Synopsis
The Platreef is a platinum-group element (PGE) deposit in the form of a mafic–ultramafic, tabular body at the base of the northern (Potgietersrus) limb of the 2050 m.y. Bushveld Igneous Complex. The reef transgresses sedimentary floor rocks (footwall) of the 2600–2200 m.y. Transvaal Supergroup and the Archaean granite basement. The roof rocks (hangingwall) of the reef are PGE-free Main Zone gabbronorites of the Rustenburg Layered Suite. At the Sandsloot open-pit mine the Platreef consists of coarse to pegmatoidal pyroxenites and gabbros with accessory plagiopside, base-metal sulphides and oxides. Thermal metamorphism of siliceous dolomites that form the footwall has produced clinopyroxenites and calc-silicate hornfelses with a variety of skarn assemblages. These were subjected to later hydrothermal alteration and serpentization that also affected parts of the Platreef.

The link between sulphides and PGE in the Platreef has led previous authors to consider the mineralization as an orthomagmatic sulphide deposit, where sulphide separation collected PGE from a large volume of melt. In the reef and footwall, however, the development of extensive alteration zones with high concentrations of PGE- and semi-metal (Te, Sb, Se, Bi and Ge)-bearing platinum-group minerals that are typical of many low-temperature PGE deposits suggests syn- to post-magmatic crystallization or redistribution of PGE by hydrothermal fluids. The results obtained to date in a new study suggest that the Platreef at Sandsloot is a complex PGE deposit that has been subject to a number of different processes during its development.

Regional overview
From south to north the mafic rocks of the northern Bushveld limb transgress progressively lower units of the 2600–2200 m.y. sedimentary Transvaal Supergroup (Fig. 1). These units are the Magaliesberg quartzites and shales of the Pretoria Group and the Penge Banded Iron Formation and Malmani Dolomite of the Chuniespoort Group. The Malmani Dolomite wedges out north of the Sandsloot mine, where the Platreef comes into direct contact with Archaean granite basement. Main Zone gabbronorites of the Rustenburg Layered Suite constitute the roof rocks (hanging-wall) of the Platreef along its entire strike length. The Platreef appears to continue south of Potgietersrus and may become part of the normal Bushveld stratigraphic sequence rather than a marginal facies. To the south of Potgietersrus the Zebediela Fault juxtaposes the Platreef against the Panarozoi Karoo sedimentary sequence (Fig. 1). In the north the Platreef is covered by 1800-m.y. Waterberg volcano-sedimentary rocks. A gravity high just west of Potgietersrus is thought to represent the throat or feeder of the northern limb, and differentiation indices suggest at least four major influxes of fresh, undifferentiated magma.10

North of Sandsloot the Platreef has been divided into three main units: (1) a PGE-poor, upper feldspathic pyroxenite (‘C-reef’) in contact with the hanging-wall of Main Zone gabbronorites; (2) a medium- to coarse-grained pyroxenite (‘B-reef’); and (3) a lower, generally coarse-grained felds-
pathic pyroxenite (‘A-reef’) in contact with a dolomitic or granitic footwall. The thickness of the reef units varies along strike, and the B- and A-reefs are major economic targets. In the present study only B-reef pyroxenites and gabbrros have been identified with certainty at Sandsloot.

**Structure**

Three linear geological features may have controlled the emplacement of the northern Bushveld limb. These are the northeast-striking Eersteling Basin, the northwest-trending,
2900-m.y. Usushwana basic dyke complex and a north–south chain of igneous bodies from the Great Dyke in Zimbabwe to the Trompsburg Complex in the south. The intersection of these three features just west of Potgietersrus coincides with the interpreted feeder of the northern Bushveld limb. Regionally, north–south- and WSW–ESE-trending fold structures have been identified. The sinuous trace of the northern Bushveld limb appears to reflect a megascopic WSW–ENE-trending fold in the Transvaal Supergroup. More locally, a characteristic feature of the Sandloot area is the ‘dolomite tongue’ at the south end of the Sandloot pit (Fig. 1), which is a shallowly plunging antiform or possibly a dome. The Platreef appears to be concordant with the ‘dolomite tongue’, i.e. enveloped around it, suggesting late- or post-tectonic intrusion of the reef. Pre-existing fold structures have been proposed to explain the presence of ‘footwall domes’ in the eastern Bushveld lobe that compartmentalized the Lower Zone and Critical Zone magmas in that area. Compartmentalization of Lower Zone rocks around Potgietersrus may reflect similar pre-existing structures on the northern Bushveld limb that controlled the intrusion of the Platreef magma.

