984); Geijer (1915, 1930a, 1960); Geijer and Odman (1974); Gilmour (1985); Nystrom (1985); Nystrom and Henriquez (1989, 1994); O'Farrelly (1990); Parak (1975, 1984, 1988); Romer *et al.* (1994); Vollmer *et al.* (1984) and Wright (1986, 1988). Other magnetite-apatite deposits are noted by Frietsch (1997); Svappavaara (Frietsch, 1966; 1980a); Mertainen and Painirova (Lundberg and Smellie, 1979; Frietsch, 1980b); Ekstromsberg (Frietsch, 1974); Malmberget (Geiger, 1930b; Ljunggren, 1960).

These deposits contain varying proportions of magnetite, haematite, apatite and actinolite, displaying great variability in size and geometry. They form elongate, massive tabular bodies; magnetite-haematite, matrix supported, wall rock breccia bodies; actinolite and apatite veined magnetite-haematite breccias; and iron oxide-apatite-actinolite vein systems. Controversy surrounds the origin of these deposits, with genetic interpretations including 'magmatic segregation' and injection, extrusion, metasomatic replacement, hydrothermal deposition and replacement or syn-sedimentary surface exhalation.

The Kiirunavaara deposit (>2.0 Gt @ 60 to 62% Fe) is a 4 to 5 km long, 80 to 100 m wide and at least 2 km deep, tabular body dipping east within a structurally thickened sequence of the Porphyry Group. The orebody lies along the contact of massive, sodic (albitic), trachyandesitic lavas "syenite porphyry" in the structural footwall to the

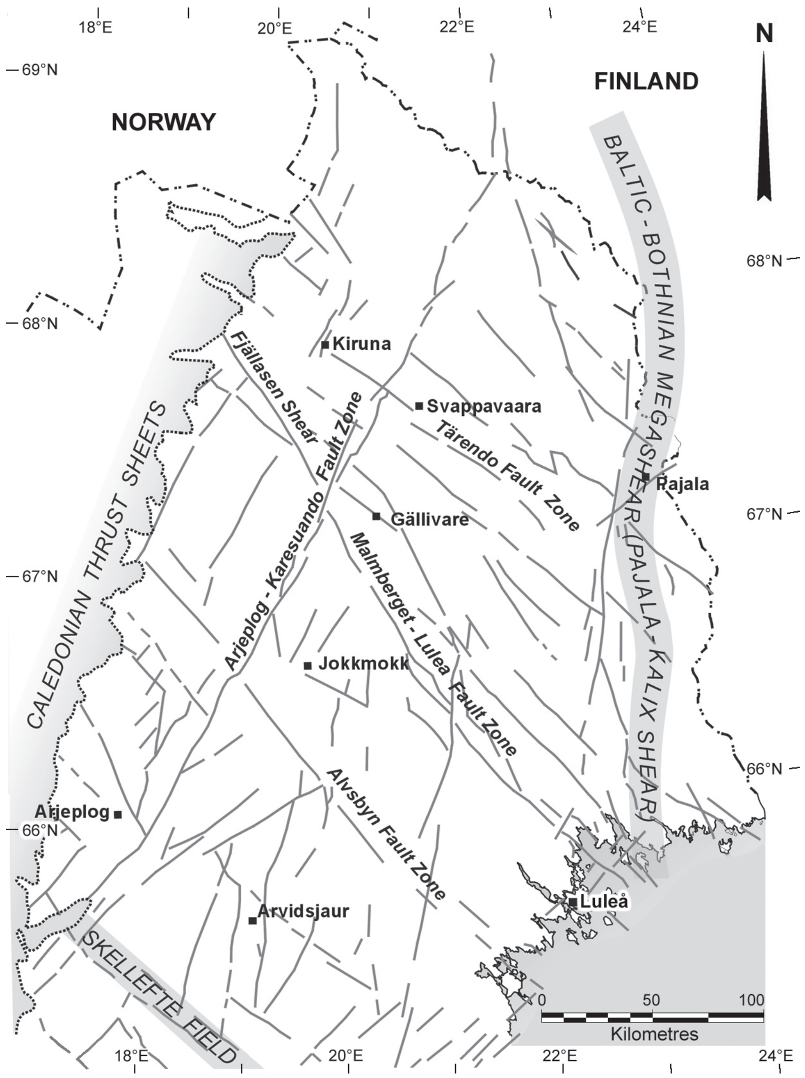

Figure 5: Principal regional structures of northern Sweden.

west, and porphyritic rhyolite, rhyodacitic pyroclastics and inferred rhyolite ash flows "quartz-porphyry" in the structural hangingwall to the east.

The Luossavaara deposit, sits in the same sequence of rocks as Kiirunavaara, while a parallel but separate tectonic-stratigraphic interval in the Kiirunavaara hangingwall sequence hosts the apatite rich and mixed magnetite-haematite 'Per Geiger' orebodies and the breccia-type deposit at Tuolluvaara. The Mertainen deposit 25 km southeast of Kiruna, sits at the northern end of a 7 km long, 3 km wide magnetic anomaly within andesites and trachytes of the Porphyry Group which also host the Leveaneimi, Gruvberget and Painirova deposits in the Svappavaara area nearby.

Mineralisation is typically magnetite with subordinate haematite, averaging 25 to 64% Fe, with apatite, tremolite-actinolite, biotite-chlorite, diopside and minor calcite. The ores are either massive fine grained almost apatite free magnetite, or banded fluorapatite averaging 1% P. The Kiirunavaara deposit contains an apatite poor ore cut by a later apatite rich magnetite. Ti content is <1%, usually present as titanite, and Mn and S contents are generally below 0.1%.

