Genesis of the Per Geijer apatite iron ores, Kiruna area, northern Sweden

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Abstract. Apatite iron ores are rather uncommon and the genesis of these deposits has been debated for more than a century. In the Kiruna area in northern Sweden the Per Geijer deposits shows a large variation in mineral composition, structures and textures. Apatite, carbonate and quartz are gangue minerals occurring disseminated in varying amounts in the ore as well as segregations in the form of blebs. Larger accumulations of apatite-carbonate-quartz exhibit cutting contacts or mingling structures to the ore.

The Per Geijer deposits are interpreted as having formed from iron oxide melts with high content of volatiles. During cooling these iron oxide melts underwent unmixing of volatile rich and iron-poor magma that generated apatite-carbonate-quartz rocks. The volatile components expelled during formation of the apatite iron ores also generated extensive hydrothermal brecciation and alteration in the wall rocks. The alteration is mainly developed in the hanging wall and includes K-feldspar, quartz, sericite, chlorite and carbonates.

Keywords. Apatite iron ores, Kiruna, genesis, magmatic, hydrothermal, Per Geiger

1 Introduction

The northern region of the Fennoscandian Shield, including parts of Finland, Norway and Sweden, is an important metallogenic province dominated by Fe-oxide, Cu±Au and orthomagmatic Cr-Ni-Cu-PGE deposits. Economically most important in northern Sweden are the apatite iron ores with more than 2 billion tons of ore produced since 1888.

Apatite iron ores are rare and they were first described in the Kiruna area in northern Sweden by Geijer (1910). The genesis of these deposits has been discussed for more than 100 years. Suggested ore forming processes include magmatic (Geijer, 1910) and hydrothermal (Parák, 1975; Hitzman, et al., 1992). Peculiar textures including columnar-, dendritic and skeletal magnetite have been used as arguments for the magmatic origin (Geijer, 1910; Nyström and Henriquez, 1994). However, not all features of the apatite iron ores are easily explained with a single genetic model and a magmatic-hydrothermal process has been suggested by Martinsson (2004).

Totally about 40 apatite iron occurrences are known from northern Sweden. They exhibit a considerable variation in host rock lithology, host rock relations, host rock alterations, P-content and associated minor components. They are often tabular and concordant with their host rock and consist mainly of magnetite and hematite with apatite, actinolite and carbonates as important gangue minerals (Martinsson, 2004).

2 Geological setting

The geology of northern Sweden includes a rift related Paleoproterozoic Greenstone Belt (~2.3-2.0 Ga) and subduction related Svecofennian igneous and sedimentary rocks deposited on an Archean basement. These rocks were deformed and metamorphosed during the Svecokarelian Orogen at 1.8-1.9 Ga.

2.1 Local geology

In the Kiruna area, a succession of greenstones, porphyries and clastic sedimentary rocks rest unconformably on a deformed 2.7–2.8 Ga Archean basement. These rocks are metamorphosed in upper greenschist facies and locally intruded by quartz monzonite. The stratigraphically lowest are the 2.5-2.1 Ga Karelian rocks including the Kovo Group and the overlying Kiruna Greenstone Group. These rocks are unconformably overlaid by the 1.9 Ga Kurravaara Conglomerate, the Kiirunavaara Group and the Hauki Quartzite (Fig. 1).

