Platinum-bearing magmatic rocks of the Southern Brook Street Terrane, South Island, New Zealand

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Abstract

Major occurrences of platinum group minerals (PGM) are in crustally-contaminated, huge, layered igneous complexes (Bushveld and Stillwater) and gabbroic intrusions (Norilsk); relatively minor occurrences include arc-related "zoned Alaskan ultramafics". In terms of arc-related provenances, the recognition of alluvial PGM in river and beach deposits of southern South Island (Mitchell, 1995), in-situ in the Longwoods (Cowden et al., 1990), and the ultramafic-mafic layered Greenhills Complex at Bluff (Spandler et al., 2000) raise the possibility that some economically-significant PGM deposits may exist in New Zealand. The Longwoods and Greenhills are in the Brook Street Terrane which is a remnant of a primitive intra-oceanic arc system of Late Permian-Early Triassic age. The Terrane comprises volcanogenic sequences containing plagioclase- and clinopyroxene-phyric basalts, high-MgO ankaramite and dolerite dikes, trondhjemite plutons, and basaltic to andesitic volcaniclastic and sedimentary rocks. The cumulate complexes contain early-formed olivine- and clinopyroxene-rich ultramafic cumulates overlain by anorthite and hornblende-bearing gabbros. Primary (isoferroplatinum) and secondary (sperrylite) platinum group minerals are preserved in chrome-rich spinel pods in basal dunite of the Greenhills Complex. Saturation during early fractionation of primitive high-MgO magmas rather than magma mixing seems likely for the primary PGM. Together with correlative terranes in Queensland and New Caledonia, the Brooks Street Terrane is an exposed cross-section of an extensive Permo-Triassic island-arc system. Most parental magmas were primitive island-arc tholeiites, but other primary magma-types include high–MgO ankaramites and trondhjemites – the latter formed by partial melting of lower crustal clinopyroxene-rich cumulates and gabbros, respectively. The parental ankaramites fractionated to form mafic-ultramafic cumulates and primitive to evolved melts of high-Al basalt to andesite compositions (Takitimus). The Brook Street Terrane is an analogue for modern intra-oceanic island-arc systems and allows detailed study of subvolcanic arc processes.

Introduction

Due to high relative insolubilities of Pt and Pd in basaltic magmas, saturation with PGM is known experimentally to occur early in the crystallisation sequence. Other mechanisms for saturation however, especially in some of the world's largest and economically significant deposits, (Merensky – Bushveld; JM Reef – Stillwater) include magma mixing wherein one of the magmas bears the PG elements and the other sulfur. Development of large PGM deposits in either case requires of course large volumes of magma and comparatively rare events such as the impact of a mantle plume head with the continental crust. A relatively minor occurrence of PGM is within island arc-related plutonic bodies such as the "zoned Alaskan ultramafics". While the potential for discovery of huge layered plutons in New Zealand is minimal, the possibility of relatively small volume PGM deposits developed in island arc-associated plutons seems more reasonable. However, if there is a requirement that such deposits only become developed in primitive cumulate fractions, then the general paucity of exposure of such materials in arc terranes makes exploration difficult.

Apart from the economic aspects there is also significant interest in the general issues associated with the character of overall mantle-derived, arc magmatic fluxes, and the nature of crust-mantle structure in arcs. Currently, the volumetrically most significant magma flux from the mantle wedge in suprasubduction zone systems is subalkaline basalt containing variable amounts of water but typically <6 wt%. The critically important feature of the crystallization of these comparatively wet magmas is the sequence spinel-olivine-clinopyroxene-plagioclase, wherein the earliest cumulate fraction is dominated by dunites and wehrlites, unlike the sequences/assemblages at mid-ocean ridges where troctolites are associated with dunites because of the reversal of clinopyroxene and plagioclase crystallisation order. A persistence in spinel fractionation accompanied by delay in plagioclase crystallisation (plus the shift to Si-poor, Ca-rich anorthitic compositions once saturation is reached) are important in generating the low-FeO/MgO magmatic evolutionary trends, and relatively large volumes of continental crust-building, dacitic-rhyolitic fractionates in arc systems. We know that saturation with PGM also occurs early in the crystallisation sequence of subalkaline magmas, depending on oxygen and sulfur fugacities of the magma(s).

