The magnetite-apatite ore of the Kiruna district, Northern Sweden

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Abstract

The paper gives an overview about the Kiruna deposit especially the Kiirunavaara orebody. At first significant information elucidate the geology of the Kiruna deposit. The main content explains the mineralization of the orebody and the surrounding host rocks. In the last part the tow main hypotheses of genesis are depict.

Introduction

Kiruna is the northernmost town of Sweden, located circa at 68° latitude and 20°longitude. The town was found after the discovery of the ore in the 17th century. The Kiruna orebody is also termed Kiirunnavaara and is a part of the Kiruna district which includes the deposits Kiirunavaara, Luossavaara, Rektorn, Per Geijer orebody, Henry orebody, Nukutusvaara, Tuolluvaara and Haukivaara (Fig.2). Furthermore Kiirunavaara is one of the proterozoic iron oxide (Cu-U-Au- REE) deposits (after HITZMAN et al, 1992) The Kiruna orebody represent one of the world greatest magnetite-apatite deposits with a volume about 2 billion metric tons of magnetite.

The ore reach a length of 4 km, is in average 90m thick and extends down dip at least 1.5 km under the lake Luossajärvi (Fig.2). The magnetite consists of 67% Fe, if it is phosphorus-poor, and about 60% Fe with 0.1 till 4% phosphorus than phosphorus-rich ore. The mining is as civil engineering and the annual production rate amount to 18M tones. Therefore Kiruna is the world largest underground mine.

The geological situation at Kiruna

The Kiruna ore is situated of the Fennoscandian shield and occur in a mid-Proterozoic continental setting. It is underlined by Archaen granitic gneiss and Lower Proterozoic greenstone basement. The greenstone basement includes intermediate, mafic and ultramafic volcanic rocks and minor shallow marine sediments. (Fig.1)

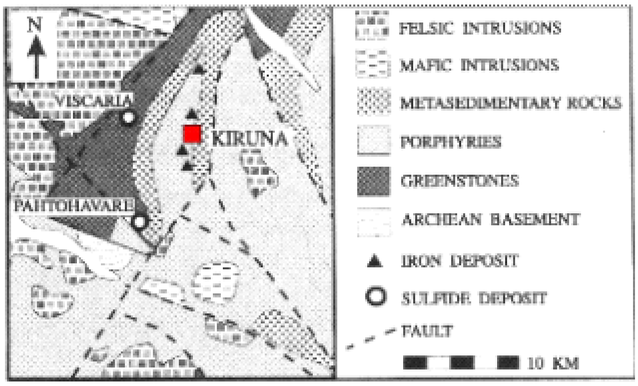

Fig.1. Regional geology of the Kiruna district (LINDBLOM et al, 1996)

The host rocks consist of alkalic rhyolite, tachyte and tachyandesite ash flows and lava flows (Fig.2), with intrusive rocks that grade upward into a continual sedimentary sequence (HITZMAN et al, 1992). The Rhyolith is in mining term 'Quarzporphyr'; the Alkalitrachyt is designate as well than 'Keratophyr' and the Quarz-Alkalitrachyt is termed 'Quarz-Keratophyr' in mining. (Fig.2 use these old names)

