Platinum-Group Elements in Komatiites From the Komati Formation, Barberton Greenstone Belt

F. Roelofse[1], W.D. Maier[1] and S.-J. Barnes[2]
[1]Centre for Research on Magmatic Ore Deposits, Dept. of Geology, University of Pretoria, Pretoria 0002, South Africa
[2]Sciences de la Terre, Universite du Quebec, Chicoutimi G7H 2B1, Canada
e-mail: wdmaier@scientia.up.ac.za

Introduction, General Geological Setting, and Sample Description

Komatiites from the Barberton Greenstone Belt are characterized by distinct major and trace element compositions relative to komatiites from elsewhere (relatively low Al_2O_3 and CaO, fractionated LREE, Nesbitt, 1982). It has been proposed that the Barberton komatiites formed in response to relatively low degrees of partial melting of the mantle, at high pressure (above 50-70 kbar, Takahashi and Scarfe, 1985). The present study has been initiated to investigate whether such a distinct melting regime and/or mantle source are reflected in the PGE geochemistry of the lavas. A further aim of the study is to evaluate the reasons for the apparent absence of magmatic Ni-PGE sulfide ores associated with the Barberton komatiites. In contrast, komatiites elsewhere may host Ni-(PGE) sulfide ores, such as at Kambalda, Alexo, and Shangani.

The Komati Formation occurs near the base of the volcano-sedimentary sequence of the Barberton Greenstone Belt. The age of the Formation is estimated at ca. 3.48 Ga and it's thickness at ca. 3.0-3.5 km (Dann, 2000). The rocks consist of interlayered komatiite (predominantly in the lower portion of the Formation) and komatiitic basalt (predominantly in the upper portion). Individual lava flows may have thicknesses between a few 10s of centimeters to > 10 m. The common occurrence of pillowed flows attest to a sub-marine eruptive setting.

We studied in detail the compositional variation through 5 komatiite flows located on the bank of Spinifex Creek. The outcrop extends approximately 6.5 m perpendicular to the layering and covers a surface of around $20m^2$. The thickest flow was 2.9 m in thickness, and the thinnest 20 cm. Some, but not all, of the flows are characterized by a basal massive unit that is overlain by zones of coarse random or oriented spinifex, fine random spinifex, and a commonly vesicular flow-top breccia.

Results

The massive portions of the flows have between 27.7 and 35.4 % MgO. The next most-MgO-rich rocks are the fine-grained spinifex textured samples, with 26.5-27% MgO. The medium-grained spinifex has 23.1-25.6% MgO, and the coarse-grained spinifex 20.3-24.7 % MgO. The flow tops have variable MgO contents, between 22.6 and 27.5%, due to the presence of abundant vesicles. We simulated a crystallization sequence by using MELTS and assuming a vesicle-free flow top (with 27.5 % MgO) as the parental magma. This gave a liquidus temperature of 1591°C, and a crystallization sequence olivine (until 33 % crystallized), followed by olivine + chromite (until 45 % crystallized), and olivine + chromite + clinopyroxene. The first olivines to crystallize have Fo_{95} (MgO 53.1%), which is in broad agreement with data from the Komati Formation by Smith and Erlank (1982) and Viljoen et al. (1983). The spinifex textured rocks are differentiates from the parent magma, representing between 0 and approximately 20% fractional crystallization of olivine. Our data further confirm the findings of Smith and Erlank (1982) that the komatiites of the Komati Formation have markedly lower Al_2O_3 (CaO/Al_2O_3>2; Al_2O_3/TiO_2 10) than those from elsewhere.

Mass balance calculations of the five flows studied indicate that they all have broadly similar bulk compositions, similar to that of the parental magma. This suggests that the rocks crystallized under relatively stagnant flow conditions.

With the exception of Ni and Co, the investigated trace elements show negative correlations with MgO, indicating incompatible behaviour during olivine crystallization, and the absence of chromite on the liquidus. The incompatible trace element data indicate about 20% fractional crystallization of olivine for the most differentiated samples, and that the massive rocks have between 20 and 30% trapped melt.

There is an enrichment in Cu by several 100% between the parental magma and the differentiated flow units. Such an enrichment can not be explained by incompatibility of Cu with respect to crystallizing silicates. Instead, it indicates that Cu is governed by other phases. The most likely candidate is magmatic sulphides. The presence of hydrothermal sulphides is considered unlikely, mainly because Cu correlates with other chalcophile elements such as Ir that are considered immobile, and because it would be difficult to explain why any hydrothermal fluids would have preferentialy mineralized the differentiated flow units.

