



Magmatic Cu-Ni-PGE-Au sulfide mineralisation in alkaline igneous systems: An example from the Sron Garbh intrusion, Tyndrum, Scotland



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ABSTRACT

Magmatic sulfide deposits typically occur in ultramafic-mafic systems, however, mineralisation can occur in more intermediate and alkaline magmas. Sron Garbh is an appinite-diorite intrusion emplaced into Dalradian metasediments in the Tyndrum area of Scotland that hosts magmatic Cu-Ni-PGE-Au sulfide mineralisation in the appinitic portion. It is thus an example of magmatic sulfide mineralisation hosted by alkaline rocks, and is the most significantly mineralised appinitic intrusion known in the British Isles. The intrusion is irregularly shaped, with an appinite rim, comprising amphibole cumulates classed as vogesites. The central portion of the intrusion is comprised of unmineralised, but pyrite-bearing, diorites. Both appinites and diorites have similar trace element geochemistry that suggests the diorite is a more fractionated differentiate of the appinite from a common source that can be classed with the high Ba-Sr intrusions of the Scottish Caledonides. Mineralisation is present as a disseminated, primary chalcopyrite-pyrite-PGM assemblage and a blebby, pyrite-chalcopyrite assemblage with significant Co-As-rich pyrite. Both assemblages contain minor millerite and Ni-Co-As-sulfides. The mineralisation is Cu-, PPGE-, and Au-rich and IPGE-poor and the platinum group mineral assemblage is overwhelmingly dominated by Pd minerals; however, the bulk rock Pt/Pd ratio is around 0.8. Laser ablation analysis of the sulfides reveals that pyrite and the Ni-Co-sulfides are the primary host for Pt, which is present in solid solution in concentrations of up to 22 ppm in pyrite. Good correlations between all base and precious metals indicate very little hydrothermal remobilisation of metals despite some evidence of secondary pyrite and PGM. Sulfur isotope data indicate some crustal S in the magmatic sulfide assemblages. The source of this is unlikely to have been the local quartzites, but S-rich Dalradian sediments present at depth. The generation of magmatic Cu-Ni-PGE-Au mineralisation at Sron Garbh can be attributed to post-collisional slab drop off that allowed hydrous, low-degree partial melting to take place that produced a Cu-PPGE-Au-enriched melt, which ascended through the crust, assimilating crustal S from the Dalradian sediments. The presence of a number of PGE-enriched sulfide occurrences in appinitic intrusions across the Scottish Caledonides indicates that the region contains certain features that make it more prospective than other alkaline provinces worldwide, which may be linked to the post-Caledonian slab drop off event. We propose that the incongruent melting of pre-existing magmatic sulfides or 'refertilised' mantle in low-degree partial melts can produce characteristically fractionated, Cu-PPGE-Au-semi metal bearing, hydrous, alkali melts, which, if they undergo sulfide saturation, have the potential to produce alkaline-hosted magmatic sulfide deposits.

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1. Introduction

Typical magmatic Ni-Cu-platinum-group element (PGE) sulfide deposits occur in five major settings in magmatic systems that are almost exclusively ultramafic-mafic in their composition (e.g. Maier, 2005; Naldrett, 2011; Barnes et al., 2016): (1) stratiform reef style deposits

mostly in the lower parts of layered intrusions, often linked with magma mixing (e.g. Merensky Reef, Bushveld Complex; J-M Reef, Stillwater Complex; Naldrett, 2011; Naldrett et al., 2011; Campbell et al., 1983); (2) deposits located in the conduits and along the margins of such intrusions, often linked with crustal contamination (e.g. Noril'sk, Voisey's Bay; Naldrett, 2011; Ripley and Li, 2011; Arndt, 2011); (3) sulfide disseminations, commonly PGE-rich, in the marginal facies of large layered intrusions; the Platreef of the Bushveld Complex is the type example (McDonald and Holwell, 2011); (4) accumulations of widely varying proportions of sulfide in komatiite lava flows (e.g., Barnes,

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2006; Leshner, 1989; Leshner and Keays, 2002) or associated shallow subvolcanic intrusions; and (5) in the unique impact melt setting of the Sudbury Igneous Complex (e.g. Keays and Lightfoot, 2004). The presence of magmatic Ni-Cu-PGE mineralisation in appinitic/lamprophyric intrusions that are more intermediate and alkaline in their composition represents a poorly documented and highly unusual setting for such deposits; though they have been noted in the Mordor Alkaline Igneous Complex, Australia (Barnes et al., 2008).

Appinite intrusions are located throughout the Scottish and Irish Dalradian belt and are considered a characteristic feature of the post-Caledonian magmatism of the region (e.g. Fowler and Henney, 1996). The ultrabasic-intermediate composition appinites are usually considered to be the plutonic equivalents of hornblende-rich lamprophyres (vogesites and spessartite), are often misclassified as diorites, and are associated with granitic intrusions (Barnes et al., 1986; Power et al., 2004). In Scotland, these appinite-diorite intrusions are part of the Argyll and Northern Highlands intrusive suites, which belong to a high Ba-Sr (HiBaSr) sub-class of igneous rocks (Tarney and Jones, 1994 and references therein). They are interpreted to be related to a post-collisional, regional-scale slab drop-off event commencing at c. 430 Ma (Neilson et al., 2009). Rare examples of the alkaline intrusions of similar age containing magmatic Cu-Ni-PGE mineralisation occur in southern Scotland at Talnoy (Power et al., 2004) and at Loch Ailsh and Loch Borralan in the Moine Thrust belt of northern Scotland (Gunn and Styles, 2002; Fig. 1). In this paper, we describe a previously unidentified Cu-Ni-PGE-Au mineralised appinite-diorite intrusion in the Tyndrum area of Scotland at Sron Garbh.