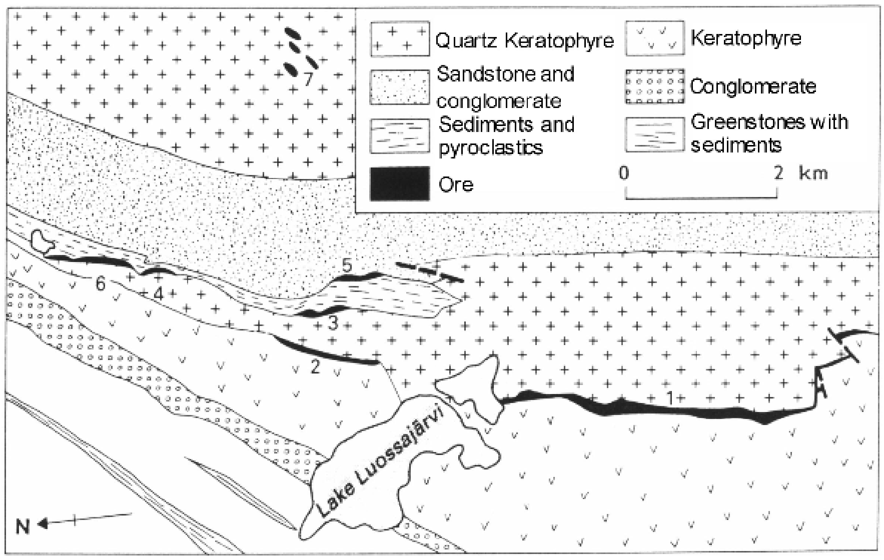

Fig.2 Geological map of the Kiruna district showing the setting of the iron ores Kiruna (1), Luossavaara (2), Rektorn (3), Henry (4), Haukivaara (5), Nukutusvaara (6) and Tuollovaara (7). (EVANS, 2000)

The characteristic footwall rocks are trachyandesitic lavas traditionally named "syenite porphyries" and the original composition of the rock has been modified by secondary alteration (CLIFF et al, 1990). These are overlain by rhyodacitic ignimbrites hanging wall rocks which are usually termed "quartz porphyries". The Porphyry Group and the iron ores have been regionally metamorphosed with preservation of primary structures and textures. Minerals like chlorite, zoisite, epidot, actinolite and albite in the mafic rocks indicate the greenschist-fazies. According to HARLOV (2002) the orebody is connect with extensive fault zone (Fig.6). It is an obvious change in the nature of the rock sequence about 1 km to the east of the main ore horizon. The boundary between the changes is marked by a major around north-south fault zone of indeterminate movement. Local deformation and recrystallisation have been resulted of reactivation of the fault system (HARLOV, 2002). Quartz and carbonates were probably introduced during the deformation and the result is that they took place in foliated regions of the ore. The actual timing of the deformation is unknown. HITZMAN (1992) found also evidence that the system may collapse. He describes later quarz-sericite-veins which cut potassic and sodic alteration zones. The distribution of the volcanic rocks in the Kiruna area indicate, according to HITZMAN (1992), emplacement within grabens or calderas. Later intrusion of potassic granites and syenites and tectonism has obscured the evidence of possible large –scale structural controls.

The volcanic succession which contains the ore is approximately 6 km thick. The iron oxid mineralization is situated on the contact zone between a lower volcanic sequence composed of porpyritic, trachytic ash-flow tuffs and tuffaceous sedimentary rocks. The majority oft these are altered and the chemistry is change from alkali-rich to poorly (HITZMAN, 1992).

The mineralization of the Kiirunavaara orebody

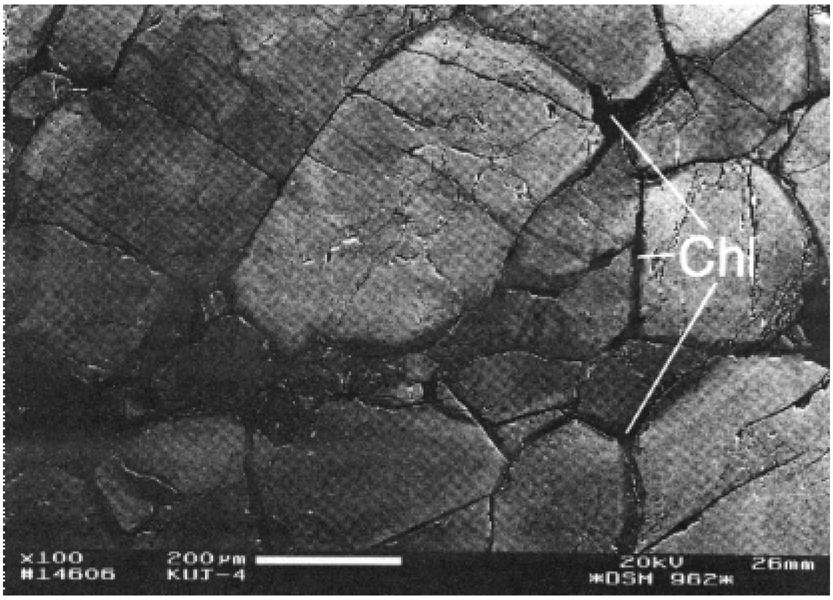

Fig.3 High-resolution BSE picture showing typical apatite grains. Black areas along apatite grain boundaries are chlorite (Chl) and talc. (HARLOV et al, 2002)