The anticipated large volumes of dunite-wehrlite cumulates are not obvious in the seismically well-determined cross-sections of intra-oceanic arcs but given the seismic wave velocities of dunite-wehrlite cumulates are relatively high (V_p>8 kms^{-1}), these cumulates would be assigned to sub-Moho depths. In terms of overall magma flux calculations however, these cumulates should be included together with the supra-Moho volumes. Generally, there are few examples of these cumulates world-wide in exhumed arc crust-mantle sections. In addition to parts of the sequences exposed in Talkeetna (Alaska) and Ladakh (Pakistan), other excellent examples include the Greenhills and parts of the Longwood Complex of the Brook Street Terrane in southern New Zealand (Spandler et al., 2005).

Hot cumulates dominated by spinel-olivine-clinopyroxene (variably ± amphibole ± phlogopite) at sub-Moho depths are plausible protoliths of the relatively common albeit volumetrically minor ankaramitic arc magma type. More generally however, it is proposed (Arculus 2004) that dunite-wehrlite cumulates are incorporated into the advective motions of the mantle wedge, and recycled deeper into the mantle. Rare examples of such cumulates that have been exhumed with ultra-high pressure blueschist-eclogite sequences following subduction possibly occur in the North Qaidam Mountains of China.

The Brook Street Terrane

The Brook Street Terrane is the westernmost of a series of accreted volcano-sedimentary, Permian-Cretaceous terranes in the South Island, and is in contact with the Median Batholith to the west (Mortimer et al., 1999a). Most of the Terrane is composed of a sequence of mafic to intermediate volcanic and volcaniclastic rocks including clinopyroxene-phyric rocks, tuffs, and ankaramite dikes. Sedimentary and geochemical characteristics are consistent with an intra-oceanic setting (Tulloch et al., 1999). While dacites and rhyolites are relatively rare, contemporaneous trondhjemite plutons and ultramafic-mafic cumulate complexes intrude the supracrustal sequences. Simplified geological maps of some of the southernmost plutonic and volcanic localities are shown in Figure 1. In the following, the petrologic aspects of these localities are described.

Bluff Peninsula

A number of cumulate complexes intrude sediments of the Greenhills Group; low grades of metamorphism constrain emplacement depths to <10 km. The Bluff and Flat Hills complexes at the southern end of the Peninsula comprise massive to layered gabbro-norite with minor amounts of olivine, amphibole, and magnetite, cut by many thin mafic dikes. The Greenhills Complex is located in the northern Peninsula, and comprises 2 bowl-shaped intrusions enclosed by a gabbroic ring dike. Cumulates include dunite, olivine clinopyroxenite, olivine gabbro, and hornblende gabbro-norite. PGMs in dunite-hosted, Cr-rich spinel schlieren occur in the south of the Complex, and are primary isoferroplatinum (Pt_3Fe) and secondary sperrylite ($PtAs_2$) (Spandler et al., 2000).

Based on a study of integrated melt inclusion compositions, it is clear that all of the cumulate rocks of the Greenhills Complex formed from a common, low-K island arc tholeiite parent magma of ankaramitic affinity (Spandler et al., 2000; 2003). Together with trace amounts of isoferroplatinum, olivine (Fo_{92-86}) and chromian spinel (Cr/(Cr+Al)= 79-57) were the first phases to crystallise followed closely by Cr-rich diopside (Mg/(Mg+Fe) = 91-83). Relatively late-crystallising minerals include calcic plagioclase (An_{96-82}), magnetite, hornblende, and orthopyroxene. Numerous mafic dikes of low-K island arc tholeiite and ankaramite intrude the Complex, together with high-Al basalt dikes that were formed by fractional crystallisation of spinel-olivine-clinopyroxene from the parental tholeiites.