It is argued on the basis of geothermobarometry that the metamorphic aureole in the Potgietersrus area was generated in two stages. The first event was related to emplacement of Lower Zone magma and is estimated to have attained 750°C at 1.5 kbar pressure. The second records the intrusion of the more voluminous gabbroic magmas of the Upper Critical, Main and Upper Zones, with equilibrium temperatures and pressures of about 900°C and 4–5 kbar. The higher pressure of the second event has been interpreted to reflect an elevated deviatoric stress component that generated a large fold in the floor rocks of the BIC.

Methods

The down-stepping benches of the Sandloot open-pit have sub-vertical rock faces approximately 15 m high, and parts of faces that expose complete sections across the Platreef were mapped at 1 : 100 scale (Fig. 2). The mapped sections were delimited by spray-painting geopoints on the faces, whose latitude, longitude and elevation were established by the mine surveyors using global positioning. About 200 samples were collected from most of the major reef and footwall lithologies at 2–5-m intervals along each rock face and at spot localities of particular interest—for example, in areas of abrupt lithological variation. Samples selected for microscopy and geochemical analysis were then cut into three parts. One part was for preparation of thin sections and polished blocks, another part was powdered in an agate tetta mill and the remaining part was stored as spare material. Thin sections and blocks were examined under microscopes in transmitted and reflected light. Detailed mineralogical examination and analysis were performed at the University of Greenwich with a JEOL JSM-5310LV scanning-electron microscope and energy-dispersive spectrometer with the aid of Oxford Instruments’ ISIS 300 software suite.

Bulk analysis for PGE and Au was carried out on a selected group of samples using NiS fire-assay collection followed by inductively coupled plasma–mass spectrometry at the

Table 1 PGE and Au concentrations, ppb, and ratios for Platreef lithologies. For comparison, data are also given for the Merensky Reef (SARM-7 preferred values from Steele and co-workers) and the UG2 chromitite

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lithology</th>
<th>Ir</th>
<th>Ru</th>
<th>Rh</th>
<th>Pt</th>
<th>Pd</th>
<th>Au</th>
<th>Ru/Ir</th>
<th>Rh/Ir</th>
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<td>54</td>
<td>84.0</td>
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<td>103</td>
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<td>220</td>
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Fig. 2 Wireframe plan view of Sandloot open-pit mine in July, 2000, showing approximate locations of geological face maps in Figs. 3 and 4. Solid black outline/bench tops, stippled grey lines/bench feet. Deepest part of pit (southern central area) is approximately 190 m.
University of Greenwich. Details of the methodology and instrumentation have been given by Huber et al. The precision was determined by repeat analyses of a sub-suite of high- and low-grade samples. The precision was 10–15% at PGE concentrations <5 ppb and 5–10% at concentrations between 10 and 1000 ppb, but became worse again in samples with PGE concentrations >1000 ppb owing to the nugget effect; in these samples it was 10–25%. Accuracy was determined by repeat analysis of the standard WPR-1. Solutions prepared from PGE-rich samples were diluted by an additional factor of 50 to give comparable concentrations with the range of calibration standards. The PGE and Au data are reported in Table 1.

**Platreef and associated units at Sandsloot**

Two face maps that show the typical relationships of hanging-wall, reef and footwall lithologies are presented in Figs. 3 and 4 and brief field descriptions of the major lithologies are given below. The first map is a northeast-facing exposure on bench 41 in the southwest part of the Sandsloot mine. It exhibits a cross-strike section through the Platreef where the reef has an approximately southwest–northeast strike and a moderate to steep dip to the northwest. The second face map is a south-facing exposure on bench 32 in the central part of the pit. Again, it displays a cross-strike section through the Platreef, and here the reef displays its typical, approximately north–south strike and moderate dip to the west. The difference in the strike of the reef between the two rock faces is due to the emplacement of the reef around the antiform ‘dolomite tongue’.