The orebodies of the Kiruna district are mainly massive and stockwork bodies like Luossavaara or Tuolluvaara. They form irregular bulbous masses and have been termed as “ore breccias”. However, Kiruna is a concordant body, i.e. it is tabular and concordant with whose host rocks.
The Kiruna ore is dominantly magnetite, although hematite has been indicated by drilling. The ore contains circa 30 % apatite (mainly fluorapatite, Fig.3) together with accessory amounts of actionolite, local biotite, calcite, quartz, sphene, diopsid, talc and albite. Actinolithe is a

typical accessory mineral of this ore and filling fractures and vesicular openings in the magnetite as well as in the wall rocks. Copper sulphides like chalcopyrite have been recognized but they are rare (HITZMAN, 1992). There against pyrite are often found in massive magnetite, in magnetite-actinolite veins and also in quartz veins. Sulphides take place as fine impregnations in the magnetite, too. As well 0.7% REO (rare earth oxides) occurs to the Kriiunavaara ore in the magnetite.

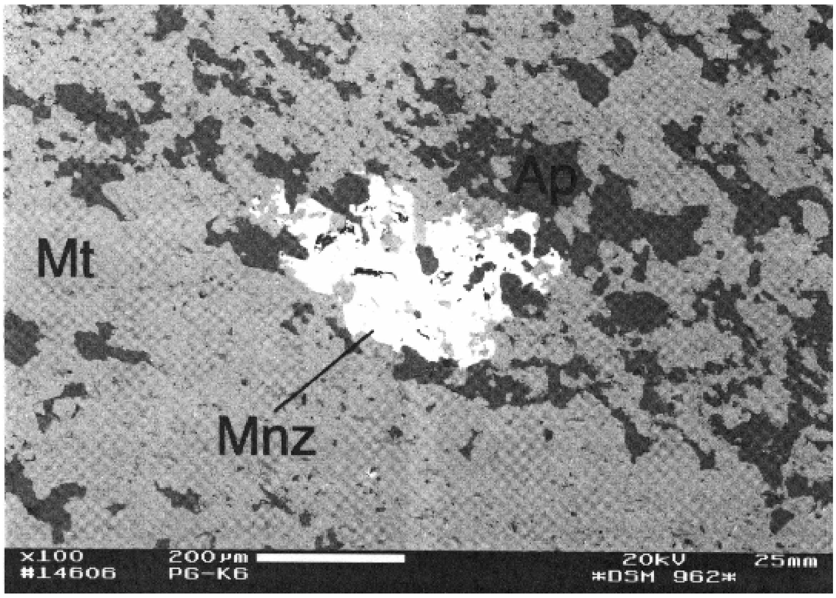

Fig.4 High resolution BSE image showing skeletal monazite (Mnz) which is intergrown with apatite (Ap) and magnetite (Mt). (HARLOV et al, 2002)

REE arise in the apatite and monazite which are irregular distributed throughout the ore (HITZMAN, 1992). A typical example is monazite (Mnz, Fig.4) which occurs as inclusions (Harlov 2002). The REE result of hydrothermal fluids obviates the need to invoke alkalic or carbonatic input of REEs at the side of deposition.

The magnetite can be divided into two types: a phosphorous-rich ore with more than 0.1 till 4 % P and a phosphorus-poor with less than 0.1%. Locally the magnetite bodies contain feldspar and quartz phenocrysts which decrease in abundance toward the centre of the bodies.

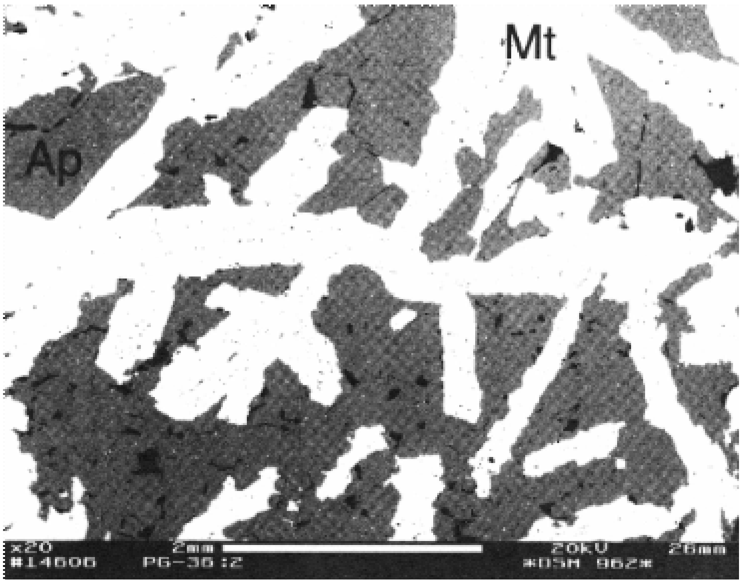

Fig.5 BSE picture showing the skeleton ore with platy magnetite dendrites (MT) enclosed by apatite (Ap). The magnetite is peppered with small inclusions of apatite.