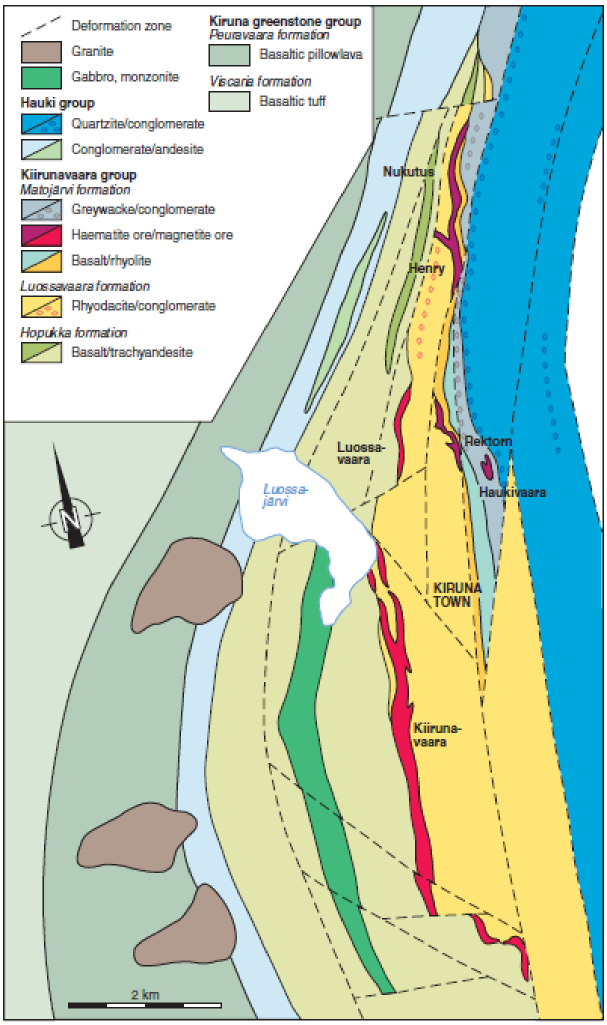

Figure 1. Geology of the Kiruna area with the Kiirunavaara, Luossavara and the Per Geijer ores (Nukutus, Henry, Rektorn and Haukivaara). From Martinsson et al., 2013.

All the apatite iron ores in the central Kiruna area are hosted by the Kiirunavaara Group and the latter is divided into three formations: (1) the Hopukka Formation is the lowest stratigraphical unit and is dominated by trachyandesitic lava; (2) it is followed by the Luossavaara Formation, a rhyodacitic pyroclastic unit and (3) finally the Matojärvi Formation is a mixed volcanic and sedimentary unit comprising rhyolite, basalt, conglomerate, greywacke and schist (Martinsson 2004).

Kiirunavaara is the largest deposit with pre-mining resources of more than 2000 Mt. It is situated at the stratigraphically lower contact of the Luossavaara Formation and occurs as a tabular body of massive magnetite with mostly low phosphorus content. The much smaller Luossavaara deposit occurs in the lateral extension of Kiirunavaara towards the north, while the phosphorus rich and hematite bearing Per Geijer ores occur at the stratigraphically upper contact of the Luossavaara Formation or within the lower part of the Matojärvi Formation (Martinsson, 2004).

3 The Per Geijer ores

The Per Geijer ores consist of five different ore bodies showing large variation in texture, mineral composition and relation to wall rocks. The Nukutus, Henry, and Rektorn occur at the stratigraphically upper contact of the Luossavaara Formation, while the Haukivaara and Lappmalmen ores at least partly are located within the overlying Matojärvi Formation. Lappmalmen is a blind and so far unexploited ore body only known from drilling, while the others have been mined as open pits.

Hematite occurs together with magnetite in different amounts and is mostly formed from magnetite. The phosphorus content is generally high and occurs as apatite, a major gangue mineral together with varying amounts of carbonate and quartz. Typical composition of ore is 40-50% Fe and 3-5% P but higher phosphorus content can be locally measured.

Wall rock alteration is generally strongest in the hanging wall with the occurrence of K-feldspar, quartz, sericite, ankerite-calcite, chlorite and minor tourmaline in up to 200 m wide zones within the lower part of the Matojärvi Formation. Characteristic is the occurrence of spotted K-feldspar in strongly silicified felsic volcanic rocks (Fig. 2). K-feldspar alteration may be overprinted by sericite in shear zones.

Figure 2. Silicified rhyolite with spots of red K-feldspar. Rektorn hanging wall. View 10 cm across.

Hydrothermal breccias are commonly found in the hanging wall and consist of strongly altered clasts of mainly basalt and rhyolite within a matrix of apatite, carbonate, sericite and magnetite/hematite. Intercalations up to 10 m in thickness of cherty hematite ore are common and may have a fragmental character. These units are mostly developed in strongly K-feldspar altered and silicified rhyolite and are commonly containing some barite with minor apatite (Geijer, 1950; Martinsson, 2004).

Footwall rocks are generally less altered than the hanging wall rocks with chlorite, biotite, carbonate, apatite and locally albite or actinolite occurring in up to 50 m wide zones in rhyodacite from the Luossavaara Formation.

3.1 The Nukutus deposit

The Nukutus deposit (Fig. 3) is the northernmost of the Per Geijer ores. It was discovered in 1888 and 0.74 Mt of ore was mined between 1961and1967 in an open pit. The average grade was 40-45 % Fe and 4% P (Grip and Frietsch, 1973).