**Hanging-wall gabbronorite**

The hanging-wall of the Platreef consists of fairly homogeneous gabbronorite representative of the Main Zone elsewhere in the BIC. An abrupt change in pyroxene composition between the Platreef (bronzite) and hanging-wall (inverted pigeonite) has been cited as evidence that the hanging-wall formed from a separate magma. Some exposures of the hanging-wall contact at Sandsloot show an essentially planar magmatic boundary (e.g. Fig. 4). Wagner reported veins of hanging-wall gabbronorite cutting the Platreef in 1920s exploration trenches at Sandsloot, but in the sections studied by the present authors it is not clear whether the Platreef or hanging-wall gabbronorite was the younger magma. In other exposures the contact is tectonized, exhibiting a heavily serpentinized, brittle–ductile shear zone up to 20 cm thick (e.g. Fig. 3).

The most common variety of hanging-wall gabbronorite is a medium- to coarse-grained, isotropic assemblage of 50 modal% plagioclase, 35% orthopyroxene and 15% clinopyroxene. Its appearance is transitional between leuco- and melanocratic. The modal content of pyroxene can be as high as 75% in the darkest melanorites and as low as 30% in the palest leuconorites. Accessory phases, such as phlogopite, oxides and sulphides, account for up to 5% of the modal mineralogy. The pyroxenes are dark grey to dark grey-green and have a subhedral to ragged habit, sometimes forming large aggregates. Plagioclase occurs as randomly orientated laths. Xenoliths of calc-silicate hornfels that constitute the bulk of the footwall to the Platreef occur sporadically in the hanging-wall gabbronorites.

**The Platreef**

The Platreef at Sandsloot consists of pyroxenites and gabbrons, mostly in a virtually unaltered state but in places showing considerable serpentinization. No conclusive evidence has yet been found for the spatial and temporal relationship of the pyroxenites and gabbrons. The thickness of the Platreef varies from a few metres to about 30 m at several localities in the central and southwest parts of the Sandsloot pit. The contact with the footwall lithologies is irregular, and variably altered footwall xenoliths up to several metres in diameter occur sporadically in the reef. Chilled margins have
not been found in the Platreef at the footwall contact, hanging-wall contact or around xenoliths. In face 132/038 (Fig. 3) a dyke-like body of aplitic gabbro with pegmatitic pods stands between the Platreef gabbro and the coarse, serpentinized clinopyroxenite of the footwall. The composition of the partly pegmatitic aplitic body appears to be the same as that of the Platreef gabbro and may represent an elongate pod of residual Platreef melt.

Pyroxenites

B-reef pyroxenites dominate the Platreef in the southwest part of the Sandsloot pit. They are commonly coarse-grained, dark grey-green assemblages of anhedral to subhedral orthopyroxene (60–90 modal%) with a subordinate content of intercumulus clinopyroxene (10–40%). Postcumulus plagioclase occurs locally in small pods and constitutes up to 15% of the modal mineralogy. Accessory phases are small booklets of phlogopite and finely disseminated base-metal sulphides (pyrrhotite, pentlandite, chalcopyrite, bornite, pyrite and minor galena–claustralite); minor oxides present are magnetite, ilmenite, perovskite, chromian spinel (picotite) and chromite.

Large zones within the pyroxenites have undergone varying degrees of alteration to serpentine and talc. In such zones the pyroxenes have a more rounded, ragged habit and are shot through by networks of serpentine microveins, suggesting widespread infiltration of hydrothermal fluids. The inter- and intragranular serpentine is black, giving the altered rock a distinctly darker colour than its unaltered counterpart.