All PGE show broadly negative correlations with MgO, although the trends for those elements that have concentrations close to the analytical detection limit are scattered. This result is in contrast to most published data on komatiites, where Ir correlates well with MgO (e.g. Bruegmann et al., 1987; Keays, 1995), and indicates that olivine or chromite are not the main controlling phases of Ir in our samples. Instead, the PGE could have behaved incompatibly with respect to crystallizing silicates and be concentrated during differentiation of the magma. For example, Ir increases with height throughout all individual flows. Alternatively, the PGE are controlled by another phase. Since Cu is apparently controlled by sulphides, and Ni and Co are partly controlled by sulphides, we suggest that the PGE are also controlled by sulfides.

In primitive mantle-normalized plots, Ni/Ir_m ratios are very high, in part due to the abundance of olivine. From Ir to Cu, the patterns show a progressive increase, but with a slight negative Au anomaly in many samples. Cu/Pd ratios are >10.000, considerably higher than in primitive mantle, and indicate depletion of the PGE relative to Cu. Pd/Ir ratios are around 2, and Pt/Pd around unity.

Discussion

The identity of the host phases to the PGE in the Earth's upper mantle remain poorly known. Most authors assume that the IPGE and Pt are partly held by metal alloys and PGM, whereas Pd is largely held in sulfides. This would explain the observation that IPGE/Pd and, to a lesser degree, Pt/Pd ratios are higher in many komatiites than in basalts. Instead, Bruegmann et al (1987) have proposed that Pd/Ir ratios of basic-ultrabasic magmas are governed largely by olivine and PGM fractionation during ascent and emplacement. This is supported by the study of Handler and Bennett (1999), who showed that in Victorian mantle xenoliths the bulk of the PGE are held by sulfides. They sugget that most of the PGM and metal alloys found in many alpine peridotites are the result of low-P recrystallization of sulfide.

How does the present study constrain this debate? Published PGE data from a number of localities are compared to our data in Table 1. The most detailed accounts on PGE contents in komatiites available are those of Crockett and McRae (1986) and Dowling and Hill (1992), who studied metal contents in komatiites from the Abitibi and the Agnew-Wiluna greenstone belts. Bruegmann et al. (1987) worked on komatiites from Alexo/Abitibi Greenstone Belt, and from Gorgona Island. Generally speaking, the Barberton komatiites are significantly depleted in PGE relative to most other komatiites from elsewhere, resulting in Cu/Pd ratios that are significantly above primitive mantle. However, in terms of Pd/Ir and Pt/Pd, all komatiites appear to be broadly similar.

The similarity in PGE patterns of the two groups of komatiites could be explained by 2 contrasting models: Firstly, the Barberton komatiites may not have formed from a distinct mantle source and melting regime, relative to the other komatiites. This appears unlikely, in view of the available geochemical data. Secondly, and more likely, the individual PGE are not held by distinct phases in the mantle, but by sulfides, and thus the degree of partial melting and depth of melting have no influence on relative PGE contents in the lavas.

High Cu/Pd in mantle-derived magmas may reflect small degrees of mantle melting, with Pd remaining in the source and partitioning into undissolved sulfide melt. This may suggest that the Komati lavas also formed due to small degree melting. We would instead like to argue that the low PGE contents and high Cu/Pd of the Komati lavas are a result of small scale sulfide segregation during ascent or emplacement, mainly because the analysed Barberton komatiites appear to be sulfide saturated. As komatiites should be S undersaturated upon extrusion (due to the effect of depressurization on S solubility) the lavas have probably interacted with crust, and it would not seem farfetched to assume that this triggered small amounts of sulfide segregation resulting in high Cu/Pd ratios. The mechanisms of possible crustal contamination remain unclear and will be investigated by future work involving stable and radiogenic isotopes.

It is perhaps notable that other investigated Kaapvaal komatiites, from the Westonaria

Formation of the Ventersdorp Supergroup, also have relatively low PGE contents, and high Cu/Pd ratios (Table 1), and thus it appears possible that the PGE-poor nature of Kaapvaal komatiites is a more general feature. It is unlikely that this is related to a generally higher S content of the Kaapvaal crust. Maier et al (2001) show that flood-type basalts and komatiitic basalts from the Kaapvaal Craton are generally undepleted in PGE. Instead, we propose that a generally smaller degree of melting may have applied to Kaapvaal komatiites relative to komatiites elsewhere. This may have resulted in less sulfide undersaturation, and thus the Kaapvaal komatiites may have reached sulfide saturation more readily upon smaller degrees of crustal contamination than komatiites elsewhere.

We explain the enrichment of PGE and Cu in the most differentiated flows analysed by a model whereby the sulfides remained in suspension within the turbulently convecting magma.

