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Mineralogy and geochemistry of indium-bearing polymetallic veins in the Sarvlaxviken area, Lovisa, Finland

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ABSTRACT

A number of polymetallic vein mineralizations of different styles and metal associations, including base, alloy, noble and critical metals, have been discovered around the Sarvlaxviken bay in the westernmost parts of the Mesoproterozoic Wiborg Batholith, south-eastern Finland. The veins occur in two rapakivi granite varieties: coarse-grained wiborgite; and medium-grained Marviken granite. The veins are divided into five groups based on the dominant metal associations.

The Li–As–W–Zn–Mn, Pb–Zn and Cu–As–In associations are hosted by wiborgite, and are strongly controlled by a NNW-trending tectonic pattern that evolved in two main stages. The Li–As–W–Zn–Mn association (generation 1) formed in a typical greisen environment with Li-bearing mica in significant alteration halos around a narrow quartz vein. This greisenization was accompanied by silicification, followed by sericitization and chloritization. The Pb–Zn association occurs in a similar vein type but without typical high-temperature minerals and is considered to have formed at a higher crustal level. Generations 2a and 2b formed under more brittle conditions leading to fracturing, quartz veining and metal precipitation of ore minerals. This metal association is characterized by very high contents of Cu, As and up to 1490 ppm In but with ≤0.4% Zn, which leads to very high In/Zn ratios (up to 8400) enabling formation of abundant roquesite.

The As–Sn–Cu and Mo–Bi–Be associations are hosted by alteration zones without hydrothermal quartz in the Marviken granite. Mineralization with moderately high contents of As, Sn and Cu is associated with greisenization while mineralization with spectacular contents of Be as well as high contents of Mo and Bi is associated with sericitization, chloritization and berylification.

The internal age relations between the wiborgite-hosted, NNW-trending veins show a clear evolution from a typical greisen type environment (the Li–As–W–Zn–Mn and Pb–Zn associations of generation 1) to cooler and more brittle conditions governing quartz veining and precipitation of ore minerals belonging to the Cu–As–In association (generations 2a and 2b). The age relations between these wiborgite-hosted veins and the veins in the Marviken granite are more uncertain but the presence of a NS-trending granitic dyke on the eastern side of the Sarvlaxviken bay, with similar ore-fertile geochemical composition as the Marviken granite, indicates that the tectonically controlled veins formed simultaneously with the emplacement of the Marviken granite and associated hydrothermal activity.

The polymetallic veins in the Sarvlaxviken bay are unique for the Fennoscandian Shield, not the least for the locally high indium grades and spectacular roquesite grains. There is an obvious exploration potential for similar veins (and hence a number of base, alloy, noble and critical metals) also elsewhere in the entire Wiborg Batholith.

1. Introduction

Until relatively recently, A-type rapakivi granites were not considered particularly prospective for metals, even if the polymetallic skarn ores at Pitkäranta (Ladoga, Karelia) were earlier linked to the emplacement of rapakivi granites (Törnebohm, 1891; Trüstedt, 1907). Since then, numerous ore deposits, associated with rapakivi granites, have been recognized across the globe, including the giant Olympic Dam Cu–U–Au–Ag deposit, South Australia (e.g., Roberts and Hudson, 1983), Sn-bearing polymetallic deposits in Rondônia and Amazonas, Brazil (e.g., Bettencourt and Dall'Agnol, 1987), and at St. Francois Mountain, Missouri, USA (Kisvarsanyi and Kisvarsanyi, 1991) as well as minor deposits in Arizona (e.g., Anderson et al., 1955; Goodman, 1986), Ukraine (e.g., Dagelaysky, 1997) and southern Finland (e.g., Haapala, 1977a, 1988).

The metal concentrations in Finnish rapakivi granites have previously been studied by Haapala (1973, 1977b, 1988), mainly focusing on

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elevated contents of Sn and Be and associated minerals (Haapala and Ojanperä, 1969, 1972), including several discoveries of greisen-type Sn–W–Be–Zn occurrences in the Eurajoki and Kymi stocks and the Ahvenisto Batholith (Haapala, 1974, 1977b, 1995, 1997).

Recent discoveries of new exploration targets in the 1.64 Ga Wiborg Batholith of southeastern Finland have extended the exploration potential in rapakivi granites to also include several other metals. Besides high contents of a number of base, alloy and noble metals, the significant amounts of In make them also attractive exploration targets for high-tech metals given the current supply and demand issues (British Geological Survey, 2012). Three ore types were recognized in the western parts of the Wiborg Batholith (Sundblad et al., 2008): compact In-bearing magnetite-sphalerite ore (Pahasaari and Getmossmalmen); Zn–Cu–Pb–Ag–In-bearing greisen veins (Jungfrubergen); and polymetallic veins (Sarvlaxviken), the latter area highlighted for the first time by Cook et al. (2011). In this study, more details are provided for the ore types around the Sarvlaxviken bay, including descriptions of field relationships, vein types, mineral paragenesis and geochemistry.

2. Geological setting

Finland occupies the central part of the Precambrian Fennoscandian Shield, and comprises Archaean 3.1–2.6 Ga crust in the east, and the 2.5–1.8 Ga Palaeoproterozoic Svecofennian Domain, which includes the remnants of magmatic and sedimentary components of ophiolites, island arcs, and active continental margins (Korsman et al., 1997). A number of Mesoproterozoic anorogenic granitic intrusions occur in southern Finland. The most significant are the 1.64–1.54 Ga rapakivi granites in the Vehmaa, Laitila, Wiborg and Åland areas, but several smaller bodies also occur (Rämö and Haapala, 2005) (Fig. 1).