Gabbros

Platreef gabbros have coarse-grained to pegmatoidal textures. Dark green orthopyroxene occurs as a sub- to euhedral cumulus phase (40–70 modal%) with dark clinopyroxene (up to 10%) in a colourless postcumulate mass of plagioclase (30–50%). Plagioclase is locally saussuritized, whereas pyroxene appears to have evaded alteration in most of the observed B-reef gabbros. Quartz is a minor phase. Other accessory and minor phases are the same as those found in the Platreef pyroxenites. However, interstitial base-metal sulphides are larger and more sporadic, rather than finely disseminated throughout the rock body as they are in the pyroxenites. Coarse gabbros occur at different stratigraphic positions in the Platreef (as large irregular pods or contiguous bodies?) and seem to dominate the central part of the pit. This is typified by face 132/038 (Fig. 3), where the reef consists almost exclusively of gabbro.

Footwall lithologies

Clinopyroxenites

A characteristically pale grey, granoblastic, diopsidic clinopyroxenite normally occurs between the Platreef and layered calc-silicate hornfelses, but the shapes of the clinopyroxenite bodies are irregular. Clinopyroxenites are also seen as elongated lenses and semi-continuous bands concordantly interlayered with calc-silicate hornfels (e.g. Fig. 3), and the boundaries between these two lithologies are usually transitional over centimetre-scale distances.

The Sandsloot mine geologists refer to the clinopyroxenite bodies as 'parapyroxenite', probably following the term originally used by Wagner,28 who evidently regarded the diopside-rich footwall lithologies as highly metamorphosed dolomites. Recent geochemical work has shown that the clinopyroxenites have a non-igneous genesis.14 The clinopyroxenites contain little Cr, whereas the ‘normal’ reef pyroxenites and gabbros have Cr contents of thousands of parts per million. Serpentine with relict cores of olivine is common and the clinopyroxenites rich in olivine also contain little Ni, whereas igneous olivine with the same Mg/Fe ratio contains thousands of parts per million Ni. Some clinopyroxenites do contain Ni, but also have high Cu contents because

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**Fig. 4** Geological map of face 132/038 in southwest part of Sandsloot pit

B40
sulphides are present as well as olivine and the Ni is contained in the sulphides. These trace-element characteristics suggest that both clinopyroxene and olivine are derived by high-grade metamorphism/metasomatism of the siliceous footwall dolomites. The paragenesis of the clinopyroxenites has involved such a thorough textural transformation that no primary layering is preserved. Further support for a metamorphic origin comes from the presence of grossular–andradite and idocrase (vesuvianite). Similar lithologies in the metamorphic aureole of the northern BIC limb are considered to reflect extreme metasomatism.7 The mineralogy of the clinopyroxenite bodies also appears to correspond to at least one of the 11 assemblage groups in calcareous rocks of the Bushveld metamorphic aureole in the Potgietersrus area identified by Nell.23

Calc-silicate hornfels and serpentinites

The calc-silicate hornfels and serpentinite footwall lithologies can be crudely described as skarns and they contain minerals that reflect a wide range of prograde and retrograde metamorphic reactions. The original sedimentary layering is clearly preserved, with a bedding thickness of 5–60 cm. Relatively unaltered footwall hornfels have a mottled beige and pale green colour. Only minor parts of the footwall are untouched by retrograde hydrothermal alteration. This alteration is mostly characterized by serpentinization of prograde metamorphic phases, such as forsterite. The colour of the footwall at any locality is usually an indication of the extent of serpentinization, such that the darkest (virtually black) zones represent extreme alteration to virtually pure serpentinite. These zones tend to take the shape of irregular bodies varying in size from a few decimetres to tens of metres and are often elongate parallel to the footwall layering. The boundaries of serpentinized zones are usually transitional, yet surprisingly sharp in a few places. Less extensive serpentinization in the hornfelses follows the original bedding, such that darker altered layers are visibly continuous. The varying degrees of alteration between layers are thought to reflect primary compositional variations.