The economic potential of the Barberton komatiites is generally considered to be low, largely due to the apparent absence of Ni sulfide ores similar to those at Kambalda or in the Abitibi. Our study suggests that the potential of the Barberton komatiites to host Ni sulfides has possibly been underestimated. The lavas appear to be of similar composition as other komatiites, but have lost sulfides before or during emplacement. The high Cu/Pd ratios of the present flows indicate that sulfide segregation was a rather high R-factor event, but there is no reason why other flows, particularly in channelized and more dynamic environments, should not have experienced more severe sulfide segregation. A more detailed investigation of komatiites from the entire Onverwacht Group is presently underway to produce possible exploration vectors.

Table 1: *Comparison of compositional data from various komatiites*

	MgO	Pd	Ir	Pd/Ir	Pt/Pd	Cu/Pd
Komati[1]	26.30	3.30	1.15	2.90	0.76	14400
Westonaria[2]	22.83	3.50	1.16	3.00	13.60	31500
Mt. Keith[3]						
west. ultram.	34.00	4.80	1.35	3.60	1.00	6300
centr. ultram.	29.00	11.30	2.36	4.90	0.86	6800
Kambalda[4]						
Lunnon Shoot	23.55	11.10	1.42	7.80	na	6100
Long Shoot	24.32	7.50	1.29	5.80	na	9300
MtClifford	26.62	8.00	2.50	3.20	na	7400
Pyke Hill[5]	30.83	16.60	7.60	2.20	0.31	1750
Alexo[6]	27.21	8.70	2.20	4.00	na	6500
Gorgona[6]	21.35	10.80	2.10	5.40	na	10000

1: This study; 2: Unpubl. data of Maier; 3: Dowling and Hill (1992)
4: Keays (1982); 5: Crockett and McRae (1986); 6: Bruegmann et al (1987)

References

Bruegmann, G.E., Arndt, N.T., Hofmann, A.W. and Tobschall, H.J. (1987) Noble metal abundances in komatiite suites from Alexo, Ontario, and Gorgona Island, Colombia. Geochim. Cosmochim. Acta, 51, 2159-2169.

Crockett, J.H. and McRae, W.E. (1986) Platinum-group element distribution in komatiitic and tholeiitic volcanic rocks from Munro Township, Ontario. Econ. Geol., v. 81, p. 1242-1251.

Dann, J.C. (2000) The 3.5 Ga Komati Formation, Barberton Greenstone Belt, South Africa, Part I: New maps and magmatic architecture. S. Afr. J. Geol., 103, 47-68.

Dowling, S.E. and Hill, R.R.T. (1992) The distribution of PGE in fractionated Archean komatiites, Western and Central ultramafic units, Mt. Keith region, Western Australia. Austr. J. Earth Sci., v. 39, p. 349-363.

Handler, M.R. and Bennett, V.C. (1999) Behaviour of PGE in the subcontinental mantle of

esatern Australia during variable metasomatism and melt depletion. Geochim. Cosmochim. Acta, 63, 3597-3618.

Keays, R.R. (1982) Paladium and iridium in komatiites and associated rocks: application to petrogenetic problems. In Arndt, N.T. and Nisbett, E.G. (eds), Komatiites, Allen and Unwin, London, p. 435-457.

Keays, R.R. (1995). The role of komatiitic and picritic magmatism and S saturation in the formation of ore deposits. Lithos, v. 34, p. 1-18.

Maier, W.D., Barnes, S.-J. and Marsh, J.S. (2001) PGE in southern African flood basalts : implications for magmatic sulphide exploration. Mineral Deposits at the beginning of the 21st century,Piestrzynski et al. (eds), Balkema, Lisse, p. 665-668. Joint 6th biannual SGA-SEG meeting, Krakow, Poland.

Nisbet, E.G. (1982) The tectonic setting and petrogenesis of komatiites. In Arndt, N.T. and Nisbet, E.G. (eds), Komatiites, Allen and Unwin, London, 501-520.

Smith, H.S. and Erlank, A.J. (1982) Geochemistry and petrogenesis of of komatiites from the Barberton greenstone belt, South Africa. In Arndt, N.T. and Nisbett, E.G. (eds) komatiites, Allen and Unwin, London, p. 347-398.

Takahashi, E. and Scarfe, C.M. (1985) Melting of peridotite to 14 GPa and the genesis of komatiite. Nature, v. 315, p. 566-568.

Viljoen, M.J, Viljoen R.P., Smith, H.S. and Erlank, A.J. (1983) Geological, textural, and geochemical features of komatiitic flows from the Komati Formation. in Anhaeusser, C.R. (ed) Contributions to the geology of the Barberton Mountain Land, Geol. Soc. S. Afr. Spec. Publ., 9, Geol. Soc. S. Afr. Johannesburg.