# Multimillion-Ounce PGE Deposits of the Portimo Layered Igneous Complex, Finland

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## Structure and Megacyclic Units

The ca. 2440 Ma Portimo Layered Igneous Complex (Portimo Complex) is located in the central part of an intrusion belt that crosses Finland almost along the Arctic Circle. Other intrusions in this belt include the Kemi and Penikat intrusions containing a chromitite deposit and PGE reefs, respectively. The Portimo Complex is composed of three principal structural units (Fig. 1): 1) the Portimo Dikes, 2) the Narkaus intrusion, and 3) the Suhanko-Konttijärvi intrusion with the last one having two separate igneous bodies, Suhanko and Konttijärvi.

The Narkaus and Suhanko-Konttijärvi intrusions contain a marginal series and an overlying layered series. The two marginal series differ in thickness and their prevailing rock types. The Narkaus Marginal Series generally varies from 10 to 20 m in thickness, while the Suhanko-Konttijärvi Marginal Series reaches several tens of meters. The Narkaus Marginal Series is mainly composed of pyroxenites, whereas olivine cumulates commonly constitute the upper half of the Suhanko-Konttijärvi Marginal Series.

A striking difference between the layered series of the two intrusions is the presence of marked reversals in the Narkaus intrusion, as shown by thick ultramafic olivine-rich cumulate layers, whereas crystallization in the Suhanko-Konttijärvi intrusion proceeded without any notable reversals (Fig. 1). The major reversals in the Narkaus Layered Series resemble those of the Penikat intrusion and enable its layered series to be divided into three megacyclic units (MCU). The Megacyclic unit II is, however, found only in the central part of the Narkaus intrusion and fades away eastwards.

Mafic and ultramafic dikes called the Portimo Dikes are encountered in the basement below the Suhanko-Konttijärvi intrusion in the Konttijärvi and Ahmavaara areas (Fig. 1). The dikes have not been dated, and their inclusion in the same magmatic event as the intrusions proper is based on geochemistry. The dikes are subparallel to the basal contact of the intrusion and merge with it locally, so that a dike can actually form the basement of the intrusion.

The MCUs of the intrusions and the dikes were generated from two kinds of parental magmas differing slightly in composition: Cr-richer and Cr-poorer, in this order. The former type resembles SHMB or the Bushveld B1 magma. The Portimo Dikes and MCU I-II have been interpreted to have crystallized from the Cr-richer magma, while the Cr-poorer magma was parental for the Suhanko-Konttijärvi intrusion and MCU III of the Narkaus intrusion.

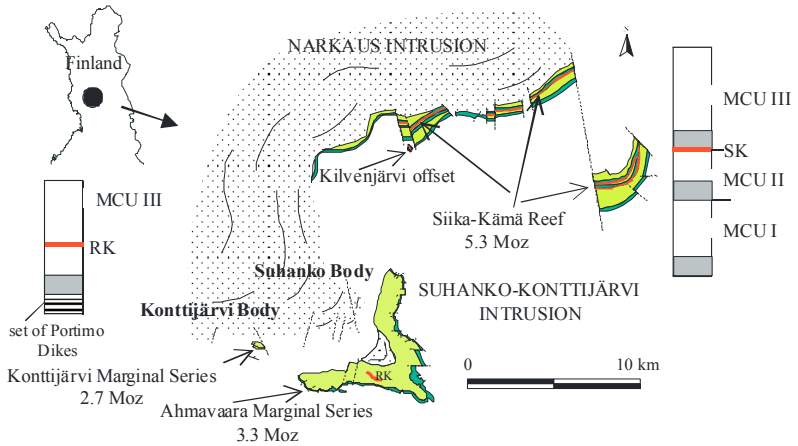


***Figure 1.*** *General geology, stratigraphic columns of the Suhanko-Konttijärvi (left) and Narkaus intrusions (ultramafic cumulates in gray). Archean rocks in white, layered intrusions in yellow (gabbros) and green (ultramafic) and younger supracrustal rocks stippled. SK = Siika-Kämä Reef and RK = Rytikangas Reef. Pt+Pd+Au resources, Outokumpu oyj press release.*