This study provides the first description and classification of the field relations, petrology, base and precious metal mineralogy and geochemistry of the Sron Garbh appinite intrusion and its Cu-Ni-PGE-Au mineralisation. In combination with an S-isotope study of sulfides in the intrusion and the country rocks, we are able to provide a number

of constraints on a petrogenetic and emplacement model for Sron Garbh. The significance of this occurrence of mineralised appinite is then discussed in terms of the implications for PGE mineralisation in similar systems throughout the Caledonides of the British Isles, and lamprophyric magmas in general. We propose a model for PGE-enrichment in these alkaline systems to be primarily linked to slab drop off and hydrous remelting of mantle wedge material.

2. Regional geological setting

The Sron Garbh intrusion is located in Glen Orchy, in the Scottish Caledonides, and is part of a suite of magmatic intrusions across northern Britain emplaced into the Dalradian Supergroup (Fig. 1) during a regional episode of widespread post-collisional (Tarney and Jones, 1994) magmatism c. 430–408 Ma (Neilson et al., 2009). The Dalradian Supergroup is composed of marine clastic sediments with occasional carbonate and volcanic horizons, and has a depositional history ranging from c. 800 Ma in the Neoproterozoic (Cryogenian) to c. 510 Ma in the mid-Cambrian (Cowie et al., 1972; Tanner and Sutherland, 2007; Stephenson et al., 2013). The Dalradian sequence in the Grampian Terrane (Fig. 1) is composed of: (1) the Grampian Group, comprising psammities and semi-pelites deposited in an extensional basin; (2) the Appin Group: a limestone-pelite-quartzite assemblage from a stable shelf environment (Wright, 1988); (3) the Argyll Group, composed of black slate, graphitic schist, mafic lavas and sills, and coarse turbidite sequences (Anderson, 1985) with some locally developed sedimentary exhalative (SEDEX) mineralisation (Stephenson et al., 2013); and (4) the Southern Highland Group of greywackes with volcanoclastic green beds.

The Dalradian Supergroup underwent polyphase deformation during the earliest phase of the Caledonian Orogeny: the Grampian event (e.g. Soper et al., 1992) in the mid Ordovician. This was responsible for

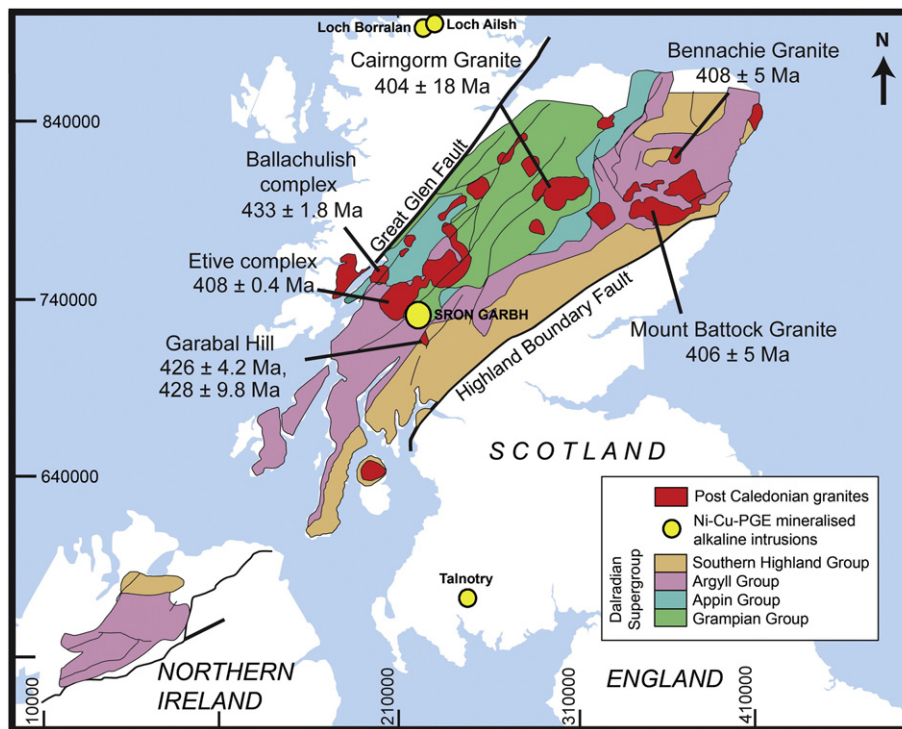


Fig. 1. Simplified regional geological map of Scotland and Northern Ireland showing the post-Caledonian intrusives, the Dalradian Supergroup and Cu-Ni-PGE-Au mineralised alkaline intrusions. The Grampian terrane lies between the Highland Boundary Fault and the Great Glen Fault. Dates for post-collisional intrusives are taken from; Conliffe et al. (2010); Neilson et al. (2009); Oliver et al. (2008). Adapted from Hill et al. (2013).

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