



Effects of hydrous alteration on the distribution of base metals and platinum group elements within the Kevitsa magmatic nickel sulphide deposit



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ABSTRACT

Platinum and nickel are commonly assumed to be immobile in most conditions, especially during low temperature hydrothermal alteration. However, only a small number of studies have rigorously tested this assumption. The Ni–Cu–(PGE) sulphide ore body hosted by the Kevitsa intrusion, northern Finland, provides a natural laboratory to study the behaviour of base metals and platinum group elements (PGE) during low temperature alteration. This ca. 2060 Ma mafic–ultramafic intrusion, located in the Central Lapland greenstone belt, hosts disseminated Ni–Cu–(PGE) sulphide mineralisation in the middle part of the main ultramafic body. The mineralisation, which contains a range of Ni, Cu and PGE grades, is affected by three main alterations (serpentinisation, amphibolitisation and epidotisation), and is cross cut by various types of veins. The effect of the circulation of hydrothermal fluids on the distribution of base metals and PGE was studied at two different scales. Interrogation of an extensive deposit-wide assay database provided information on the deposit-scale (kilometre scale) effect of these different alteration styles, and a detailed study, involving laboratory X-ray fluorescence (XRF), portable XRF and micro-XRF mapping, of drill-core samples containing cm-scale cross-cutting veins provided information on the small scale (centimetre to decimetre scale) remobilisation of base metals and PGEs. Results show that the hydration and carbonation of the Kevitsa mineralised mafic–ultramafic intrusion did not significantly affect the distribution of Ni and PGE at scales larger than a few mm, and that Cu and Au are the only metals that are affected by small to large scale remobilisation from centimetre to kilometre scale.

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1. Introduction

Platinum group elements (PGEs) are widely used as petrogenetic indicators in ore deposits and their host rocks. Commonly these ores and rocks have been subjected to hydrothermal alteration, particularly in the case of Precambrian terranes and greenstone belts. It is a common assumption that PGEs and nickel are relatively immobile elements, not easily remobilised by hydrothermal fluids, and this assumption underpins their use in petrogenetic interpretations. However, there is good evidence for mobility of PGE and Ni under some circumstances. The conditions favourable for hydrothermal modification of originally magmatic abundances of Ni and PGEs are poorly known, and very few studies to date have systematically examined their mobility. This study aims to

address that deficit by investigating distributions of these elements in fresh and altered rocks from a well-characterised, texturally homogeneous disseminated sulphide orebody that has undergone a variety of styles of localised alteration.

Nickel is known to be among the least soluble first-row transition metal in most common geological fluids (Liu et al., 2012). Likewise the platinum group elements are known to have very low solubilities in association with common ligands. Reviewing the extensive literature on PGE solubility in aqueous fluids (e.g. Gammons, 1995, 1996; Mountain and Wood, 1988), Barnes and Liu (2012) concluded that Pt and Pd could readily be soluble as bisulphide complexes in acidic fluids and reduced conditions, and as chloride complexes in unusually acidic and oxidised conditions, accounting for the dispersion and concentration of Pt and Pd in some specific hydrothermal environments. Based on ab initio molecular dynamic modelling backed up by experiments, Mei et al. (2015) showed that Pd is mainly carried as the $\text{Pd}(\text{HS})_4^{2-}$ hydrosulfide complex at neutral-alkaline and reduced (pyrite/pyrrhotite stable) conditions, and as the PdCl_4^{2-} chloride complex at

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acidic and oxidised conditions. At 300 °C, significant Pd mobility at ppb level as Pd bisulfide complexes is predicted under fluid-buffered conditions (e.g., pH ~ 7–8, near HS-/H₂S(aq) pH buffer), but only limited Pd solubility is predicted under rock-buffered conditions (e.g., pH ~ 4–5, quartz–feldspar–muscovite buffer).

Many examples show the importance of hydrothermal remobilisation during the modification or the genesis of Ni–Cu and/or PGE rich ore. Evidence for variations in metal distribution and tenors due to hydrothermal remobilisation has been documented at the Donaldson West Deposit in Québec (Dillon-Leitch et al., 1986), at various locations within the Sudbury Igneous Complex in Canada, such as the Fraser mine, the Barnet property, the Strathcona mine and the McCreedy West mine (Farrow and Watkinson, 1997), at Ni sulphide deposits around the Kambalda Dome in Western Australia (Heath et al., 2001; Lesher and Keays, 1984) and at the Jinbaoshan Pd–Pt deposit in South West China (Wang et al., 2008). Gal et al. (2011) describe PGE minerals associated with the products of Cl-rich late magmatic or hydrothermal fluids in contact rocks of the Duluth Complex, although no whole-rock concentrations were reported. Several PGE-rich ores of hydrothermal origin have also been described over the years, such as the PGE-rich ore formed within cross-cutting faults at the Fortaleza de Minas deposit in Brazil (De Almeida et al., 2007), the low-S Cu–Ni–PGE footwall ores at Sudbury in Canada (Farrow and Watkinson, 1997; Hanley and Mungall, 2003; Molnár et al., 2001a, 2001b; Molnár and Watkinson, 2001), the McBratney deposit in Canada (Bursztyn and Olivo, 2010), and the high Pt concentrations observed in dunite pipes in the Bushveld Complex which are generally regarded as being hydrothermal in origin (Schiffries, 1976). Elevated Pt and Pd contents are found in some porphyry Cu–Au systems (Augé et al., 2005; Economou-Eliopoulos, 1991; LeFort et al., 2011) and unconformity-type uranium deposits (Jaireth, 1992; Mernagh et al., 1994). Finally, several nickel deposits such as the Avebury deposit in Tasmania (Keays and Jowitt, 2013), the Epoch deposit in Zimbabwe (Pirajno and González-Álvarez, 2013), the Doriri Creek deposit in Papua New Guinea (González-Álvarez et al., 2013) and the Enterprise sediment-hosted Ni deposit in Zambia (Capistrant et al., 2015) have been interpreted as having a hydrothermal origin.