Like the Platreef, the footwall rocks contain common base-metal sulphides, such as pyrrhotite–troilite (Fe7S8–FeS), pentlandite (Fe,Ni)9S8, chalcopyrite (CuFeS2) and bornite (Cu9FeS8), but less common base-metal sulphides occur in the footwall that have not yet been identified in the reef. These are sphalerite (ZnS), bravoite (Fe,Ni,Co)S2, godlevskite (Ni7S6), millerite (NiS) and hydrous valeriite [(CuFeS2)1.5(Mg,Al)(OH)2]. An unidentified Fe–Zn–Mn–S phase is frequently encountered in serpentinites (highly altered calc-silicate hornfels), and stibnite (Sb2S3) and molybdenite (MoS2) are rare sulphides in the hornfelses and serpentinites. Magnetite is the only oxide found so far in the footwall. Other rare phases include altaite (PbTe), plumboan barite or hokutolite (Ba,Pb)SO4, as well as halogen-bearing phases, such as bismoclite (BiOCl), and unidentified Fe–Nd–F-bearing and Pb–Cl-bearing species.

Pegmatoidal mafic dykes

In the east-central part of the Sandsloot pit a 4–5 m thick, pegmatoidal mafic dyke intrudes almost vertically through the footwall (Fig. 3). Several smaller dykes and veins branch from the large dyke into the Platreef (these occur just below the base of the face map in Fig. 3). Locally the texture is extremely pegmatitic and pyroxene crystals up to 30 cm long have been found in blasted-out boulders near the main exposure of this dyke. Its relationship to the hanging-wall is not known. Small dykes and veins of similar composition are observed in some drill cores from various locations at the mine. Like the Platreef, the dyke has no chilled margins. Two consistently characteristic features of the dyke and its branching veins are their pegmatoidal texture and green cumulus feldspar laths with intercumulate grey to black pyroxene, although locally the two phases display eutectic intergrowth. Sub- to euhedral pyroxene crystals in tooth-like or radial arrangements occur along the dyke margins. Within the dyke and larger veins signs of flow are observed in the form of bowed pyroxene crystals and fragments of pyroxene evidently broken away from the dyke margins and entrained in the central flow. Phlogopite is an accessory phase, comprising large booklets. Base-metal sulphides are notably rarer than in the Platreef, but large, interstitial blebs of pyrrhotite and pentlandite occur sporadically. Ilmenite and perovskite represent minor oxide phases, sometimes containing chlorapatite (Ca5[PO4]3Cl) and baddeleyite (ZrO2). Veins of similar composition and appearance to this major dyke are observed in the footwall lithologies along the east highwall of the Sandsloot mine, but the feldspar in these instances is often colourless to milky white.

Late hydrothermal veins

Planar, hydrothermal quartz-feldspathic veins cut all lithologies and their boundaries. Two large veins (>1 m) cross the Sandsloot pit, striking approximately north–south with a moderate to steep dip to the east. In addition to coarse-grained quartz and feldspar, calcite and fibrous white chrysotile aggregates occur in the veins as later, lower-temperature phases. Minor brittle–ductile shear structures occur at the margins of the largest vein, but do not occur within the vein itself. This suggests either that an earlier shear zone may have been the favoured locus of this hydrothermal channel or that the competence contrast between the vein and country rock has generated high contact strains during deformation and given rise to the shearing along the contacts.

PGE concentrations in the reef and footwall

PGE and Au concentrations and metal ratios in the Platreef and footwall lithologies are given in Table 1 and compared with those of other Bushveld PGE reefs. Chondrite-normalized patterns for PGE-rich samples are shown in Fig. 5. Although the B-reef pyroxenites and gabbros are consistently mineralized, there is considerable variation in PGE.

![Fig. 5 Chondrite-normalized plot of PGE-rich reef and footwall lithologies. CI chondrite values from Jochum.16 Filled symbols, Platreef B-reef samples; open symbols, footwall samples](B41)
concentration within the reef. The mineralization extends for a significant distance below the reef into the footwall. Some footwall lithologies are essentially barren, but certain zones of clinopyroxenite and some highly serpentinitized zones and layers within the calc-silicate hornfels contain Rh+Pt+Pd+Au concentrations approaching those in the B-reef. The minor pegmatically pods within the aplite dyke that separates the footwall and B-reef in face 132/038 (Fig. 3) have high PGE concentrations, while the aplite itself is relatively poor in PGE. The pegmaticoidal mafic dyke that cuts across the footwall and B-reef contains very low PGE concentrations (<100 ppb Rh+Pt+Pd+Au).