Deposits commonly exhibit remarkably low strain being resistive to penetrative fabrics, but heterogeneous ductile-brittle shearing and ductile deformation affects the contact zones of most deposits. The Malmberget deposit (930 Mt of 60 to 62% Fe), comprises 10 currently mined iron ore bodies sitting within an elongate east-west zone that is 5 km long and 2.5 km wide, containing around 20 discrete bodies. The host rocks (Geiger 1930b) comprise red and grey, alkalic, syenitic metavolcanites as at Kiruna. However, the Malmberget orebodies are highly deformed and 'stretched', refolded and rodded into a series of dismembered shoots with complex geometry. Pre-deformation dimensions of the ore zone appear to have been similar to Kiirunavaara (Fig. 6). Recrystallisation has increased the grain size of the iron oxides and apatite from 0.1 mm, as at Kiirunavaara, to ~0.7 mm. The 'layering' in the apatite-magnetite at Malmberget is a recrystallisation phenomena, and can be considered a 'gneissic texture' the magnetite clearly having 'flowed' as a solid-state ductile medium. The deposit has also suffered thermal metamorphism from an adjacent post-orogenic Lina Granite.

The contact zones of the magnetite-haematite-apatite-actinolite iron deposits are marked by veining, brecciation of the wallrocks, iron-oxide matrix supported breccias, host-rock xenoliths within the iron oxides, wall rock clast reaction rims and clast digestion and corrosion phenomena. Magnetite matrix supported, wall rock slab-clast and 'blow-apart' jigsaw clast breccias, suggest rapid decompression phenomena, while fine grain size and thin reaction rims indicate rapid deposition of iron oxides from a fluid medium. Brecciation often occurs in both hangingwall and footwall contact zones suggesting emplacement vertically rather than horizontally, and there is no silicate fusion in contact with iron oxides as would be expected with magmatic magnetite emplacement into a brittle fractured, solid metavolcanic host.

Age dating of the host rocks, cross-cutting altered granophyric dykes, and titaniferous magnetite veining at Luossavaara-Kiirunavaara deposit gives U-Pb dates of 1.88 to 1.89 Ga (Cliff *et al.*, 1990; Romer *et al.*, 1994). The magnetite-haematite-apatite-actinolite deposits formed coeval with the enclosing alkali metavolcanites and intrusives of the Porphyry Group from high temperature magmatic fluids (Blake, 1992) and pre-date the Svecokarelian and Svecofennian deformation and metamorphism. Cliff and Rickard (1992) have identified a later isotopic resetting event.

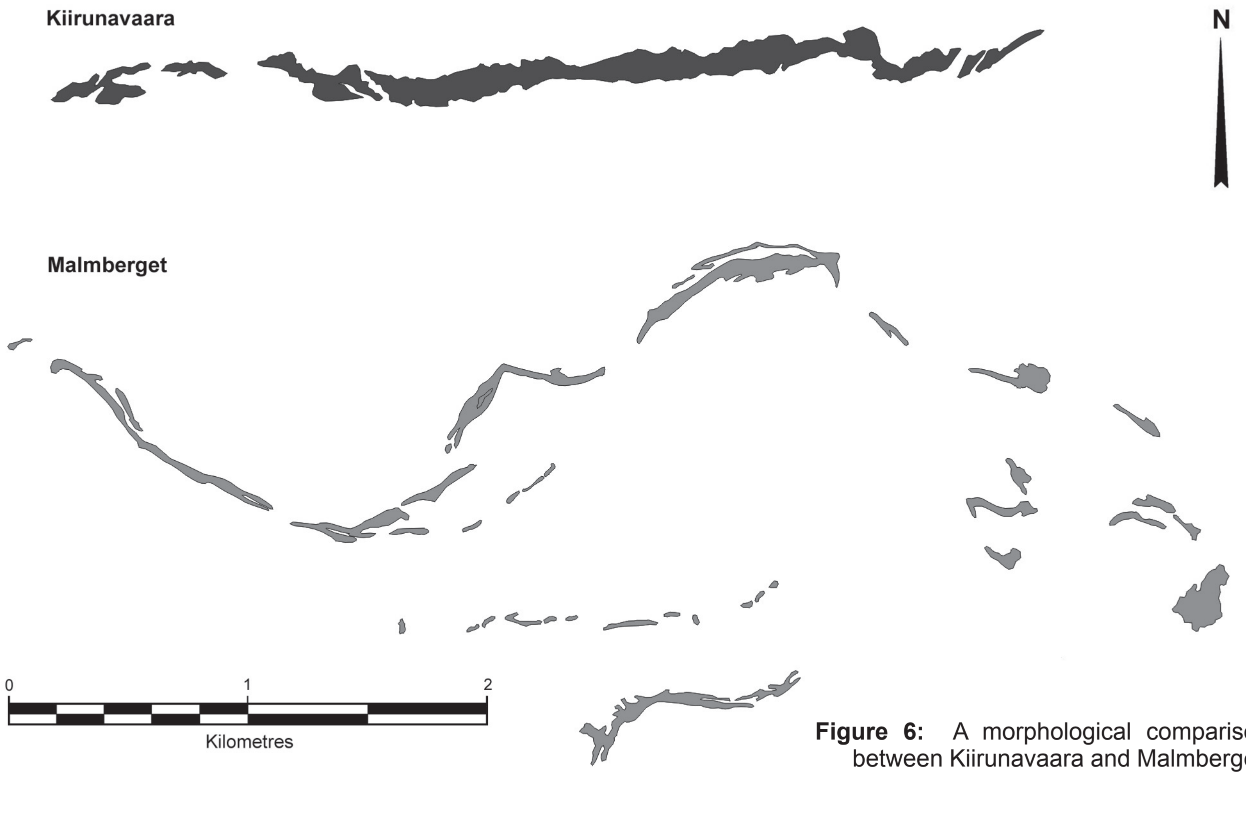

Figure 6: A morphological comparison between Kiirunavaara and Malmberget.

Frietsch (1997) and Frietsch at al (1997) note the occurrence of enigmatic 'epigenetic, metasomatic" and "magmatic-tectonic" iron mineralisation in the Kevus and Teltaja iron ores in the Lannavaara-Pajala region. In the Pahtohavare area southwest of Kiruna magnetite-silica and carbonate veining indicates a late stage, structurally controlled iron oxide mineralisation. These deposits are associated with characteristic alkali-silica alteration and copper-iron sulphides.

The only sulphides seen to be spatially associated with the main magnetite-haematite-apatite-actinolite deposits are minor, late stage, fracture fill pyrite and minor chalcopyrite.