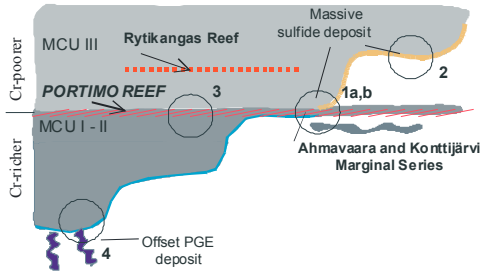


***Figure 2.*** *Structural interpretation of the Portimo Complex and the location of the PGE mineralization. Circles 1 - 4 refer to drill hole intersections depicted in Figures 3 - 6, respectively.*

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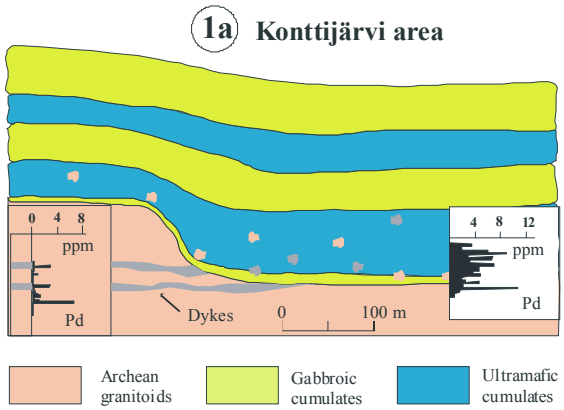


***Figure 3.*** *A: Incline cross-section through the Konttijärvi Marginal Series.*

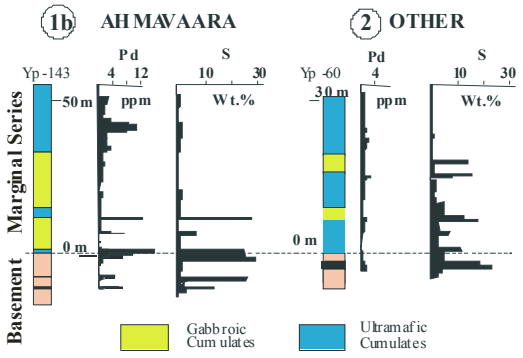


***Figure 4.*** *Comparison of Ahmavaara and another marginal series section of the Suhanko Body.*

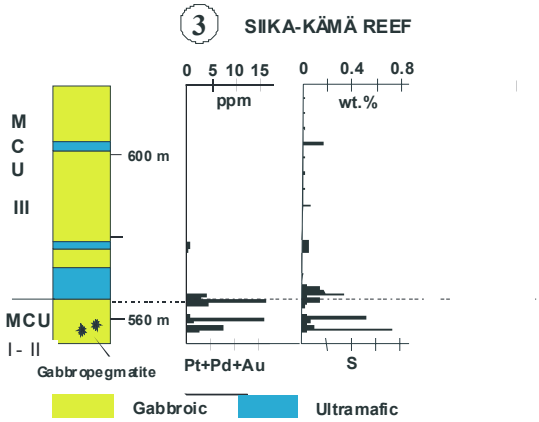


***Figure 5.*** *Drill hole section through the Siika-Kämä Reef.*

**PGE-Cu-Ni Mineralization**

Among the layered intrusions in Fennoscandia, the Portimo Complex is exceptional in hosting a variety of PGE mineral deposits. Published resources are indicated in Fig. 1. The mineralization types include (Figs 2-6): a) PGE-bearing Cu-Ni sulfide disseminations in the marginal series of the Suhanko-Konttijärvi intrusion and Portimo Dikes; b) predominantly massive pyrrhotite deposits located close to the basal contact of the Suhanko-Konttijärvi intrusion; c) the Siika-Kämä PGE Reef in the Narkaus Layered Series; d) the Rytikangas PGE Reef in the layered series of the Suhanko Body; e) the offset Cu-PGE mineralization below the Narkaus intrusion

Disseminated PGE-bearing base metal sulfide concentrations (10–30 m thick) are encountered throughout the marginal series of the Suhanko-Konttijärvi intrusion (Alapieti et al., 1989; Iljina, 1994). Their distribution is erratic, and they generally extend from the lower peridotitic layer downwards for some 30 m into the basement. The PGE content varies from only weakly anomalous values to 2 ppm in most places in the marginal series of the Suhanko Body, but rises to over 10 ppm in several places in the Konttijärvi and Ahmavaara areas (Ni and Cu contents are generally less that 1 wt.% combined). In the same areas, the Portimo Dikes locally carry PGE up to several ppm (Circle 1a, Figs. 2 and 3). Co-precipitation of thorium and uranium minerals with Pd-Se minerals is also found within the Portimo Dikes.