Given the wide range of examples of hydrothermal remobilisation of Ni and PGEs, it is necessary to critically examine the common assumption that these elements can be reliably used as alteration-stable trace elements in petrogenetic studies of hydrothermally altered rocks. Barnes and Liu (2012) made a case for relative immobility of PGEs during serpentinisation and talc carbonate alteration of ultramafic

rocks (komatiites) in Archaean greenstone terranes, but apart from that study no systematic investigations on the scale and the conditions of PGE mobility in altered rocks exist. Our study uses the Kevitsa Ni–Cu–PGE ore deposit, Finland, as a natural laboratory to test the behaviour of base metals and PGEs during vein-related hydrothermal alteration.

The Kevitsa mineralised ultramafic intrusion has been the subject of many studies which provide good constraints on its geometry, internal compositional variations in base metals and PGE, intensity and distribution of the various hydrothermal alteration styles, and on the main structures possibly affecting the system (Gervilla and Kojonen, 2002; Grinenko et al., 2003; Hanski et al., 2001; Mutanen, 1997; Mutanen and Huhma, 2001; Standing et al., 2009; Yang et al., 2013; Santaguida et al., 2015). The Kevitsa deposit shows a wide range of primary metal tenors, in texturally homogeneous disseminated ores, with rock types ranging from essentially fresh igneous pyroxenites and peridotites to extensively hydrated amphibolites showing a range of different alteration assemblages (Mutanen, 1997). Hence, this deposit is perfect to study the effects of hydrothermal alteration on metal tenors and grades of the sulphides. Our work also addresses specific claims made in previous work (Mutanen, 1997; Standing et al., 2009) that alteration has resulted in significant modification of sulphide and metal concentrations.

2. Geological background

The ca. 2.06 Ga Kevitsa intrusion (Mutanen, 1997; Mutanen and Huhma, 2001) is located in the Central Lapland greenstone belt in northern Finland (Fig. 1A). It is part of a suite of small- to medium-sized mafic–ultramafic intrusions occurring in the area, including the large ca. 2.44 Ga Koitelainen layered intrusion (Mutanen, 1997) as well as the neighbouring Sakatti intrusion hosting the Sakatti Cu–Ni deposit (Coppard et al., 2013), which has not yet been dated.

The Central Lapland greenstone belt, which spans a range of ages from ~2400 Ma to ~1800 Ma, is mainly composed of volcanic rocks ranging from komatiites (Hanski et al., 2001; Heggie et al., 2013) to rhyolites, intercalated with thick sequences of quartzitic to pelitic sedimentary rocks (Hanski and Huhma, 2005; Lehtonen et al., 1998). The Kevitsa intrusion was emplaced into mica schists and black schists of the Matarakoski Formation and is thought to be roughly contemporaneous with komatiitic volcanic rocks (ca. 2.06 Ga; Hanski et al., 2001) which occur in the vicinity of the intrusion (Fig. 1). The Kevitsa intrusion occupies a surface area of approximately 16 km² and consists of a lower ultramafic unit up to 2 km in thickness, overlain in an uncertain

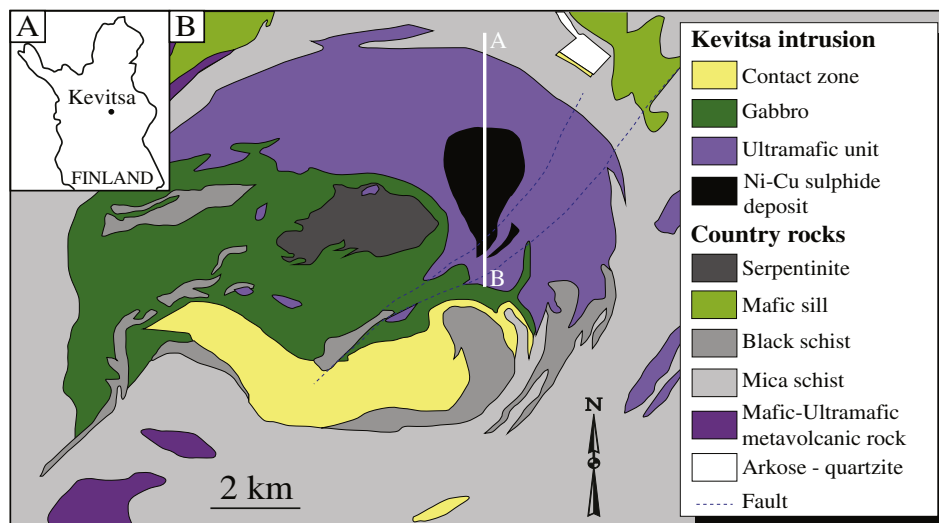


Fig. 1. A) Location of the Kevitsa intrusion in the Central Lapland greenstone belt, northern Finland (after Hanski et al., 2001). B) Simplified geological map of the Kevitsa intrusion (after Mutanen, 1997). Section A–B is presented in Fig. 2.

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