Alteration Phenomena

There is a regional developed, multi-episodic, rock alteration in northern Sweden, characterised by scapolite and more locally developed actinolite, biotite, chlorite, albite, K feldspar, sericite, carbonate (ankerite-calcite), tourmaline, barite, allanite, and silica (Frietsch *et al.*, 1997). This alteration represents changes in bulk chemistry marked by increases in Na (albite and marialitic scapolite), K (microcline, sericite, biotite and chlorite) and Ca (calcite, dolomite and epidote).

Scapolite occurs as porphyroblasts, disseminations and layers along S_{0-1} (?), cuts schistosity, and forms multistage vein systems often parallel to fold axial planes. It selectively replaces plagioclase, and is invariably a Na-Cl marialite (Freitsch *et al.*, 1997). An origin by mobilisation of evaporites within the Greenstone Group (Frietsch at al. 1997) and fluids associated with felsic intrusives (Ödman 1957) have been advocated for the regional scapolite formation.

Host rock alteration around magnetite-haematite-apatite-actinolite iron deposits is characterised by actinolite and biotite around the magnetite dominant bodies (Kiirunavaara, Luossavaara, Svappavaara, Malmberget), and sericite, biotite-chlorite and carbonate alteration, with barite, fluorite, tourmaline calcite and apatite around magnetite and haematite rich deposits (Per Geiger Ores, Leveaneimi, Malmberget).

The iron ore bodies often exhibit a 'red-rock' alteration caused by reddened K feldspar, albite or silica containing fine dusted haematite, and is a common feature of Fe-oxide-Cu-Fe deposits (Pollard and Williams 1999). It is clearly a multi-episodic alteration, often cut by extensive magnetite-actinolite and actinolite magnetite veins, and later epidote. Epidote veins cut foliation marked by biotite-chlorite, and epidote sometimes replaces scapolite and feldspars, invariably cutting haematitic 'red-rock' alteration. Allanite is commonly associated with the epidote.

Silica and carbonate are usually late stage vein infills and are characteristically associated with base metals sulphides. Tourmaline distribution and origin is discussed by Freitsch *et al.* (1997).

Host rocks around the Norrbotten iron oxide bodies and certain sulphide deposits show patterns of Na, K, Si, Fe and Ca alteration in common with other "iron oxide Cu-Au" provinces around the world, (Pollard and Williams 1999) with an extreme 'metasomatic' end product of scapolite-biotite schist or albite-actinolite schist.

Sulphide Mineralisation

Northern Sweden contains a wide variety of known sulphide mineralisation, characterised by copper-iron sulphides and occasionally by sphalerite and galena. Recent reviews (Frietsch *et al.*, 1997; Martinsson, 2000; Martinsson and Weihed 1999) classify these occurrences in terms of syngenetic or epigenetic sulphides, and three broad types can be defined:

1. Inferred, 'syngenetic' or 'stratabound', iron sulphide rich, Cu deposits with subordinate Zn and Zn-Pb mineralisation in Greenstone Group metasediments.
2. Syngenetic-epigenetic Zn-Pb-Ag mineralisation in the Porphyry Group.
3. Epigenetic Cu-Au in the Upper Greenstones and Porphyry Groups within ductile-brittle fracture zones and sites of host rock brecciation, with or without massive magnetite, but usually accompanied by disseminated iron oxides.

Only three significant base metal occurrences have been mined in Norrbotten, at Viscaria (supposedly of type 1 above), and at Aitik and Pahtohavare (of type 3). There is growing evidence that many of the so called 'syngenetic' and stratabound ores are in fact epigenetic and related to hydrothermal deposition and replacement phenomena along high strain zones, previously unrecognised low angle thrusts and apparently 'bed-parallel' (S_{0-1}) shears.

'Syngenetic' and 'Stratabound' Sulphide Deposits

A number of stratiform quartz banded iron horizons and reaction calc-silicate magnetite-hematite layers ('skarn iron ores') in the Greenstone Group have associated pyrite-pyrrhotite-chalcopyrite mineralisation, notably at Tervaskoski in the Vittangi district, with 0.3% Cu and associated scapolite and tourmaline (Frietsch 1997). The only known economic sulphide occurrence in the Greenstone Group, apparently in the footwall sequence of the Kiirunnavaara magnetite-apatite deposit, is the 'synsedimentary' or early diagenetic, Viscaria Cu-Zn deposit (Godin, 1986; Martinsson, 1991, 1992, 2000). The Viscaria mine produced around 13 Mt of 2.29% Cu from a mineralised envelope and narrow zones containing 40 Mt of 1.5% Cu and 0.7% Zn. The principal A-zone was 3 km long, northeast-southwest-trending and up to 30 m thick. It was known to a depth of 700 m dipping at 80^{o}E, decreasing at depth to 45 to 50^{o} and taking the form of a curved 'listric' structure.

The mineralisation is hosted by a marble-black schist-chert-tuffite sequence with albite rich rocks, scapolite and K alteration. Pyrrhotite with chalcopyrite and minor sphalerite, galena and barite occurs as fracture fillings, veins, disseminations, carbonate replacements, laminations, apparent rhythmic banding and slumping, and massive remobilised sulphides. Magnetite is common as massive lenses and laminae in tuffites, and disseminations and laminae in calcite marbles. The ore zones contain enrichments in P, LREE's, Mn, Ba, Co and U.

Martinsson (1991, 1992) notes a large alteration zone in the footwall of the main A zone, marked by the formation of K-phyllosilicates from the breakdown of Na-plagioclase, considered a typical footwall alteration under a syngenetic exhalative deposit. However the deposit displays carbonate host rock replacement, is variably strained, ductile deformed, cut by the imbricate thrust package of the Kiruna belt (Talbot and Koyi, 1995) and partially remobilised. Banding, and possible 'slumping' seen in the deposit is similar to that occurring in the Fe oxide-Cu-Au manto mineralisation at Punta del Cobre Chile, and could be replacive rather than synsedimentary. If syn-sedimentary, the deposit has clearly been affected by a later tectonic and hydrothermally induced remobilisation. Fluid inclusion data (Martinsson, 1991, 1997) indicates mineralisation from high salinity fluids at ~210°C. Scapolite occurring in the deposit (Freitsch *et al.*, 1997) has the same characteristic chemistry (dipyre with 1.5% CO_2 and 2.9% Cl) as scapolite in the nearby epigenetic Pahtohavare Cu-Au deposit.