The next paragraph follows the accomplishment of HARLOV (2002).
Three types of magnetite-apatite ore are known. One type is the so-called skeleton ore in which platy crystals of magnetite enclosed in a matrix of apatite. The plates are tenths to a few millimetres thick and sometimes they are orientated or form subparallel arrays (Mt, Fig.5). The magnetite includes evenly small (10-20 µm) apatite crystals (Fig.5).The second type is the brecciated magnetite-apatite ore with fragments of magnetite ore in apatite. (HARLOV (2002) represent the opinion that the ore is a product "of brittle deformation at relatively low temperatures" and he also found magnetite's with plastic conditions which probably have been formed at higher temperatures). The third is a banded ore with "fine alternating apatite- and magnetite-rich bands of relatively constant thickness (1-2mm)" (HARLOV 2002).These bands give the ore a gneiss-like appearance. The apatite of this type has a smaller grain size than in other varieties.

The mineralization of the host rocks

The footwall volcanic sequence is mineralised with magnetite and accessories like chlorite, actinolite and/or albite, which occur as disseminations, vesicle-fillings and hairline veinlets within the syenite. A cm to half m tick amphibole layer has been developed as the contact zone between the footwall rocks and the magnetite ore body. The amphibole comprises minor titanite and this represents perhaps indigenous titanium mobilized during hydrothermal alteration of the host vulcanite (HITZMAN, 1992). The overlying rocks are a complex succession of interlayered rhyolitic ash-flows and flows, vulcaniclastic sediments and minor trachytic flows. The Haukivaara hematite ore is over this volcanic complex with mineralization of magnetite, hematite, quartz, sericite, apatite and barite.

The age of the ore

The Kiruna ore is cut by syenitic, ryolitic and mafic dikes. Cliff (1990) explores a crosscuts granophyre. The age of this granophyre is comparable to the age of the rhyolite from the hanging-wall and the footwall complex (determined by Wellin, 1987). All results by Cliff (1990) show that the Kiruna orebody was completed before 1.880±0.003 Ga. Because the ore can not be younger than the crosscutting granophyre and it cannot be older than the host rocks with 1.9 Ga. Therefore Kiirunavaara must have been originated before 1.88 Ga. Consideration the errors the ore must have been formed between 1.88 and 1.90 Ga, thus it is possible that the ore was formed during the Svecokarelian-Hudsonian orogeny (1.8-1.9 Ga). The Kriiunavaara area has been affected by a secondary event at 1.54 Ga, it is corresponds to a later period of granitic intrusion in the region. Koark et al (1978, HITZMAN, 1992) dating single crystal apatite and has been got a date of 486±95 Ma. These Phanerozoic dates probably represent reset ages, related to later metamorphism.

The alteration of the Kiruna ore

The alteration at Kiruna shows a variance “from sodic alteration at deeper levels (albite-rich) to potassic alteration at intermediate levels (potassium feldspar, sericite), to sericitic and silicic alteration in the uppermost portion of the system (sericite, quartz)” (HITZMAN, 1992).Fig.6 shows the alteration zones with there relationship and the connection to the mineralization areas. The magnetite is limited to sodic and potassic alteration zones. Deeper alteration in these systems is characterized by the development of albite, albite-magnetite and albite-sodium amphibole assemblages.