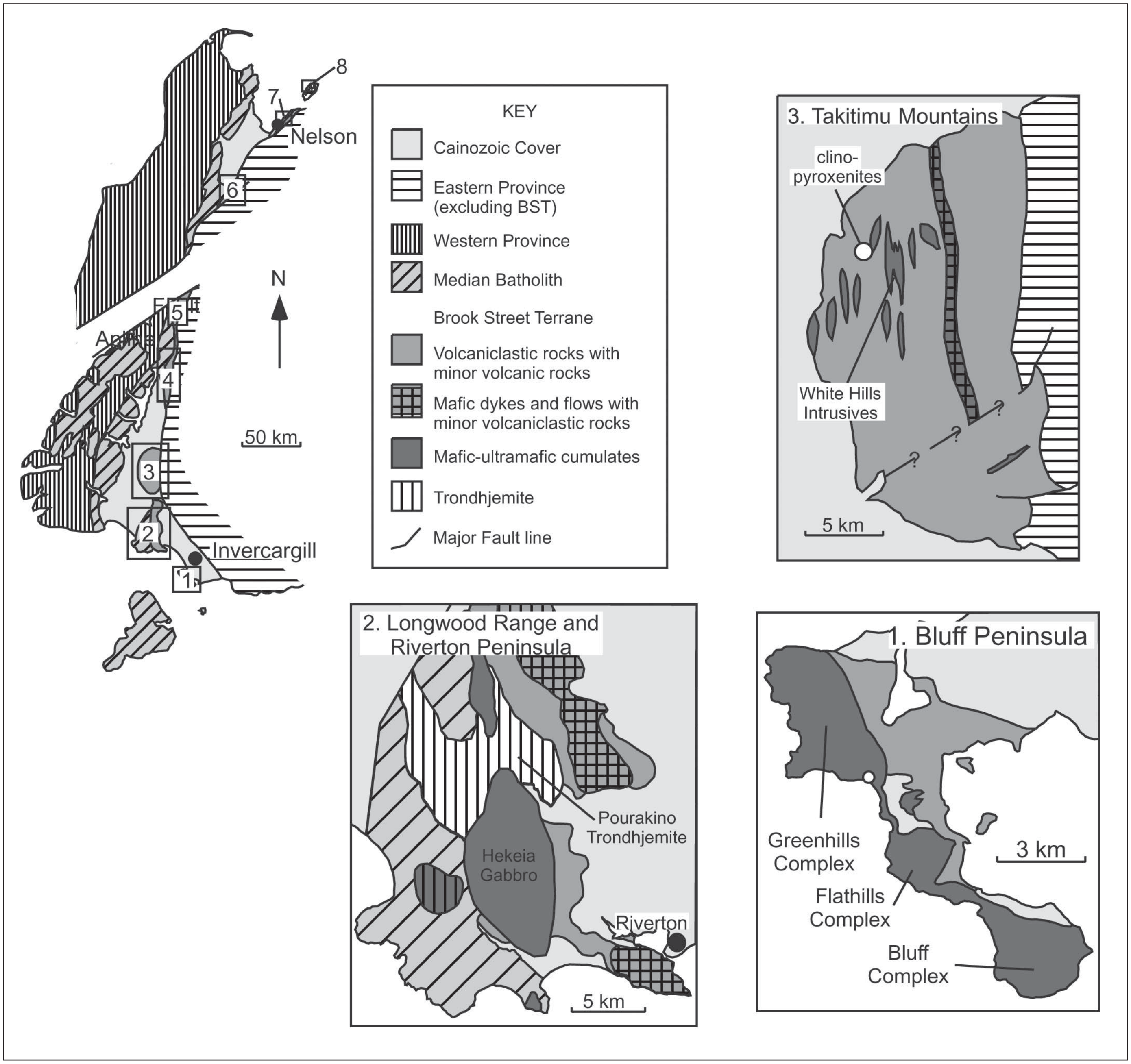

Figure 1. Simplified geological maps of the arc-related cumulate and volcanic sequences of the southern Brook Street Terrane. Additional localities of similar sequences are: 4. Eglinton Valley; 5. Skippers Range; 6. St Arnaud; 7. Nelson; 8. D Urville Island.