At Kurkkionvaara (Niiniskorpi 1986), pyritic schists, cherts and tourmalinites of the Pahakurkkio Group (Fig. 3), broadly comparable with the Viscaria sequence, contain pyrrhotite, galena, sphalerite and arsenopyrite. Mineralisation appears to be synsedimentary and stratabound, as veinlets and disseminations, and is known at other sites in eastern Norrbotten.

At Huornaisenvuoma (Frietsch 1997; Billstrom *et al.*, 1997) a steeply dipping, apparently stratiform Pb-Zn-Cu-Ag mineralisation, with magnetite and spatially associated pyrite-pyrrhotite lies within scapolite altered, calc-silicate 'skarn' rich dolomite, mafic metatuffites and intermediate volcanics within the Greenstone Group. Pb isotopic composition (Billstrom *et al.*, 1997) indicates a model age of ~2.0 Ga, and a potentially syn-sedimentary original deposit. The mineralisation is structurally remobilised, and the main massive sulphide lens is a sheared, recrystallised, clastic textured, sulphide-wallrock mylonite breccia.

At Kopparåsen (Adamek, 1975; Romer and Boundy 1988, Frietsch *et al.*, 1997) massive and disseminated pyrite, pyrrhotite, chalcopyrite, bornite, arsenopyrite, uraninite, magnetite, galena and sphalerite, occur within tourmaline and scapolite bearing mafic metavolcanites, epiclastics, graphitic mica-schists and albite-cherts. Mineralisation is within inferred upper Greenstone-Lower Porphyry Group stratigraphy in a 1.8 km wide, 9.7 km long supracrustal belt striking north-south. Lead model ages (Romer and Boundy, 1988) indicate an early mineralisation remobilised by later Caledonian activity. The uranium mineralisation is epigenetic and superimposed on strongly sheared and mylonitic sulphide bearing host rocks which contain gold.

The Arjeplog manganiferous quartz-magnetite sequence, in a variable sedimentary facies of chemical sediments, epiclastics and carbonate units at the inferred top of the Porphyry Group, passes NNE into carbonates and manganiferous 'exhalite' mineralisation on the Ultevis plateau near Tjåmotis and around Porjus, (Ödman, 1947, 1950; Carlon, 1984). This mineralisation is probably syngenetic and contains up to 46% Mn, 27% Fe, and elevated apatite, barite, zinc, lead, silver, arsenic, fluorine, tungsten, molybdenum and boron. The area also contains Pb-Zn-Ag mineralisation (Carlon, 1984) of type 3, possibly representing inferred syngenetic sulphides, remobilised within or adjacent to high strain zones and in part epigenetic.

Epigenetic Cu-Au and Pb-Zn (Ag) Deposits

Vein and replacement styles of base metal mineralisation occur within ductile-brittle deformation zones and host rock breccia bodies, with or without massive magnetite, but usually accompanied by disseminated iron oxides. Billström and Martinsson (2000) note that initial investigation of U-Pb isotopic age dates from titanite within sulphide mineralisation suggests two major age groups at 1.88 to 1.86 Ga and 1.80 to 1.75 Ga, the latter typical of epigenetic sulphides within major structures (Aitik) and massive magnetite bodies (Gruvberget). These ages are broadly comparable with the intrusion of the Haparanda Granite Suite and the Lina Granite. Broman and Martinsson (2000) define a systematic change in fluid chemistry and temperature with time within the sulphides.

Rheological contrasts between massive magnetite and enclosing host rocks have created brittle fracture zones, and some magnetite bodies host minor copper-iron sulphides in contact breccia bodies and peripheral wallrocks. Mineralisation of this type occurs with the Gruvberget and Tjärrojåkka magnetite deposits, and at Rautuvaara in Finland (Fig. 5).

Copper ore was discovered and mined at Gruvberget in the late 1600's. Mineralisation as veinlets and schlieren, cuts trachytic to basaltic volcanics of the Porphyry Group in the contact zone of a magnetite-apatite body. The contact rocks are hydrothermally altered with scapolite, tremolite-actinolite, and late stage microcline, epidote, calcite and quartz with low grade copper sulphides, copper carbonates, rare pyrite, arsenopyrite, erythrite, molybdenite, gold (0.8g/t) and native Cu.

At Tjärrojåkka, 13 Mt of 0.43% Cu mineralisation lies 400 m WNW of a 53 Mt 51.5% Fe magnetite-apatite deposit within Porphyry Group metavolcanics and metasediments (LKAB open file data). Wallrock-magnetite contact breccia zones are altered by albite, scapolite, actinolite, biotite, K spar, sericite and mineralised with veinlet bornite and chalcopyrite, REE's, and elevated Ba, Mo and Au.

The Rautuvaara and Hannukainen magnetite deposits in Finland (Hiltunen 1982, 1997), contain disseminated and schlieren copper-iron sulphides within magnetite bodies and associated calc-silicate host rocks adjacent to a Haparanda suite (1.89 to 1.87 Ga) foliated monzonitic intrusion.

Where massive magnetite-apatite bodies and breccias are mineralised, copper sulphides are invariably within cross cutting veins and fracture infills of limited extent. At Ahmavuoma (Fig. 4), Cu-Co with disseminated and vein magnetite mineralisation occurs within a pipe-like breccia body in biotite-scapolite-microcline altered andesite metavolcanics. However, the two principal known epigenetic sulphide deposits in Norrbotten form two distinct ore types as vein, disseminated, schlieren and replacement Cu-Au in altered Greenstones at Pahtohavare, and within a major ductile-brittle shear zone in highly strained supracrustals and intrusives at Aitik.