Comparison of the PGE ratios of the PGE-rich Platreef and footwall lithologies with the Merensky Reef and UG-2 chromitite reveals some interesting features. The B-reef and footwall are richer in Pt, Pd and Au relative to Ir than the Merensky or UG-2 reefs, producing more fractionated PGE patterns. Pt/Pd and Pt/Au ratios in the Platreef and footwall are lower than those in the Merensky or UG-2 reefs, indicating that the Platreef is richer in Pd and Au relative to Pt than the Merensky or UG-2 reefs. PGE-rich footwall samples and pegmaticoidal apiles have lower Pt/Pd (consistently <1.0) than B-reef gabbro or pyroxenite (1.0 or greater). This would appear to indicate some fractionation of Pd over Pt into late-stage fluids in the reef and footwall—a feature noted by Wagner28 and Ainsworth.1 Rh/Ir in the Platreef is comparable with that of the Merensky Reef, but lower than the UG-2.

Nonetheless, the B-reef and the PGE-rich footwall lithologies show a remarkably close similarity in terms of PGE ratios and normalized patterns (Fig. 5). The aplite dyke and some of the low-grade footwall samples (e.g. PA-S3-0 and PA-S2-12) exhibit dramatic enrichments in Pt, Pd or Au, but the relative distribution of various PGE between PGE-rich reef and footwall is very consistent and seems to be more than mere coincidence. This type of footwall mineralization is a general feature of the Platreef and it is present across the Sandsloot pit as well as along strike at Tweefontein Hill to the south and at Zwartfontein to the north.28 Any comprehensive genetic model for the Platreef must take it into account.

### Platinum-group mineralogy

Initial SEM studies of four polished blocks from the Platreef—three from the footwall and one from a pegmaticoidal mafic dyke—have revealed 54 individual occurrences of platinum-group minerals (PGM), ten occurrences of electrum (Au–Ag) and a single instance of stromeyerite (AgCuS). The last is the only precious-metal sulphide found to date. The great majority of PGE in the Platreef and footwall are of very small grain size—nearly all <10 μm and most <5 μm; a few exceptions are in the size range 20–60 μm. Each PGM grain was analysed and grouped according to type and textural/mineralogical association. The PGM identified are classed as: (1) high-temperature alloys, e.g. Pt–Fe and Pt–Sn alloys; (2) high-temperature semi-metallics, e.g. (Pt,Pd) arsenides and antimonooarsenides; (3) lower-temperature semi-metallics, e.g. Pd antimonides and (Pd,Pt) tellurides and bismuthotellurides; and (4) lower-temperature alloys, e.g. Pt–Pd–Ge–Pb, Pd–Au and Au–Ag alloys (Table 2).

The textural/mineralogical associations of the PGM are: (1) in base-metal sulphides; (2) on the rims of base-metal sulphides; (3) in oxides; (4) in primary silicates; and (5) in alteration silicates. Table 3 shows the types of PGM found in the Platreef, footwall and pegmaticoidal mafic dyke. Table 4 gives a more detailed grouping of the PGM showing their textural/mineralogical associations. Unlike the Merensky Reef, in which PGE occur mostly as PGE alloys and sulphides and where laurite (RuS2) is usually present even in the most alloy-dominated assemblages, the Platreef at Sandsloot is virtually free of PGE sulphides. The authors’ preliminary data show that the Platreef and footwall host a wide variety of PGM associated with primary silicates, metamorphic silicates, alteration silicates, primary and remobilized sulphides, and oxides. More significantly, the present work demonstrates the abundance of lower-temperature PGM in the form of (Pd,Pt) tellurides and bismuthotellurides and low-temperature alloys, such as palladian gold (Au,Pd) and electrum (Au–Ag) (Table 2).

