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CONTROLS ON PGE MINERALIZATION IN THE EARLY PALEOPROTEROZOIC KEMI-KOILLISMAA-OULANKA MAFIC INTRUSION BELT, FENNOSCANDIAN SHIELD

Saini-Eidukat, B. (1); Thalhammer, O.A.R. (1); Alapieti, T. (2); Halkoaho, T.(2) & Iljina, M. (1,2)
(1) Inst. of Geological Sciences. Mining University of Leoben, A-8700 Leoben, Austria
(2) Dept. of Geology, University of Oulu, P.O. Box 400, SF-90571 Oulu, Finland

ABSTRACT: A number of processes operate to concentrate PGE's in mafic intrusions, including pre-magmatic mantle enrichment, intermediate staging chambers during partial melting with crustal contamination, and exsolution of an immiscible sulfide or magmatic volatile phases which mobilize and concentrate PGE's in the intrusion itself. When more than one of these processes occurs, the possibility of ore deposit formation increases. Some parent magmas of the early Paleoproterozoic intrusion belt of the Fennoscandian Shield have chemistries similar to modern boninites, which implies a previous mantle melting event. Slightly negative Nd isotopes indicate crustal contamination occurred before or during emplacement. The varied types of rich PGE concentrations were formed by the superposition of different concentration processes, including magma chamber and metamorphic processes.

1. Introduction

Understanding of the major PGE-bearing mafic intrusions of the world is maturing rapidly with the application of a variety of petrological and geochemical tools. The PGE-rich early Paleoproterozoic Kemi-Koillismaa-Oulanka mafic intrusion belt, Fennoscandian Shield provides an excellent opportunity to investigate the different processes responsible for PGE concentration. Here we will describe the intrusion belt's geologic setting, its geochemical characteristics, our concepts for metallogenesis of the large types of PGE mineralizations, and will compare them to similar deposits.

2. General Geology

The belt comprises approximately two dozen intrusion fragments stretching across the center of the Fennoscandian shield from the Finnish-Swedish border into Russian Karelia. Although subsequent tectonic processes have obscured evidence of the original tectonic setting, most workers infer from the presence of overlying sediments and coeval volcanics found in some parts of the belt that the intrusions were emplaced into a continental rifting environment (Alapieti et al., 1979; Brewer and Pharoah, 1990; Turchenko, 1992). Their age has been dated to the range 2.44 Ga (Koillismaa and Penikat Complexes, Alapieti, 1982; Huhma et al., 1990) to 2.34 Ga (Tsipringa intrusion, Oulanka Complex, Turchenko, 1992).

Lower contacts of the intrusions are generally intrusive into the Archean basement granite-gneisses. Upper contacts can be in erosional contact with approximately 2.3 Ga conglomerate, or in some cases in intrusive contact with the Archean basement. In cases, as in Russia, the upper contact is with overlying volcanics (the Sumi-Sariolan group and the Imandra-Varzuga series on the Kola Peninsula) with tholeiitic chemistries (Brewer and Pharoah, 1990).

Descriptions of individual intrusions and mineralizations can be found in (Alapieti et al., 1990; Halkoaho et al., 1990a,b; Iljina et al., 1989, 1992) and references therein. The intrusions are usually made up of a number of cyclic repetitions of ultramafic-mafic packages, referred to as megacyclic units.

3. Geochemical characteristics

Two magma types have been recognized by examining the megacyclic units and basal dikes associated with the intrusions (Alapieti et al., 1990; Iljina et al., 1992). The first is enriched in MgO and Cr and depleted in Ti, Ta, Nb, and HREE's compared to tholeiites, while the second is less enriched in MgO and Cr. The chemical characteristics of the first type are similar to those referred to by different authors as modern boninites, contaminated komatiites, siliceous high magnesium basalts, and high magnesium andesites. They are also very similar to parental magmas proposed for the Bushveld and Stillwater Complexes. Regardless of the nomenclature used, these chemistries require special formation conditions to generate these very specific major and trace element characteristics.

In Finland, the overlying Juottiaapa volcanics (2.09 Ga) have an ε_{Nd} of +4.2, which indicates that the mantle source had been depleted for a long time (Huhma et al., 1990). The previous depletion may have been the formation of Archean crust during the Saamian (3.1-2.9) and Lopian (2.9-2.6) Ma orogenies. In contrast, Nd isotopic ratios for all the intrusions measured to date are between ε_{Nd} 0 to -2 (Penikat ε_{Nd} = -1.6, Huhma et al., 1990; Oulanka Complex ε_{Nd} = -0.7 to -1.7, Turchenko et al., 1991). This indicates crustal contamination may have played an important role at some time in the intrusions' history.

4. Genesis of Platinum Group Element Mineralization

The intrusions host a number of PGE mineralization types (Halkoaho et al., 1990a,b; Iljina et al., 1989, 1992; Lahtinen et al., 1989). These range from basal sulfide accumulations to stratiform layers within the layered series to basement-hosted concentrations. The layered series mineralizations occur with and without chromite, and with and without sulfides. PGE grades up to 100's of ppm have been recorded (Halkoaho et al., 1990a). Taken as a whole, the magmas of the intrusion belt must have been extraordinarily enriched in PGE to have formed such a large number of individual concentrations of different types.

In comparison to the Fennoscandian intrusions, the Bushveld and Stillwater Complexes have similar parent magma chemistries and negative ε_{Nd} values. Os isotopes of the Stillwater (Lambert et al., 1989; Martin, 1989) Complex also indicate addition of a crustal component. The tholeiitic Noril'sk-Talnakh deposits and the Duluth Complex share similar tectonic settings, although different geochemistries than the Fennoscandian intrusions, but again, trace element and S isotopic evidence indicates some sort of crustal input.

The combined geologic, geochemical, and isotopic evidence to date indicates that the PGE concentrations in the Finnish intrusions are the result of a combination of several processes. These may include some or all of the following:

• a pre-magmatic mantle PGE enrichment event due to depletion
• a high degree of melting during the partial melting event with the addition of LILE-enriched fluid phase to form the boninitic chemistries
• crustal contamination, either in a lower crustal staging chamber or during emplacement
• thermochemical interaction at the interface between two magmas
• during crystallization, exsolution of an immiscible sulfide melt (Naldrett, 1989) and/or magmatic volatiles (Ballhaus and Stumpfl, 1986; Boudreau and McCallum, 1992) which may mobilize and concentrate the PGE's. This process may be aided by the presence of an interface between magma types. The final PGE mineralization may be emplaced outside the intrusion itself (basement-hosted mineralization?).
• subsequent metamorphic events may modify the PGE mineralogy, and remobilize and upgrade the PGE's (Thalhammer et al., 1993).

We propose that any one of the processes mentioned above independently may result in concentration of PGE's, but that the coincidence of two of more of them increases the possibility for formation of an economic ore deposit. In the Fennoscandian intrusions, boninite-type magma types are not the only attribute responsible for the formation of PGE concentrations. We suggest that, as in the Noril'sk, Sudbury, and Bushveld intrusions, crustal contamination played an important role.

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