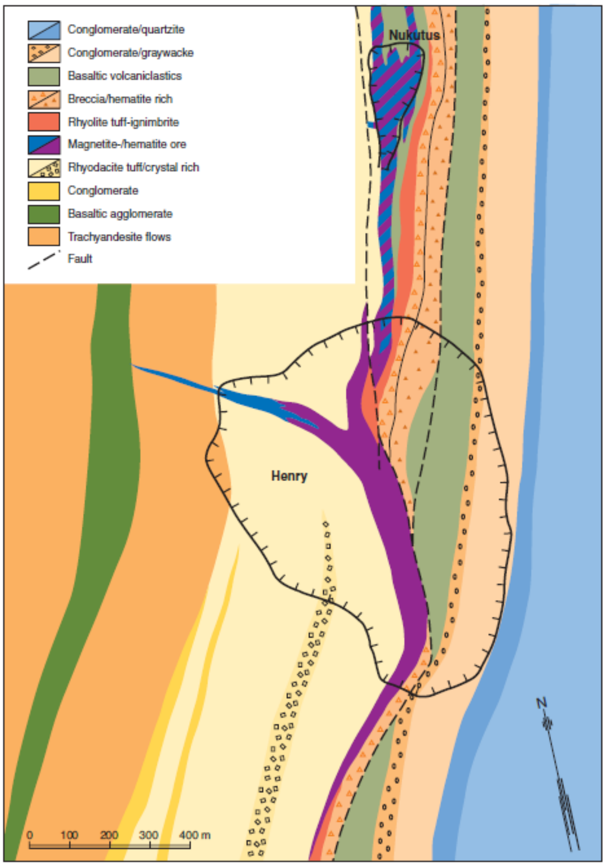

Figure 3. Geology of the Nukutus and Henry deposits. From Martinsson et al., 2013.

The ore is mostly fine grained and massive and consists of magnetite and hematite. Carbonate, apatite and quartz represent the main gangue minerals and sometimes occur also as rounded to more irregular blebs in the ore (Fig. 4). The same minerals locally occur as larger accumulations especially at the contacts of the ore and these are partly banded but could also develop structures resembling mingling with the ore (Fig. 5).

Apatite and carbonate also occur as breccia infill in crosscutting structures at the footwall contact with clasts of iron ore and silicified rhyodacite. Almost pure apatite intersects the ore in very different scales from mm to almost m-wide veins. Chalcopyrite occurs in small amounts in these associations and also together with apatite and carbonate in chlorite-sericite altered basalt in the hanging wall.

Figure 4. Magnetite-hematite ore with blebs of carbonate, apatite, and quartz in the Nukutus deposit. Scale in cm.

Figure 5. Magnetite-hematite ore (dark) in contact with apatite-carbonate-quartz rock (reddish) in the Nukutus deposit.

3.2 The Henry deposit

The Henry deposit was discovered in 1910 and 4.9 Mt of ore was mined between 1969 and1987 in an open pit. The average grade was 45 % Fe and 4.5% P (Grip and Frietsch, 1973).

A stratabound part of the ore is dominated by massive magnetite ore largely altered to hematite. Vuggy and skeletal ore occur locally (Fig. 6) and more rarely very fine grained magnetite ore with a scoriaceous character (Fig. 7). In both types magnetite is largely altered to hematite with some goethite filling cavities. A discordant part of the ore extends into the footwall and ends in trachyandesite of the Hopukka Formation (Fig. 2). It changes from hematite to magnetite with increasing depth in the footwall.

Figure 6. Massive magnetite ore with voids and sharp contact to skeletal magnetite in the Henry deposit. View 15 cm across.

Figure 7. Fine grained magnetite ore largely altered to hematite resembling scoria in the Henry deposit. View 10 cm across.

Apatite-carbonate-quartz rocks similar to what is found at Nukutus occur in the northern part of the deposit at the footwall contact. They are partly banded and in places the ore seems to intrude these rocks (Ginet and Kunzle, 1978). Strong sericite alteration occurs along the discordant part of the ore and in connection to albite±carbonate alteration of amygdaloid trachyandesite minor chalcopyrite is found in amygdales and in quartz-carbonate veins.

3.3 The Rektorn deposit

The Rektorn ore body (Fig. 8) was discovered 1987 and mined as both an open pit and underground between 1925 and 1961 with a total production of 2.5 Mt of ore. The ore had an average composition of 33% Fe and 3.5% P (Grip and Frietsch, 1973).