The data show a slight dominance of high-temperature PGM over low-temperature PGM in the reef samples, but a more convincing majority of low-temperature PGM in footwall samples. The types of low-temperature PGM and their associations with surrounding silicates and sulphides are similar in the reef and footwall, supporting a common mode of
speciation. To date, the only deviation of possible significance among low-temperature PGM is that an unnamed Pd antimondite (PdSb) is predominant in a footwall serpentinite (sample PA-S3-0).

The PGM distribution in the Platreef is very different from that of almost all of the varieties of Merensky Reef described by Kinloch and Peyerl,18 with the exception of some pothole reef and reef that has been affected by late-stage dunite pegmatoids. The association of Pt-Fe alloys in pegmatoids and in the core of a pothole with a zone of telluride-rich mineralization on the rim of the pothole have both been attributed to the effects of fluids.17,18 Given the strong evidence for fluid activity in the Platreef and the footwall, it is likely that fluids have influenced the development of PGM in the Platreef in a similar manner to volatile-rich portions of the Merensky Reef.

Discussion

Previous investigations of the Platreef have shown that it exhibits differences in mineralogy, textures, thickness and PGE distribution along strike. These differences appear to reflect, in part, interactions with different floor rocks.28,10 Studies of the Platreef should proceed, therefore, with some form of broad-scale lithological (facies?) division, of which the mineralization at Sandsloot is viewed as one facies. Generalizations about the entire Platreef based on the observations at Sandsloot should, therefore, be viewed with caution until more data become available from new mining developments. Kinloch17 recognized similar large-scale facies variation within the Merensky Reef, which led to new thinking on the processes operating in that deposit. Given the extensive strike lengths involved in both the Merensky Reef and Platreef, it would be surprising if similar lateral variations were not apparent in the latter as well. In the view of the present authors, the true complexity of the Platreef is only just being appreciated.

Wagner28 recognized the division between the pyroxenite reef and the underlying footwall assemblages and ascribed the formation of these units to magmatic and metamorphic/metasomatic processes, respectively. Many subsequent authors3,6,3,5,21,24 have emphasized contamination of the Platreef magma by the footwall. The impression given by many of these studies is that the PGE mineralization in the Platreef is the result of orthomagmatic sulphide segregation from a system with a high r factor8 and that the PGE in the reef are strongly associated with base-metal sulphides. Variable Fe/Mg ratios and PGE concentrations within the Platreef have even been ascribed to the introduction of multiple pulses of magma with different PGE budgets.1 In none of these studies have the presence of significant PGE concentrations in the footwall and its implications for the development of the mineralization been considered.

The authors feel that one of the most significant results to come out of the present study so far is the complete absence of PGE sulphides—particularly laurite (RuS$_2$)—and the abundance of alloys and semi-metallides in the Platreef. This trend acquires greater significance when comparison is made with other Bushveld PGE reefs17,20,18 and PGE-bearing sulphide deposits in other mafic intrusions, such as the Great Dyke11 and the Munni Munni Complex,2 where PGE sulphides constitute anywhere between 10% and 60% of the PGM assemblage. The PGM assemblage in the Platreef at Sandsloot is quite different from that in any of these deposits.

Another significant result to emerge from this study is the recognition of PGE signatures in the footwall broadly similar to those found in the igneous Platreef. This is not what would be expected if the PGE-rich footwall zones formed simply as a result of remobilization of the most mobile PGE (Pt and Pd) and Au from a pre-existing, PGE-rich magmatic sulphide layer (represented by the B-reef). Rather, it suggests that the final PGE distribution in both the B-reef and the PGE-rich footwall was influenced or controlled by similar processes. In accord with Wagner’s study,28 no evidence for a gravity-driven percolation of sulphide into the footwall has been found in the present work. Furthermore, models invoking assimilation and contamination of footwall rocks to produce the PGE-rich zones fail to explain why the footwall PGE mineralization is concentrated in zones that have seen the greatest fluid activity.