Riverton Peninsula and Longwood Range

A 6 to 7 km thick sequence of mafic volcaniclastic and volcanic rocks (including sheet-and pillowed flows at the present coastline) extends from the Riverton Peninsula along the eastern flank of the Longwood Range (Fig. 1). The volcaniclastic rocks are predominantly fine-grained crystal-lithic mafic tuffs. The plutonic component of the Longwoods Complex in Southland overlaps the eastern boundary of the Median Batholith (Mortimer et al.,1999a), and consists of a wide variety of coarse-grained rocks including olivine-, pyroxene-, and amphibole-bearing ultramafic rocks, gabbros, troctolites, diorites, granites, and trondhjemites (Price & Sinton, 1978). The Complex has attracted attention because of the PGM mineralization potential (Cowden et al., 1990). In 1998, Anzex Resources reported 1 m of 1.05 gpt and 2 m of 0.81 gpt of Pt/Pd in troctolite, melatroctolite, anorthosite, and olivine gabbro in the Complex. The most extensive outcrops in the Range are the Hekeia Gabbro and Pourakino trondhjemite; the former comprises layered cumulates of anorthite-bearing peridotite, troctolite, olivine gabbro, gabbro-norite, and anorthosite with mineral compositions typical of some arc cumulates, while the latter is a plagioclase-rich composite pluton with high, adakite-like Sr/Y (Mortimer et al., 1999b). The early appearance of plagioclase in the crystallisation sequence of the Longwood Range is unique among Brook Street Terrane cumulates, and unusual for arcs in general.

Takitimu Mountains

The Takitimus are underlain by a 14-16 km thick sequence of N-S striking, easterly-dipping volcanogenic rocks. Five basalt to rhyodacite, volcanic-volcaniclastic units make up the Takitimu Group (Houghton, 1981). High-Al arc basalts and andesites with phenocrysts of anorthitic plagioclase, Al-rich augite, and pargasite are the most common rock types in this Group, together with minor ankaramite flows and dikes. The ankaramites contain phenocrysts of olivine, Cr-rich diopside, and chromian spinel. Numerous gabbroic and dioritic sills that have intruded the Takitimu Group outcrop on the western flank of the Takitimus. Individual intrusions are d”700 m thick, d”10 km in strike length, and are collectively known as the White Hills Intrusive Suite (Houghton, 1986). Most of this Suite comprises clinopyroxene- or plagioclase-rich gabbroic cumulates with >5% magnetite. Inter-cumulus olivine and amphibole are minor constituents of many rocks. Although only found as xenoliths in basalt and boulder float, other rock types include wehrlite, clinopyroxenite, and hornblende clinopyroxenite and are likely to represent the plutonic levels of the predominantly volcanic Takitimu sequences as well as forming a potential source of the alluvial PGM occurrences in the nearby Waiau River (Mitchell, 1995). Overall, the mineralogy and crystallization sequence of the White Hills Intrusive Suite and Greenhills Complex are similar.

Concluding remarks

The exposure of arc-related, ultramafic-mafic cumulate sequences in the southern Brook Street Terrane is of interest for a number of reasons: the first is the opportunity for study of deep-seated, sub-volcanic processes that are not observable in active arc systems; second is the apparent high-level of intrusion of the cumulates and presumable relatively thin crust in which the sequences were emplaced, given the absence of such rock types in seismic studies of active arc crustal structures such as the Izu-Bonin and Marianas; third is the potential variety of PGM-hosting cumulate sequences from the dunites of the Greenhills to the plagioclase-rich sequences of the Longwoods. The latter are more similar to the lithologies surrounding the JM Reef in the Stillwater Intrusion and may indicate a major role for magma mixing in the Longwoods.

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