Pothole structure in the Ala-Penikka PGE Reef, Penikat layered intrusion, Northern Finland

T. A. A. Halkoaho

Geological Survey of Finland

Corresponding author e-mail: tapio.halkoaho@gtk.fi

Summary The Penikat layered intrusion is located in southwest Lapland, Northern Finland. The intrusion contains two main units: the marginal series and layered series, the layered series being further divided into five megacyclic units (MCUs). The intrusion contains three major PGE-enriched zones. The middle one, termed Ala-Penikka PGE reef contains a large PGE enriched pothole structure.

1. Introduction and background to current research

The 2.44 Ga Penikat layered intrusion is 23 km long and 1.5 to 3.5 km wide and its footwall rocks consist of late Archaean/early Palaeoproterozoic granitoids. The hanging wall rocks, younger than the intrusion, are either tholeiitic volcanic rocks, subvolcanic sills or in places a polymictic conglomerate. The intrusion forms five westward-dipping blocks, the borders of which are bounded by roughly east-west-trending faults. These blocks are designated as the Ala-Penikka, Keski-Penikka, Yli-Penikka, Kilkka and Sompujärvi. The intrusion is divided into two principal units: the marginal series and the layered series. The layered series has been divided into megacyclic units (MCUs) I - V (Fig. 1) (Alapieti and Lahtinen, 1986, Alapieti et al., 1990, Halkoaho, 1993, Halkoaho et al., 2005 and Maier et al., 2018). These are interpreted as being attributable to repeated influxes of new magma into the Penikat magma chamber (Alapieti and Lahtinen, 1986). The parental magmas are thought to be siliceous high-Mg basalts in nature, usually classified into high-Cr (MCUs I-III) and low-Cr (MCUs IV-V) types (Alapieti et al., 1990 and Maier et al., 2018).

The Penikat layered intrusion contains three major PGE-enriched zones: the Sompujärvi (SJ), Ala-Penikka (AP) and Paasivaara (PV) PGE Reefs. The SJ Reef is located at the boundary between MCUs III and IV, 500 to 1000 m above the base of the Penikat layered intrusion. The AP Reef is located 250-450 m above the SJ Reef in the lower part of MCU IV, and the PV Reef about 700-1000 m above this, in the transition zone between MCUs IV and V (Fig. 1). These PGE reefs have previously been described by Alapieti and Lahtinen (1986, 2002), Halkoaho (1993), Halkoaho et al. (1990ab, 2005), Huhtelin et al. (1990), Törmänen and Alapieti (1996), Kaukonen et al. (2004) and Maier et al. (2018).

2. Results

The PGE mineralization referred to as the AP Reef is located 250-450 m above the base of MCU IV. It is known in broad outline for almost the entire 23 km length of the intrusion (Fig. 1). (Halkoaho et al., 1990b, Halkoaho, 1993). The AP Reef is usually 20 to 40 cm thick, but at the site of the pothole structure PGEs are concentrated over a wider zone, so that the mineralized rocks attain a vertical thickness of almost 20 m. The AP Reef is situated at the border between plagioclase-augite-bronzite adcumulate and a 3-30 cm thick poikilitic plagioclase mesocumulate. The AP Reef, with highly variable PGE values, has base metal sulphide disseminations closely associated with it (Fig. 2) (Halkoaho et al., 1990b, Halkoaho et al., 2005).

Figure 1. Generalized geological map of the Penikat layered intrusion showing the locations of the megacyclic units (MCU) and PGE reefs. Modified after Alapieti et al. (1990) and Halkoaho et al. (2005).

The pothole structure of the AP Reef is about 300 m long and 100 m deep and interrupts the underlying cumulates. This structure forms three separate parts on the present erosional surface, the southernmost one representing the shallowest section of the original structure whereas the northernmost one is the deepest. The cumulus stratigraphy greatly resembles that of the normal AP Reef, but the vertical thicknesses of the layers are distinctly greater. The poikilitic plagioclase mesocumulate is now 2 to 20 m thick, whereas outside the structure its thickness is only 3 to 30 cm and the plagioclase-bronzite mesocumulate overlying this plagioclase mesocumulate is now 50 m thick, whereas it is elsewhere only about 13 m thick. The pothole structure also features large amounts of gabbro-noritic pegmatoids (Halkoaho et al., 2005, Maier et al., 2018) (Fig. 2).

2.1. Formation of the AP PGE Reef

It is proposed that the older residual magma became intermixed with the new megacyclic unit IV magma pulse and formed a volatile-rich hybrid magma. This hybrid magma settled to the base of the magma chamber. The PGEs are derived chiefly from the residual magma and to some extent from the fourth magma pulse. The AP Reef formed from an upward-migrating volatile and chalcophile element enriched intercumulus melt trapped below an approximately 10 to 20 m thick plagioclase-bronzite mesocumulate layer. The partial pressure of oxygen in the fluid phase of the intercumulus melt gradually increased. When intercumulus titanomagnetite began to crystallize, this reduced the solubility of sulphur and triggered the

formation of a sulphide melt (cf. Shima and Naldrett, 1975), leading to collection of the PGE-bearing complexes (Halkoaho et al., 1990b, Halkoaho, 1993).

Figure 2. A. Geological map of the pothole area of the AP Reef. B. Stratigraphic sequence of the AP Reef in the pothole structure showing variations in Pt+Pd+Au, S, Cr, Cu+Ni, P and Zr. Modified after Halkoaho et al. (1990b), Halkoaho (1993), Alapieti and Lahtinen (2002) and Halkoaho et al. (2005).

Halkoaho et al. (1990b) suggest that the large pothole structure (Fig. 2) has developed as the result of a disturbance in the magma chamber causing the unconsolidated cumulate layers to collapse. The currents of the convection cells in the magma of MCU IV then reworked the structure and smoothed it down, resulting in the formation of a regular channel-like structure. On the other hand, Ballhaus et al. (1988) and Stumpfl and Ballhaus (1986) came to the conclusion that the potholes of the Merensky Reef are primary disturbances and were formed where high concentrations of volatiles locally suppressed the liquidus temperature of plagioclase so that no footwall anorthosite cumulates were formed. Large amounts of discontinuous gabbro noritic pegmatoids are also encountered in the area of the pothole structure, so that one possibility is that high volatile activity may also have interfered with the normal crystallization process there (Halkoaho et al., 1990b). Buntin et al. (1985) postulate that the potholes of the Merensky Reef represent scars of late magmatic fumarole activity. Boudreau (1991) also notes that the potholes show morphological similarities to the sedimentary features known as pockmarks and suggests an origin of the same kind for potholes in layered intrusions, i.e. an escape of overpressured gas from underlying sediments and cumulates, respectively. Halkoaho (1993) suggest that the extensive pothole structure occurring in the AP Reef may thus be an outlet for fluids being squeezed out of the crystallizing magma chamber from below. The poikilitic anorthosite of the pothole structure and the plagioclase-augite-bronzite adcumulate

below it contain PGE-bearing gabbro-noritic pegmatites, and there are gabbro-noritic pegmatites perpendicular to the layering together with anorthositic fragments about 200 m above the poikilitic anorthosite (Fig. 2A).

3. Future prospects

The large pothole structure in the AP PGE Reef is a remarkable feature as far as ore potential is concerned. The question arises whether pothole is unique in the Penikat layered intrusion or whether there could be more potholes? Also, the formation of the pothole remains unclear and requires further research.

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