Recent exploration has revealed that the small Konttijärvi Body has deep embayment structure in its center (Fig. 7). Highly PGE-enriched marginal series as encountered in the Konttijärvi-Ahmavaara areas are rare in layered intrusions, and

the only other well-known occurrence is the Platreef in the northern Bushveld Complex.

Massive sulfide concentrations are characteristic of the marginal series of the Suhanko Body. The massive sulfide deposits are slab-like concentrations generally varying in thickness from 20 cm to 20 m, and the individual slabs within deposit are separated from each other by more silicate-rich cumulate layers or granitoids. The slabs vary in location from 30 m below the basal contact of the intrusion to a position 20 m above it, within the marginal series. The massive sulfide concentrations vary in size from less than one million tonnes to more than ten million tonnes. The sulfide paragenesis is composed almost exclusively of pyrrhotite, except in the Ahmavaara deposit, which also contains chalcopyrite and pentlandite. Accordingly, the sulfide fraction of Ahmavaara contains 2.7 wt. % Ni and 2.4 wt. % Cu, while the other massive deposits hardly reach a half of these values.

The massive pyrrhotite deposits show low PGE values, with the maximum Pt+Pd normally reaching a few ppm (exemplified by Circle 2, Figs 2 and 4). Similarly to the sulfide disseminated marginal series, the PGE concentrations are much higher in the Ahmavaara deposit, attaining a level of 20 ppm (Circle 1b, Figs 2 and 4).

The Siika-Kämä PGE Reef of the Narkaus intrusion is located most typically at the base of MCU III (Figs 1, 2 and 5), but it can lie even tens of meters below that or in the middle of the olivine cumulate layer of MCU III (Huhtelin et al., 1989; Iljina, 1994). The reef is continuous over the whole strike length of ca. 15 km. The thickness varies from less than one meter to several meters, and many drill cores contain a number of mineralized layers separated by PGE-poor layers, which can be some meters thick. The PGE concentration varies from anomalous values of several hundred ppb to some tens of ppm. The Siika-Kämä mineralization is one of the sulfide-deficient PGE mineralizations in the Portimo Complex, sometimes containing no visible sulfides at all and hardly ever having a whole-rock sulfur content in excess of 1 wt.%.

The main PGE occurrence in the layered series of the Suhanko-Konttijärvi intrusion is the Rytikangas PGE Reef (Figs 1-2). Its position is known over a distance of 1.5 km. The Rytikangas Reef is hosted by poikilitic plagioclase, plagioclase-bronzite, and plagioclase-bronzite-augite ortho-cumulates, all containing augite oikocrysts. The orthocumulate layer varies in thickness from 30 cm to 10 m. The thickness of the Reef itself is 30–50 cm, and it is usually encountered on top of the poikilitic orthocumulate layer. PGE + Au concentration are up to 20 ppm.

The offset mineralization is sporadically distributed in the basement gneisses and granites below the Narkaus intrusion (Figs. 1, 2 and 6). The largest deposit, and also the best-known one, is that situated below the Kilvenjärvi block. The offset mineralization represents the richest PGE deposit type within the Portimo area with its Pt + Pd content reaching occasionally 100 ppm. The offset is a Pd-dominated deposit with much higher Pd/Pt than in the other Portimo deposits and extremely low concentrations of Os, Ir, Ru, and Rh. Furthermore, it is irregular in form, being composed of disseminated sulfide-PGM 'clouds', massive sulfide veins or bodies, and breccias, in which sulfide veins brecciate granitoids.