The ore consists of magnetite and hematite in variable proportions. Apatite is disseminated in the ore, enriched in bands or forms crosscutting veins and breccia infill. Quartz and carbonate are in places important gangue minerals in the apatite-rich ore (Geijer, 1950). The ore is mostly fine grained with magnetite partly transformed to hematite. Less commonly the ore is coarse grained showing an intergranular texture consisting of tabular magnetite grains with interstitial apatite, carbonate and some quartz.

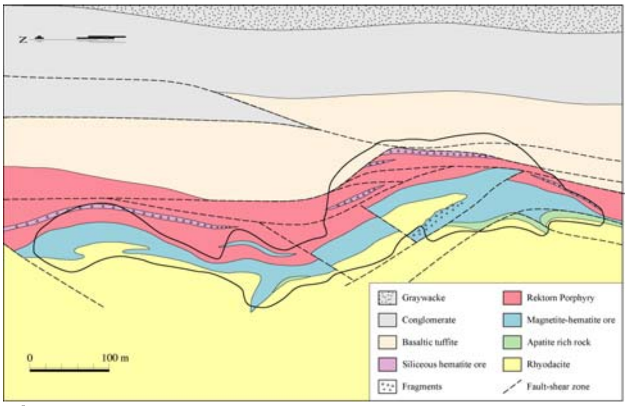

Figure 8. Geology of the Rektorn deposit Modified from Bergman et al., 2001.

The hanging wall rocks are strongly sheared and altered and contain small amounts of Cu-sulphides. Intercalations of siliceous, apatite-poor hematite ore with a fragmental character are common in the silicified and K-feldspar altered rhyolite and could reach several meters in thickness. A lens of massive iron ore occurs in the same position and change into a scoriaceous character at the stratigraphically upper contact. In the southern part of the deposit a breccia extends into the footwall. Altered clasts of rhyodacite occur in a matrix of carbonate, apatite, quartz and magnetite. Further south a banded rock with the same mineral composition occurs at the footwall contact. Several carbonate-bearing quartz veins containing minor amounts of hematite, allanite, pyrite, chalcopyrite and bornite crosscut the ore at a high angle.

4 Discussion

The host rocks to the Per Geijer ores shows evidences of strong hydrothermal alteration including albite, K-feldspar, sericite, biotite, chlorite, quartz, carbonate and minor tourmaline. Most of these alterations are clearly related to the apatite iron ores. Sulphides are rare in the altered rocks with only minor Cu-sulphides while iron oxides and apatite are common. Overall the alteration is more strongly developed in the hanging wall and is dominated by K-feldspar, sericite, carbonate and silica.

A large variation of textures and structures are developed in the ores. Most of them seem to be primary but shearing may locally have modified the ore and generated foliated, banded and breccia structures. Of genetic importance is especially the occurrence of (1) skeletal ore, (2) vuggy and scoriaceous ore, (3) ore with blebs of apatite-quartz-carbonate and (4) occurrences of apatite-carbonate-quartz rocks and their relation to massive ore.

Most of these features are not easily explained by a hydrothermal process and similar textures and structures from other apatite iron ores have been suggested as evidences of a magmatic origin (e.g. Geijer, 1910; Nyström and Henriquez, 1994). The composition and character of an iron-oxide magma is unknown but is thought to be rich in volatiles lowering the melting point and the density (Naslund et al., 2002).

Typical composition of massive ore seems to be 40-50% magnetite, 20-30% apatite, 5-25% carbonate and 2-10% quartz demonstrating a high content of “volatile” components. The existence of volatiles is further expressed by vesicles or partly unfilled spaces between magnetite laths in skeletal ore. Blebs of apatite-carbonate-quartz occurring in the ore at Nukutus are local accumulations of the ordinary gangue minerals but mostly with a significant higher proportion of quartz. They might represent globules formed by immiscibility of volatile rich and iron-poor magma that in some areas have accumulated to larger masses forming the apatite-carbonate-quartz rocks. Contact relations of these rocks to iron ore vary from cutting to mingling. The skeletal ore seems to have formed in these more volatile rich environments. Apatite and carbonate are also occurring disseminated and as breccia infill in altered hanging wall rocks at all three deposits. This demonstrates that more volatile components were expelled during formation of the apatite iron ores generating hydrothermal brecciation and alteration in the wall rocks.

Acknowledgements

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