The Wiborg Batholith is the largest rapakivi intrusion in Finland, with a diameter of 150 km and a surface area exceeding 18,000 km^2. The greater part of the Wiborg Batholith is located in southeastern Finland while a smaller part, including the type locality Wiborg, is located in Russia. The by far most common (80%) rock type in the Wiborg Batholith is wiborgite, which exhibits spectacular 1–3 cm-sized rounded orthoclase phenocrysts, mantled by a rim of plagioclase, within an even-grained groundmass of quartz, plagioclase, orthoclase, biotite and occasional hornblende (Simonen and Vorma, 1969). Other rock types in the Wiborg Batholith are pyterlite (6%), dark even-grained rapakivi granite (e.g., tirilite) (3%), porphyritic rapakivi granite (1%), and various biotite granites (8%). Collectively, this rock suite represents the products of several igneous phases between 1.65 and 1.63 Ga (Vaasjoki et al., 1991).

Rapakivi granites are geochemically within-plate granites (WPG) and have characteristics of A-type granites. Rapakivi batholiths commonly consist of various types of granites, thus implying several different intrusive phases that cross-cut older ones. The differences between these phases are mainly in the proportions and speciation of mafic minerals; earlier stages have hornblende, Fe-rich biotite as well as fayalite, whereas the later phases only have Fe-rich biotite. In general, the rapakivi granites are rich in light rare earth elements (LREE) with negative Eu anomalies, but the later (topaz-bearing) granites, have fairly flat chondrite-normalized REE fractionation trends and display pronounced negative Eu anomalies (Rämö and Haapala, 2005). LREE depletion and relative enrichment in heavy rare earth elements (HREE) have also been proposed to relate to processes of greisenization (Öhlander et al., 1989).

The study area (Fig. 2) is located in the south-western part of the Wiborg Batholith, around the Sarvlaxviken bay (forming part of the Gulf of Finland), where the contact between 1839 Ma Late Svecofennian potassium-rich anatectic granites (Kurhila et al., 2011) and 1645 Ma wiborgitic rapakivi granites is indicated on the bedrock map sheet of the Geological Survey of Finland (Laitala, 1964). This map has no indications of any metallic mineralization in the region and it was not until the discovery of roquesite and associated sulphide minerals in a quartz vein at Korsvik (Cook et al., 2008, 2011) that this area came into focus for metallogenetic studies. The Fennoscandian region was subject to glacial erosion at repeated intervals during the Quaternary, with the latest glacial maximum at 30–13 ka BP (Räsänen et al., 2015), causing significant transport and redeposition of rock debris from the bedrock surface along the ice transport directions. Based on ice striae in the bedrock surface, the most powerful and oldest advances of the continental ice sheet in the Sarvlaxviken area was from the northwest (320–330°) while a younger ice movement was from 350 to 360° (Punakivi et al., 1977).

3. Material and methods

The bedrock geology of the Sarvlaxviken area was re-examined by carefully visiting all outcrops with respect to rock types, structures as well as any expression of alteration and mineralization. Structure measurements were made with a standard compass but all strike directions have been recalculated from magnetic north to the north direction of zone III in the national grid system. Vein samples from the eastern side of the Sarvlaxviken bay were collected with the help of a diamond saw to create 25–40 cm-long rock slabs along the strike directions of the veins. The samples were split into two pieces, from which one was used to prepare polished thin and thick sections, polished sections and rock powders for whole rock geochemistry. The second piece was preserved for further studies. Vein samples from the western side of the bay were collected with the help of a hammer and were further cut in the laboratory. In total, 31 polished sections, 20 polished thin sections and 10 thick sections were prepared. Petrographic observations were made by using a combination of reflected and transmitted light microscopy.

A scanning electron microscope (SEM) was used to investigate smaller mineral grains and textures. Two different instruments were used; HITACHI S-3600 N equipped with Energy Dispersive X-ray

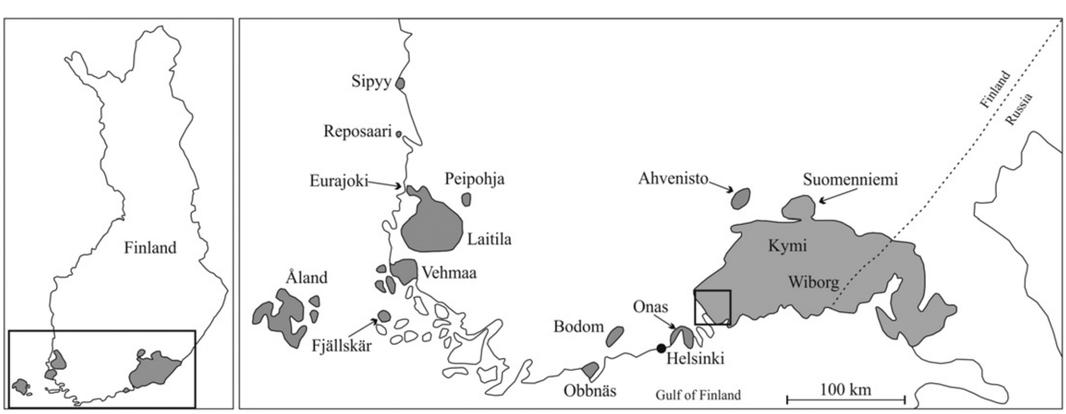

Fig. 1. Distribution of the anorogenic rapakivi granites in Finland and adjacent areas.