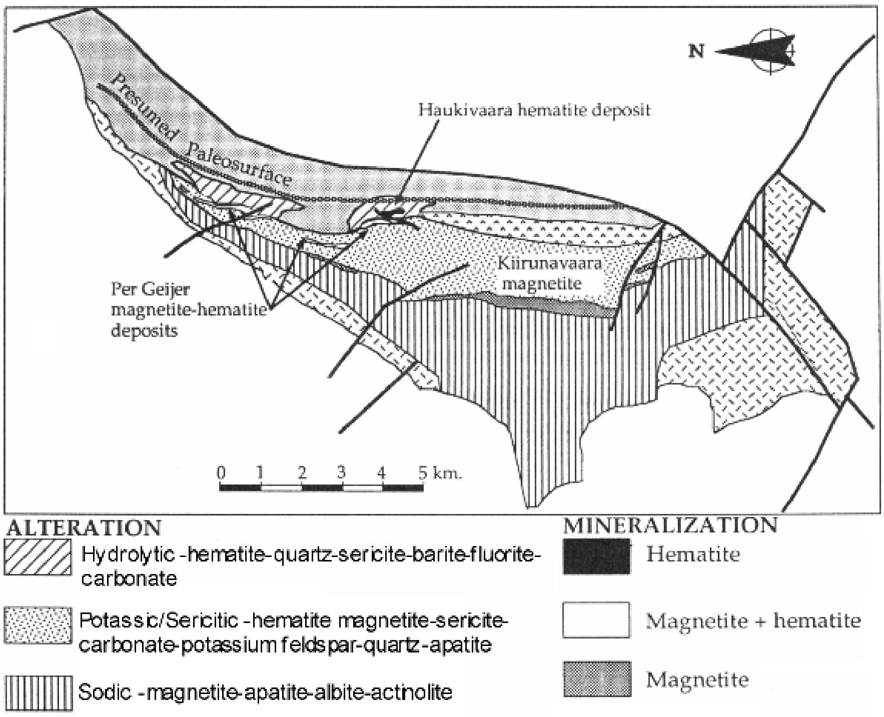

Fig.6 Generalized cross-sectional reconstruction of the Kiruna district based on present surface geology and illustrating inferred broad alteration relationships and mineralization zones. (HITZMAN, 1992)

Theses of the genesis

Although Kiruna has been discovered in the 17th century, the genesis of Kiruna has been the subject of extensive controversy. Today two principal hypotheses exist:

- liquid immiscibility of an iron-rich melt with a hydrothermal replacement
- a hydrothermal exhalative process.

In the next paragraph a short overview is give about the "iron-rich melt" and the "exhalative process" thesis.

HARLOV (2002) has the opinion and that Kiruna has been formed from volatile-rich iron oxide magmas. He argues this magma was separated as immiscible iron-rich melts from calc-alkaline to slightly alkaline parental magmas during cooling. Furthermore the ore has been formed "in a volcanic system due to the extrusion of iron oxide lava and ash as well as emplacement of subvolcanic orebodies" (HARLOV, 2002). He explicates the thesis with magnetite relicts in the hematite which shows that the hematite is a secondary oxidation product and not the original ore. The occurrence of pyrite and gypsum in veins and as individual grains is the product of hydrothermal overprinting at lower temperatures in originally porous regions of the ore. He is point out that "is no evidence that any part of the orebody itself has been hydrothermally deposited" (HARLOV, 2002). This view is one of the oldest about the genesis but many geoscientists support it like NYSTRÖM & HENRIQUEZ (1995) and BOTTKE (1981). Thereagainst CLIFF (1990) and EVANS (2000) stand for the opinion that the Kiruna orebody is situated in volcanic or volcanic-sedimentary terrane and is an exhalative deposit. The evidences are the concordant nature of the ore body and his volcanic betting, the massive in part and just as banded ore. CLIFF (1990) has been tested samples with radiometric dating methods and declared that the ore was probably formed during the orogenesis. He also describes oxygen isotope geothermometry indicators which give a temperature of 600°C. It is "well below that required to keep an iron oxide melt fluid" (EVANS, 2000).

Summary

The Kiruna orebody has been formed in the Proterozoikum probably at the age at 1.8- 1.9 Ga (CLIFF, 1990). The ore is surrounding of Quarzporphys; Keratophyrs and Quarz-Keratophyrs. The deposit is a concordant body made of magnetite-apatite ore which contains circa 30 % apatite and some accessory minerals. Therefore the magnetite is dived in phosphorous-rich ore with more than 0.1 till 4 % P and a phosphorus-poor with less than 0.1%. Three types of appearances of the ore are known. In the deposit different alterations occur and show a variance from sodic to potassic to sericitic and silicic alteration (HITZMAN, 1992).
Kiruna has been discovered in the 17^{th} century but about tectonic setting like the emplacement within grabens or calderas and the genesis of the orebody are unclear until today. Kiruna remain the subject of extensive controversy.

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