At Pahtohavare (Carlson 1991; Lindblom *et al.*, 1996; Martinsson 1991,1992, 1997) 10 km southwest of Kiirunavaara, three small Cu-Au deposits are hosted by fine grained albite rocks, tuffites, black graphitic schists, thin banded iron formations and mafic sills. The original reserve estimate in 1989 was 5.4 Mt @ 2.18% Cu, and 1.28 g/t Au (Carlson 1991) from which two ore lenses were mined to produce 1.68 Mt of 1.89% Cu, 0.88 g/t Au.

Pyrite, chalcopyrite, pyrrhotite and minor ZnS, PbS, MoS_2, cobaltite, native gold and telluro-bismuthinite minerals form veins, impregnations and breccia fillings with quartz, calcite, ankerite, ferroan-dolomite and mariolitic scapolite. Mineralisation is associated with areas of intense albitisation, surrounded by barren biotite-scapolite rocks. Graphite horizons and schist units are completely replaced in the ore zones and the mineralisation is accompanied by coarse grained ferroan dolomite veins and disseminations within albite felsites.

Mineralisation was emplaced upon a complex, northwest-southeast axial trending, easterly plunging, isoclinally folded antiform, cut by northeast-southwest faults and breccia zones. The structure is also cut by WNW-ESE dextral wrench faults, shears and crush zones. Fluid inclusions (Lindblom *et al.*, 1996) indicate early formation of quartz and pyrite at 500°C and 2 to 2.4 Kbars from a supersaturated solution of magmatic origin and deposition by mixing of solutions at temperatures below 350°C and 1 to 2 Kbars deposits along tectonic fractures, buffered by graphite.

The deposit contains at least two phases of magnetite, with early, isoclinally folded, banded iron formation, veined and cut by magnetite and copper-iron sulphides, the latter partly emplaced down the bedding foliation. There are at least two phases of scapolite, one porphyroblastic along the S_{0-1} banding and a second cross cutting along isoclinal axial planar foliations. Mineralisation shows strong similarities with Viscaria and the non-auriferous, Eastern ore at Pahtohavare was considered to be of Viscaria-type (Martinsson 1997). The deposit is very similar to Bidjovagge (Bjørlykke *et al.*, 1987), and other greenstone hosted deposits in northern Scandinavia suggesting a common origin.

The Aitik deposit (Danielsson and Lindroos, 1986; Monroe, 1988; Wanhainen *et al.*, 1999; Wanhainen and Martinsson, 2000; Zweifel, 1972, 1976, 1980), is a low grade Cu-Au resource of over 800 Mt of 0.3% Cu, 0.2 g/t Au, 2 g/t Ag (with a 0.22% Cu cut off). In 1999 the mine produced 61 800 t Cu from 18 Mt of raised ore (0.34% Cu). The mineralised zone is 3 km long, 400 m wide forming an envelope around higher grade ore 2 km long and up to 200 m wide, which has been drill indicated to 600 m. The ore contains disseminated and stringer chalcopyrite, exhibits multiple brittle-ductile deformation with sheared sigmoidal quartz-sulphide veinlets, pyrite, pyrrhotite, molybdenite, bornite, sphalerite, galena, arsenopyrite and 3% magnetite.

Host rocks are muscovite-biotite-quartz schist and gneiss, with a biotite, scapolite, tourmaline, epidote, K feldspar, late sericite/muscovite alteration, intruded by a monzo-dioritic body. Mineralisation has been interpreted as a strongly sheared, structurally extended and deformed porphyry copper type.

Aitik sits within a 5 km wide and 40 km long, multistage ductile-brittle deformation/supracrustal zone, trending NNW-SSE to north-south, (Nautanen-Aitik- Jårbojoki Shear Zone). This hosts over 50 known Cu-Au occurrences including the magnetite rich Nautanen deposit (Danielsson and Lindroos, 1986; Geijer, 1918), 13 km north of Aitik and northeast of Gällivare. With proven reserves of 0.8 Mt of 2.36% Cu, 1.3 g/t Au, 13 g/t Ag the Nautanen mineralisation comprises magnetite, chalcopyrite, and Co pyrite with minor molybdenite, sphalerite, galena, silver tellurides, Au and Bi. Host rocks are garnet-magnetite calc-silicate and biotite-microcline gneisses with extensive scapolite, fluor-apatite, tourmaline and elevated Ba and Mn.

Conclusions

The spatial association of characteristic Na, K and Ca alteration, major iron mineralisation and copper-iron sulphides in northern Sweden indicates a potential genetic link. The detail of this association is still unclear but a number of points can be made in conclusion:

Iron mineralisation is present in at least three temporally distinct forms; early banded iron formations, magnetite-apatite bodies, and later magnetite-sulphide veining. The banded iron formations and magnetite apatite bodies formed in the 2.1 to 1.88 Ga interval and suffered 1.9 to 1.8 Ga brittle-ductile deformation in the Svecofennian orogeny. There may have been an early apatite poor and later apatite rich mineralisation.

Early scapolite, albite, tourmaline, and red-rock alteration is cut by iron oxide-apatite mineralisation, in turn overprinted by later scapolite, K feldspar, and epidote-carbonate alteration.

Cu-Au mineralisation cuts iron formations and magnetite-apatite bodies, is focussed by ductile-brittle fracture zones and is partly associated with a later magnetite-silica-carbonate mineralisation. Initial U-Pb dating indicates two main Cu-Au mineralising events corresponding to plutonic, hydrothermal and tectonic activity associated with the emplacement of the Perthite-Monzonite and Lina granite suites between 1.88 to 1.75 Ga.

During cycles of ductile and brittle deformation, magma generation and post orogenic collapse, large volumes of fluid may have been periodically generated. Magmatic intrusives and hydrothermal fluids are likely to have been channelled by principal structures and focussed by structural intersections, particularly by zones of rheological contrast adjacent to magnetite bodies.

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References

Adamek, P.M., 1975 - Geology and mineralogy of the Kopparåsen uraninite-sulphide mineralisation, Norrbotten County, Sweden; *Sveriges Geologiska Undersokning*, Series C. No.712, 69p.

