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Super-concentration of PGE, Au, Se and Te by Sulfide Liquid Dissolution in Closed Systems: Evidence from the Skaergaard Intrusion, East Greenland

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1 Introduction

The majority of magmatic platinum-group element (PGE) deposits in layered mafic/ultramafic intrusions are characterized by visible Cu-Ni sulfide mineralisation, often located in the lower parts of a magmatic stratigraphy that shows evidence of multiple magma injections, and crustal contamination.

The Platinova Reef, hosted by the 55 Ma Skaergaard Intrusion, east Greenland, is an example of a rarer type of PGE deposit, typified by a Pd-Au-Cu-dominant, Ni-Pt-poor, sulfide assemblage present in the upper parts of the host intrusion. Such deposits are generally considered to form through prolonged fractional crystallization of the magma, with magnetite crystallization playing a role in late-stage S saturation. In the case of the Skaergaard Intrusion, the crystallisation of the cumulate rocks, and the generation of the mineralisation hosted within them, occurred within a closed system, from a single, homogenized batch of magma.

2 The Platinova Reef

The Platinova Reef, hosted by a sequence of layered gabbros referred to as the Triple Group, at the top of the middle Zone of the Intrusion, is characterized by: offsets in the stratigraphic position of individual metal peaks; an anomalously low sulfide content (<0.01 wt % S in bulk rock); a mineralized zone with high precious metal tenor sulfides overlain by more abundant, but much lower tenor sulfides; and lateral variation in the thickness of the mineralized interval.

Holwell and Keays (2014) divided the mineralized units of the Platinova Reef into five zones based on the presence

of Pd, Au and Cu mineralization (Fig. 1): the lower Subzone, the Pd zone (Pd >1 ppm), the Intermediate zone (Pd 0.1-1 ppm), the Au zone (Au >1 ppm) and the upper Cu zone (Cu >200 ppm with precious metals <1 ppm). The mineralization beneath the Cu zone is associated with very low volume sulfides with calculated Pd and Au tenors of 103 to 104 ppm, low Cu/Pd ratios and a remarkable upward decrease in Pd/Au ratio from 40 to 1, whereas the sulfides in the Cu zone are lower tenor (103 ppm Pd), higher volume and have high Cu/Pd ratios and Pd/Au <1.

The relationship between Pd and Cu/Pd ratio indicates that sulfides from beneath the Cu zone formed at a very high R factor, with variable, but low volumes of sulfides, whereas those in the Cu zone formed at a lower R factor from a PGE-depleted magma. A broad correlation between V and Pd through the Subzone, Pd, Intermediate and Au zones indicates that the crystallization of magnetite may be linked to sulfide saturation.

3 Geochemistry of the Sulfides

3.1 PGE and Se concentrations

Laser ablation ICP-MS analysis of sulfide droplets in all the zones of the Platinova Reef has revealed extremely high tenors of precious metals and semi metals. In the Pd zone and Intermediate zone, the Pd content of the sulfides in the region of 1000 ppm, and in the Intermediate zone, around 3000 ppm Pd. In the Au zone, the Au tenor of the sulfides is around 15,000 ppm Au.

The Se contents of the sulfides are very high. The sulfide droplets of the Subzone, Pd zone and Intermediate zone have very consistent Se contents of around 300-420 ppm. The Se in sulfide rises to ~750 ppm in the Au zone and the basal portions of the Cu zone has

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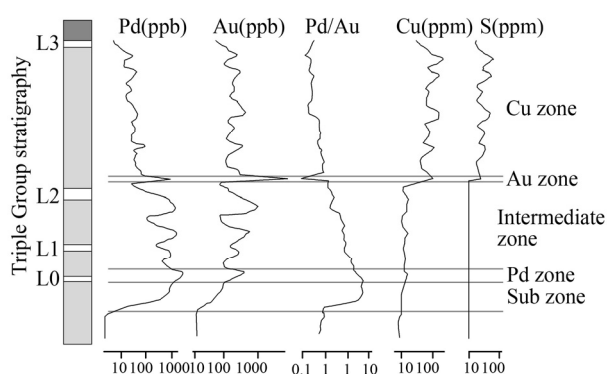


Fig. 1. Metal zonation through the Platinova Reef (after Holwell and Keays, 2014).

the highest values of 1000-1200 ppm Se. Figure 4A shows a remarkably smooth decrease in Se content of the sulfides upwards away from the base of the Cu zone, down to 870 ppm 30 m from the base. Tellurium mirrors the behavior of Se, with the highest concentrations also present in the sulfides at the base of the Cu zone.

3.1 S/Se ratios

The S/Se ratios of the sulfide droplets are the lowest ever recorded in magmatic sulfides. The Subzone, Pd and Intermediate zones have S/Se ratios in the region of 500-800; the Au zone ~300 and the base of the Cu zone ~190, which rises gradually and remarkably smoothly with distance from the base of the Cu zone (195 at +3m; 232 at +13m; and 260 at +23m above the base). The lack of evidence for any post-magmatic S loss through alteration, with droplets trapped in cumulus phases implies that this extremely low S/Se ratio is a true magmatic characteristic of the Platinova Reef.

4 A model for superconcentration

To explain these features, we present a multi-stage model of pre-concentration, dissolution upgrading, and

further metal enrichment. This involves initial S saturation of the Skaergaard magma at a late stage in the crystallization history. The sulfide liquid produced scavenged metals from the entire volume of the chamber as it sank, but was then dissolved as it came into contact with hotter, Fe-rich and S-undersaturated magma at the bottom of the chamber, releasing first Se, the PGE and Au into a highly metal-rich magma layer at the bottom of the chamber.

This layer then became S-saturated as a result of continued magnetite crystallization, with the tiny sulfide droplets that segregated into this precious metal-enriched magma layer becoming highly enriched in PGE themselves. These were then trapped in situ by the crystallizing cumulate pile forming the Subzone, Pd zone and Intermediate zone. Sulfides formed in the rest of the chamber, which was PGE-depleted at this stage would have been of low tenor. These sulfide droplets grew and settled, concentrating the bulk of the redissolved Se, and any remaining Au when they encounter the floor to form the Au zone and formed the low tenor sulfides, but high Se concentrations of the Cu zone above this.

We propose that the Platinova Reef exhibits an unusual example of a style of magmatic precious metal mineralization formed through sulfide dissolution upgrading in the latter stage of crystallization of a closed system.

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