Table 3 clearly shows that the footwall contains a greater proportion of lower-temperature PGE antimonides, tellurides and alloys than the Platreef, in line with the obvious temperature gradient across the footwall contact. However, the same low-temperature species occur in the same associations in both units, indicating that $P-T-X$ conditions in the Platreef and footwall were broadly similar during the crystallization of these PGM.

The evidence for ‘resets’ in MgO and Fe/Mg ratios and variation in PGE concentrations within the Platreef presented by Ainsworth1 also merits further consideration. The reports of distinctive PGE-rich zones or shoots (over distances of more than 10 m) within the B-reef and the enrichment in Pd at the base of the B-reef reported by Ainsworth1 are confirmed by observations of the present authors. Variations in PGE concentrations over these distances are difficult to reconcile with sulphide immiscibility and collection of sulphide droplets from an overlying magma unless there were multiple pulses of magma (and sulphide) or a single generation of sulphides (and associated PGE) was somehow redistributed. The low Fe/Mg ratios and MgO resets cited by Ainsworth1 as evidence for multiple magmas actually correlate with the presence of serpentine and talc and reflect fluid replacement or the presence of highly altered olivine-bearing dolomite xenoliths, not primary magmatic variability. It is maintained here that the metre-scale variability in PGE concentration, coupled with the absence of any PGE sulphides and the abundance of low-temperature PGM, cannot be linked to any orthomagmatic model and is best explained by the action of fluids.

The observations outlined above lead to the view that the final distribution of PGE at Sandsloot was controlled by the action of fluids. These played the dominant role in mobilizing

### Table 4 PGM types and their textural/mineralogical associations found in eight polished blocks from Platreef, footwall and pegmatoidal dyke samples

<table>
<thead>
<tr>
<th></th>
<th>In sulphide</th>
<th>In oxide</th>
<th>In primary silicate</th>
<th>In altered silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High- $T$ Pt–Pd alloys and semi-metallides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>In sulphide</td>
<td>On sulphide rim</td>
<td>In oxide</td>
<td>In primary silicate</td>
</tr>
<tr>
<td>Platreef</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Footwall</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Dyke</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
and homogenizing PGE within the Platreef and carrying them into the footwall, where they formed irregular zones and regular layers containing high PGE concentrations. The PGM assemblage crystallized under hydrothermal conditions in a fluid envelope that affected both the reef and footwall, but the means by which the PGE were initially concentrated is less obvious. On the basis of stable isotope data Harris and Chaumba concluded that the Platreef fluid was a mixture of predominantly magmatic water with a minor component derived from the footwall. It is not yet possible to say whether this fluid activity introduced PGE into the Platreef from deeper cumulates or residual melt during fluid migration along the intrusion margin under a pressure and temperature gradient, or whether it simply disrupted and redistributed the metals from magmatic sulphides that had already scavenged PGE. At this stage both possibilities must remain open. What is clear is that the Platreef at Sandsloot can no longer be considered as a purely or predominantly orthomagmatic PGE deposit. The extent of PGE remobilization is poorly constrained, and attempts to model the PGE distribution in the Platreef using $R$ factor calculations or sulphide fractionation models are likely to be invalid.

Although the role of fluids within the B-reef and footwall has been emphasized above, it is important to recognize that not all fluid-rich rocks associated with the Platreef contained PGE. The crosscutting pegmatoidal mafic dyke in face 132/038 in the central part of the pit (Fig. 3) is almost barren. PGE mineralization appears to have been restricted to the B-reef pyroxenites and their associated fluid envelope, but later intrusions or crosscutting pegmatoids carried little or no PGE.

Following Wagner's original subdivision of the deposit, it could be argued that the Platreef and associated footwall at Sandsloot show features associated with skarn deposits. The envelope of footwall PGE mineralization hosted within the metamorphosed carbonates could certainly be considered an 'exoskarn'. The case for the Platreef proper being an 'endoskarn' in the strictest sense is more difficult to establish. PGE(Ni,Cu) skarns have not been recognized as a skarn deposit type in themselves before this study. This work and Wagner's original subdivision of the deposit, it could be argued that the Platreef and associated footwall at Sandsloot show features associated with skarn deposits.


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