Berthelsen, A. and Marker, M., 1986 - 1.9-1.8 Ga old strike-slip megashears in the Baltic Shield, and their plate tectonic implications; *in* Galson, D.A. and St. Mueller (eds.), The European Geotraverse, Part 2, *Tectonophysics, 128 163-181.*

Billstrom, K., Freitsch, R. and Perdahl, J-A., 1997 - Regional variations in the Pb isotopic compositions of ore galena across the Archean-Proterozoic border in northern Sweden; *Precambrian Research*, v. 81, pp. 83-99.

Billstrom, K. and Martinsson, O., 2000 - Links between epigenetic Cu-Au mineralisation and magmatism/ deformation in the Norrbotten county, Sweden; *in* Weihed, P and Martinsson, O., (eds.), Abstract volume and Field trip guidebook, 2nd annual GEODE-Fennoscandian shield field workshop on Palaeoproterozoic and Archean greenstone belts and VMS districts in the Fennoscandian Shield 28 August to 1 September, 2000, Gallivare-Kiruna, Sweden, *Luleå University of Technology*, Research Report 2000:6.

Blake, K.L., 1992 - The petrology, geochemistry and association to ore formation of the host rocks of the Kirunavaara magnetite-apatite deposit, northern Sweden; Unpublished PhD. thesis, *University of Wales, Cardiff ,UK.*

Bjørlykke, A., Hagen, R. and Söderholm, K., 1987 - Bidjovagge copper-gold deposit in Finnmark, N. Norway; *Economic Geology*, v. 82, pp. 2059-2075.

Broman, C. and Martinsson, O., 2000 - Fluid inclusions in epigenetic Fe-Cu-Au ores in northern Norrbotten; *in* Weihed, P and Martinsson, O., (eds.), Abstract volume and Field trip guidebook, 2nd annual GEODE-Fennoscandian shield field workshop on Palaeoproterozoic and Archean greenstone belts and VMS districts in the Fennoscandian Shield 28 August to 1 September, 2000, Gallivare-Kiruna, Sweden, *Luleå University of Technology*, Research Report 2000:6.

Carlon, C.J., 1984 - The BP-LKAB-Jokkmokk Mineral Joint Venture, Tjamotis, Jokkmokk, Swedish Lappland; *LKAB*, Report No. Bsg 84-372, p. 73 *(Open File Report).*

Carlson, L., 1991 - The Pahtohavare copper-gold prospect; *Geologiska Foreningenr i Stockholm Forhandlingar*, v. 113, pp. 45-46.

Cliff, R.A., Rickard, D and Blake, K., 1990 - Isotope systematics of the Kiruna magnetite ores, Sweden: Part 1. the age of the ore; *Economic Geology*, v. 85, pp. 1770-1776.

Cliff, R.A. and Rickard, D., 1992 - Isotope systematics of the Kiruna magnetite ores, Sweden: Part 2. Evidence for a secondary event 400 m.y. after ore formation; *Economic Geology*, v. 87, pp. 1121-1129.

Danielsson, S. and Lindroos, H., 1986 - Aitik and Nautanen copper-gold deposits; *in* Lindross and Sundblad (eds.), Proterozoic Mineralisation in Northern Sweden, *7th IAGOD Symposium*, Excursion Guide No.6, pp. 12-16.

Ekdahl, E., 1993 – Early Proterozoic Karelian and Svecofennian formations and the evolution of the Raahe-Ladoga ore zone, based on the Pielavesi area, central Finland; *Geological Survey of Finland,* Bulletin 373.

Fleischer, M., 1983 - Distribution of lanthanides and yttrium in apatites and iron ores, and its bearing on the genesis of ores of the Kiruna type; *Economic Geology*, v. 78, pp. 1007-1011.

Frietsch, R., 1966 - Berggrund och malmer i Svappavaarafältet, norre Sverige; *Sveriges Geologiska Undersökning*, Series C, No.760, p. 282.

Frietsch, R., 1974 - The Ekstromberg iron ore deposit, Northern Sweden; *Sveriges Geologiska Undersökning*, Series C, No.708, p. 52.

Frietsch, R., 1978 - On the magmatic origin of iron ores of the Kiruna type. *Economic Geology*, v. 73, pp. 478-485.

Frietsch, R., 1980a - Geology and ores of the Svappavaara area; *in* Frietsch, R., (ed.), Precambrian Ores of the Northern Part of Norrbotten County, Northern Sweden, Guide to excursions 078 A+C Part 1 (Sweden), *26th International Geological Congress, Paris*, pp. 20-25.

Frietsch, R., 1980b - Mertainen iron ore; *in* Frietsch, R., (ed.), Precambrian Ores of the Northern Part of Norrbotten County, Northern Sweden, Guide to excursions 078 A+C Part 1 (Sweden), *26th International Geological Congress, Paris*, pp. 27-28.

Frietsch, R., 1984 - On the magmatic origin of iron ores of the Kiruna type - A reply; *Economic Geology*, v. 79, 1949-1951.

Frietsch, R., 1997 - The iron ore inventory programme 1963-1972 in Norrbotten County; *Sveriges Geologiska Undersökning Rapporter*, och Meddelanden nr. 92.

Frietsch, R., Billstrom, K. and Perdahl, J-A., 1995 - Sulphur in Lower Proterozoic iron and sulphide ores in Northern Norrbotten; *Mineralium Deposita*, v. 30, pp. 275-284.

Frietsch, R. and Perdahl, J-A., 1989 - Geochemical Features of Early Proterozoic volcanites in the Aitik sulphide ore and some other sulphide and iron ores in Norrbotten, northern Sweden; STU Project 84-5039, *Luleå Technical University*, Research Report 1989:25.

Frietsch, R., Tuisku, P., Martinsson, O. and Perdahl, J-A., 1997 - Early Proterozoic Cu-(Au) and Fe ore deposits associated with regional Na-Cl metasomatism in northern Fennoscandia; *Ore Geology Reviews*, v. 12, pp. 1-34.

Geijer, P., 1915 - Some problems in iron ore geology in Sweden and America; *Economic Geology*, v. 10, pp. 299-329.

Geijer, P., 1918 - Nautanen omradet. En malmgeologisk undersökning; *Sveriges Geologiska Undersökning*, Series C. No. 283, 104p.