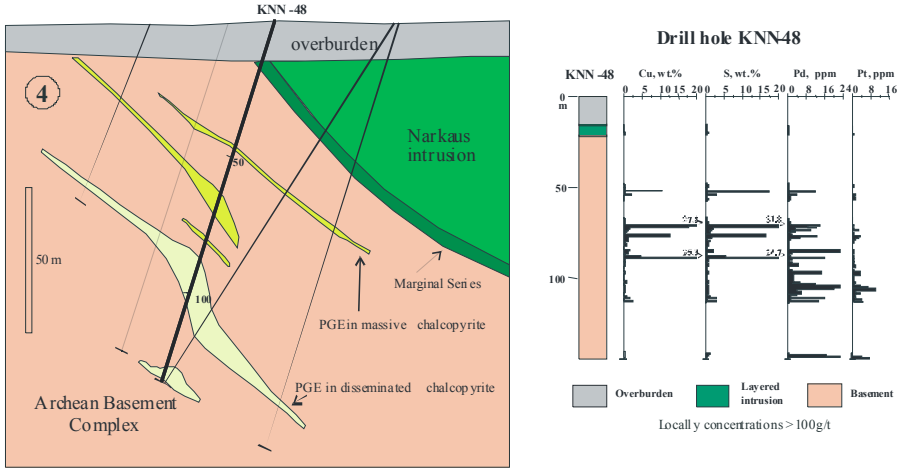


***Figure 6**. An example of an offset deposit, Kilvenjärvi.*

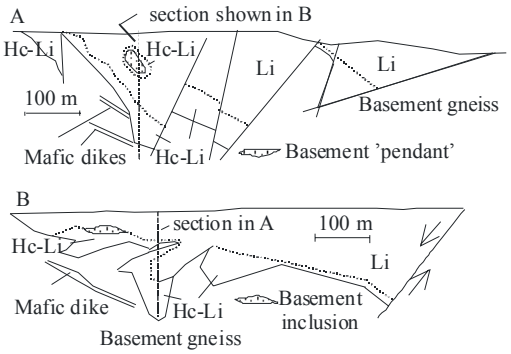


***Figure 7.*** *Cross-section (A) and longitudinal section (B) of the Konttijärvi Body. Li, layered intrusion, Hc-Li, heavily contaminated layered intrusion. Redrawn from Arctic Platinum Partnership Oy material.*

The proportions of base metal sulfides and PGM are variable, but the massive sulfide bodies are always rich in PGE, while some samples containing hardly any visible sulfides can have several tens of ppm of Pd as well. In general terms, the more sulfide-rich occurrences are situated closer to the basal contact of the intrusion and those poorer in sulfides are encountered in a wider zone below the intrusion (Fig. 6).

Figure 2 shows a structural model for the Portimo Complex and the position of the above described mineralization sites and deposits. Taking the boundary region of the two parental magmas as a reference level, it can be seen that the Siika-Kämä Reef, the highly mineralized Ahmavaara and Konttijärvi Marginal Series, and the mineralized Portimo Dikes are located in the same positions in terms of the magma stratigraphy. Accordingly, they were referred to as a group name the 'Portimo Reef' by Iljina (1994). In the Konttijärvi and Ahmavaara areas, the pulses of the earlier parental magma are represented by the Portimo Dikes lying immediately below the marginal series. It is crucial that a marked decrease in PGE values and Ni and Cu contents of the sulfide fraction in the Suhanko-Konttijärvi Marginal Series takes place as soon as the Portimo Dikes disappear below it. In addition, regardless of the quantity of base metal sulfides present, the PGE ratios and chondrite-normalized PGE patterns are practically constant throughout the Portimo Reef. This is the case in the Ahmavaara Marginal Series, for instance, where the variation from disseminated to massive sulfides has only a marginal effect on the PGE patterns.

**Discussion**

The 'Portimo Reef' seems to lie in an ideal position in the light of the magma mixing model for PGE ore genesis. The two parental magmas inevitably mixed**,** at least in the Narkaus chamber, while the Portimo Dikes may have had thickenings in the Konttijärvi and Ahmavaara areas, which were not totally solidified at the time of subsequent magma injection, allowing the magmas to mix. The magma mixing model entails, however, certain problems. One is that the Reef can sometimes be located in cumulates or gabbropegmatites far below the first signs of a new magma. Another problem is found in the Konttijärvi and Ahmavaara areas, where higher tenor of PGE is sporadically found in the footwall granitoids and Portimo Dikes. These PGE enrichments are disseminated in character and therefore not indicative of a stream of immiscible sulfide liquid. Local co-precipitation of U- and Pd-Se minerals refers to co-trasportation and mineralization through a fluid phase. The above-mentioned features rule out magma mixing as the sole cause of ore formation.

The location of the 'Portimo Reef' excludes the possibility that its genesis could be exclusively related to the processes that took place in the present intrusions, but suggests that the ore-forming processes started much earlier in some intermediate magma chamber in the crust below the Narkaus and Suhanko-Konttijärvi intrusions and the last batch of the Cr-richer magma was already highly enriched in PGE at the time of emplacement. The PGE was possibly carried by a fluid phase and/or small amounts of immiscible sulfides. The multi-million ounce PGE deposit in the Konttijärvi Body demonstrates that the small size of a mafic body does not make it non-prospective when it is related to large volumes of magma of the whole intrusion belt.

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