Geijer, P., 1930a - The iron ores of the Kiruna type; *Sveriges Geologiska Undersökning*, Series C. No.367. Arsbok 24, No.4 pp. 1-39.

Geijer, P., 1930b - Gällivare malmfält (Geology of the Gallivare orefield); *Sveriges Geologiska Undersökning*, Series Ca No.22, 115p.

Geijer, P., 1960 - The Kiruna Ores; *in* Guide to Excursion Nos A27 and C22, 21st International Geological Congress, Norden, *Sveriges Geologiska Undersökning*, pp. 24-38.

Geijer, P. and Ödman, O.H., 1974 - The emplacement of the Kiruna ores and related deposits; *Sveriges Geologiska Undersökning*, Series C, No.700, 48p.

Gilmour, P., 1985 - On the magmatic origin of iron ores of the Kiruna type - A further discussion; *Economic Geology*, v. 80, pp. 1753-1757.

Godin, L., 1986 - The Viscaria copper ore, Kiruna; *in* Lindroos, H. and Sundblad, K., (eds.), Proterozoic Mineralizations in Northern Sweden: complementary guidebook to IAGOD excursion No. 6, *Sveriges Geologiska Undersökning*, Unpublished report BRAP 86011, pp. 9-11.

Gorbatshev, R and Bogdanova, S., 1993 - Frontiers in the Baltic Shield; *Precambrian Research*, v. 64, pp. 3-21.

Grip, E. and Frietsch, R., 1973 - Malm i Sverige. 2 Norra Sverige; *Almqvist and Wiksell Läromedel, Stockholm*, 295p.

Henkel, H., 1991 - Magnetic crustal structures in northern Fennoscandia; *Tectonophysics*, v. 19, pp. 57-79.

Hiltunen, A., 1982 - The Precambrian geology and skarn iron ores of the Rautuvaara area, northern Finland; *Geological Survey of Finland*, Bulletin 318, 133p.

Hiltunen, A., 1997 - The skarn iron ores of the Rautuvaara area, northern Finland; 4th Biennial SGA Meeting, Turku, Finland, August 1997, *Geological Survey of Finland*, Guidebook 43, pp. 17-19.

Lindblom, S., Broman, C. and Martinsson, O., 1996 - Magmatic hydrothermal fluids in the Pahtohavare Cu-Au deposit in Greenstone at Kiruna, Sweden; *Mineralium Deposita*, v. 31, pp. 307-318.

Lundberg, B. and Smellie, J.A.T., 1979 - Painirova and Mertainen iron ores: two deposits of Kiruna iron ore type in northern Sweden; *Economic Geology*, v. 74, pp. 1131-1152.

Ljunggren, S., 1960 - Geology of the Gallivare iron ore field; *in* Guide to Excursion Nos A27 and C22, 21st International Geological Congress, Norden, *Sveriges Geologiska Undersökning*, pp. 39-45.

Martinsson, O., 1991 - Geological and geochemical evidence for the genesis of the Viscaria Cu deposit, northern Sweden; *in* Ohlander, B. and Frietsch, R., (eds.), New Ore Types in Northern Fennoscandia, *Geologiska Foreningenr i Stockholm Forhandlingar*, v. 113, pp. 58-59.

Martinsson, O., 1992 - Greenstone hosted Cu-Au ores. The Viscaria and Pahtohavare sulphide deposits and the stratigraphy of the Kiruna greenstones; *NUTEK Project,* Report 89-05116P, 79p.

Martinsson, O., 1997 - Tectonic setting and metallogeny of the Kiruna Greenstones; Unpublished Ph.D thesis, *Luleå Technical University, Luleå, Sweden*, 97p.

Martinsson, O., 2000 - Metallogeny of the northern Norrbotten Fe-Cu-Au ore province; *in* Weihed, P and Martinsson, O., (eds.), Abstract volume and Field trip guidebook, 2nd annual GEODE-Fennoscandian shield field workshop on Palaeoproterozoic and Archean greenstone belts and VMS districts in the Fennoscandian Shield 28 August to 1 September, 2000, Gallivare-Kiruna, Sweden, *Luleå University of Technology*, Research Report 2000:6.

Martinsson, O. and Weihed, P., 1999 - Metallogeny of juvenile Palaeoproterozoic volcanic arcs and greenstone belts in rifted Archean crust in the northern part of Sweden, Fennoscandian Shield; *in* Stanley *et al.* (eds.), Mineral Deposits: Processes to Processing, *Balkema, Rotterdam*, pp. 1329-1332.

Mellqvist, C., Ohlander, B., Skiold, T. and Wikstrom, A., 1999 - The Archean-Proterozoic Palaeoboundary in the Lulea area, northern Sweden: field and isotope geochemical evidence for a sharp terrane boundary; *Precambrian Research*, v. 96, pp. 225-243.

Monroe, D., 1988 - The geology and genesis of the Aitik Cu-Au deposit, Arctic Sweden; Unpublished PhD thesis, *University of Wales, College of Cardiff*, 386p.

Niiniskorpi, V., 1986 - Kurkkionvaara. En Zn-Pb-Cu-mineralisering i norra Sverige, en case-studie; Unpublished Fil. Lic. thesis, *Åbo University, Finland.*

Nironen, M., 1997 - The Svecofennian Orogen: a tectonic model; *Precambrian Research*, v. 86, pp. 21-44.

Nystrom, J.O., 1985 - Apatite iron ores of the Kiruna Field, Northern Sweden: Magmatic textures and carbonatitic affinity; *Geologiska Foreningenr i Stockholm Forhandlingar*, v. 107, pp. 133-141.

Nystrom, J.O. and Henriquez, F., 1989 - Dendritic magnetite and miniature diapir-like concentrations of apatite: two magmatic features of the Kiirunavaara iron ore; *Geologiska Foreningenr i Stockholm Forhandlingar*, v. 111, pp. 53-64.

Nystrom, J.O. and Henriquez, F., 1994 - Magmatic features of iron ores of the Kiruna type in Chile and Sweden: Ore textures and magnetite geochemistry; *Economic Geology*, v. 89, pp. 820-839.

Ödman, O.H., 1947 – Manganese mineralisation in the Ultevis District, Jokkmokk, Northern Sweden. Part 1: Geology; *Sveriges Geologiska Undersökning*, Arsbok 41, No.6, Series C. No.487.

Ödman, O.H., 1950 - Manganese mineralisation in the Ultevis District, Jokkmokk, Northern Sweden. Part 2: Mineralogical Notes; *Sveriges Geologiska Undersökning*, Arsbok 44, No.2, Series C. No.516.

O'Farrelly, K.S., 1990 - A stable isotope investigation of the origin and evolution of the Kiirunavaara iron mine, northern Sweden; Unpublished PhD thesis, *University of Wales, College of Cardiff*, 391p.

Parak, T., 1975 - Kiruna iron ores are not 'intrusive magmatic ores of the Kiruna type'; *Economic Geology*, v. 70, pp. 1242-1258.

Parak, T., 1984 - On the magmatic origin of iron ores of the Kiruna type - a discussion; *Economic Geology*, v. 79, pp. 1945-1949.

Parak, T., 1988 - How the classical intrusive related ores were re-interpreted (re-examined) and became exhalative -sedimentary - A process exemplified by the Kiruna-type ores; *Geological Society America*, Abstracts with Programs, v. 20, p. 20.

Pharoah, T.C. and Pearce, J.A., 1984 - Geochemical evidence for the geotectonic setting of early Proterozoic metavolcanic sequences in Lapland; *Precambrian Research*, v. 25, pp. 283-308.

Pollard, P.J. and Williams, P.J., 1999 - Short course on Fe-oxide-copper-gold deposits (The Candelaria-Ernest Henry-Olympic Dam family); Imperial College and Natural History Museum, London, 21 August 1999, *James Cook University EGRU, SGA and IAGOD*, short course notes 132 p.

Romer, R.L. and Boundy, T.M., 1988 - Interpretation of lead isotope data from the uraniferous Cu-Fe-sulphide mineralisation in the Proterozoic greenstone belt at Kopparåsen, northern Sweden; *Mineralium Deposita*, v. 23, pp. 256-261.

Romer, R.L., Martinsson, O. and Perdahl, J-A., 1994 - Geochronology of the Kiruna iron ores and hydrothermal alterations; *Economic Geology*, v. 89, pp. 1249-1261.

Skiöld, T., 1986 - On the age of the Kiruna Greenstones, northern Sweden; *Precambrian Research*, v. 32, pp. 35-44.

Skiöld, T., 1987 - Aspects of the Proterozoic geochronology of northern Sweden; *Precambrian Research*, v. 35, pp. 161-167.

Skiöld, T. and Cliff, R.A., 1984 - Sm-Nd and U-Pb dating of Early Proterozoic mafic-felsic volcanism in northernmost Sweden; *Precambrian Research*, v. 26, pp. 1-13.

Skiöld, T., Öhlander, B., Markkula, H., Widenfalk, L. and Claesson, L-Å., 1993 - Chronology of Proterozoic orogenic processes at the Archean continental margin in northern Sweden; *Precambrian Research*, v. 64, pp. 225-238.

Talbot, C.J. and Koyi, H., 1995 - Palaeoproterozoic intraplating exposed by resultant gravity overturn near Kiruna, northern Sweden; *Precambrian Research*, v. 72, pp. 199-225.

Vollmer, F.W., Wright, S.F. and Hudleston, P.J., 1984 - Early deformation in the Svecokarelian greenstone belt of the Kiruna iron district, northern Sweden; *Geologiska Foreningenr i Stockholm Forhandlingar*, v. 106, pp. 109-118.

Wanhainen, C., Martinsson, O. and Kontturi, M., 1999 - The Aitik Cu-Au Deposit, Gällivare area, Northern Sweden; *Proceedings, Gold 99, Trondheim, May 1999,* Abstract volume, pp.163-165.

Wanhainen, C. and Martinsson, O., 2000 - The Aitik Cu-Au deposit, Gallivare area, Northern Sweden; *in* Weihed, P and Martinsson, O., (eds.), Abstract volume and Field trip guidebook, 2nd annual GEODE-Fennoscandian shield field workshop on Palaeoproterozoic and Archean greenstone belts and VMS districts in the Fennoscandian Shield 28 August to 1 September, 2000, Gallivare-Kiruna, Sweden, *Luleå University of Technology*, Research Report 2000:6.

Welin, E., 1987 - The depositional evolution of the Svecofennian supracrustal sequence in Finland and Sweden; *Precambrian Research*, v. 35, pp. 95-113.

Wikstrom, A., Skiöld, T. and Ohlander, B., 1996 - The relationship between 1.88 Ga old magmatism and the Baltic-Bothnian Shear Zone in northern Sweden; *in* Brewer, T., (ed.), Precambrian Crustal Evolution in the North Atlantic Region; *Geological Society Special Publications*, No.112, pp. 249-259.

Witschard, F., 1984 - The geological and tectonic evolution of the Precambrian of Northern Sweden. A case for Basement reactivation; *Precambrian Research*, v. 23, pp. 273-315.

Wright, S.F., 1986 - On the magmatic origin of iron ores of Kiruna type - An additional discussion; *Economic Geology*, v. 81, pp. 192-206.

Wright, S.F., 1988 - Early Proterozoic Deformation History of the Kiruna District of Northern Sweden; Unpublished Ph.D. thesis, *University of Minnesota,* 170p.

Zweifel, H., 1972 - Geology of the Aitik Copper Deposit; *24th International Geological Congress, Montreal*, Section 4, pp. 463-473.

Zwiefel, H., 1976 - Aitik-geological documentation of a disseminated copper deposit; *Sveriges Geologiska Undersökning*, Series C No.720.

Zweifel, H., 1980 - Aitik Copper Ore; *in* Frietsch, R., (ed.), Precambrian Ores of the Northern Part of Norrbotten County, Northern Sweden, Guide to excursions 078 A+C Part 1 (Sweden), *26th International Geological Congress, Paris*, pp. 28-33.