

Platinum-group metals—a resource in the tailings of chromium mines in South Africa

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SYNOPSIS

Although the concentration of platinum-group elements in the LG-6 Chromitite Layer is very low—about 0,5 g/t—the minerals that contain these elements occur largely between the chromite grains. Because of their small grain size, these minerals, during the washing of the ore, become concentrated together with the silicate impurities in the tailings.

The platinum-group elements in the tailings are such that their extraction appears to be a highly profitable exercise. It is estimated that the tailings dumps of the chromium mines in the Bushveld Complex contain close to 400 000 oz of platinum-group elements, to which about 38 000 oz are added annually.

SAMEVATTING

Hoewel die konsentrasie van platinumgroepelemente in die LG-6-chromitietlaag baie laag is—ongeveer 0,5 g/t—kom die minerale wat hierdie elemente bevat, hoofsaaklik tussen die chromietkorrels voor. Vanweë hul klein korrelgrootte word hierdie minerale tydens die was van die erts saam met die silikaatonsuiwerhede in die uitskot gekonsentreer.

Die platinumgroepelemente in die uitskot is sodanig dat die ekstraksie daarvan blykbaar 'n uiters winsgewende onderneming is. Daar word beraam dat die uitskothope van die chromium in die Bushveldkompleks byna 400 000 onse platinumgroepelemente bevat en dat daar jaarliks ongeveer 38 000 onse bygevoeg word.

Introduction

Because of the suitability of hard lumpy chromium ore as a direct furnace feed in the production of ferrochromium, this ore has frequently been mined selectively in the chromium mines of the Bushveld Complex. However, the availability of this type of ore with a suitable chromium-to-iron ratio, Cr_2O_3 content, and low impurities is very limited, with the result that friable chromium ore now constitutes a large proportion of the production at many of the chromium mines in the Bushveld Complex. The introduction of spiral concentrators several years ago afforded an efficient way of separating the impurities in the friable ore from the chromite, so that it became possible to produce a clean chromium sand, with the impurities, mostly silicates, going to the tailings.

This paper describes briefly the way in which the platinum-bearing minerals tend to occur in the chromitite layers, and from this predicts their behaviour during the separation of the chromite grains from the silicate impurities. Throughout this paper the abbreviations PGE and PGM are used for platinum-group elements and platinum-group minerals respectively.

Association of PGE and Chromitite

The association of the PGE with the chromitite layers of the Bushveld Complex has been known since the twenties^{1,2}. In those early days, values of from less than 1 to 6 dwt/t were reported, with those from the upper chromitite layers being generally higher than those from the layers lower in the sequence. It is only in very recent

years that more information on the PGE content and the nature of the PGM in the UG-2 Chromitite Layer, one of the chromitite layers of the Upper Group, has become available as a result of detailed studies of this reef by Kinloch³, McLaren and De Villiers⁴, Gain⁵, Hiemstra⁶, and Vermaak⁷. The work of these authors has shown that

- (1) the PGE values are not evenly distributed through the reef but display peaks at the base and near the top,
- (2) the PGM are predominantly associated with base-metal sulphides or occur close by as discrete minerals enclosed by silicates,
- (3) the amount of PGM enclosed within chromite grains is generally very low (less than 12 per cent),
- (4) the most common PGM enclosed in chromite is laurite, i.e. RuS_2 containing small amounts of iridium and osmium,
- (5) there is considerable lateral variation in the platinum-group mineralogy of the reef, and
- (6) the PGM are extremely small (about $5\ \mu\text{m}$ in diameter) whilst the associated base-metal sulphides are up to $50\ \mu\text{m}$ in diameter.

The occurrence of most of the PGM between the chromite grains and their association with base-metal sulphides make it possible for these minerals to be liberated by grinding before being concentrated by advanced flotation techniques⁸. Consequently, the PGE are now being profitably recovered from the UG-2 Chromitite Layer by all three major platinum producers in South Africa⁹.

Much less is known about the occurrence and distribution of the PGM in the other chromitite layers of the Bushveld Complex. New data were recently presented by

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Von Gruenewaldt *et al.*¹⁰, who showed that the PGE values vary between 1,52 and 4,7 g/t in the other chromitite layers of the Upper Group and those of the Middle Group (Fig. 1). Microscopic observations by these authors on the lower two chromitite layers of the Middle Group have shown that as much as 50 per cent of the PGM, mostly laurite, are enclosed in the chromite grains. The remaining PGM, mostly sulphides and antimonides of platinum and palladium, as well as laurite, are associated with small quantities of base-metal sulphides and occur either between adjoining chromite grains or enclosed within interstitial silicates.

No systematic investigation of the PGE or PGM content of the LG-6 or Main Chromitite Layer, which is being exploited on a large scale in both the eastern and the western Bushveld, has yet been undertaken, and the only indication of the presence of small quantities of the PGE is the report by Wagner² and an average value of 0,52 platinum plus palladium reported by Von Gruenewaldt *et al.*¹⁰ from the inspection of a limited number of bore-hole intersections. However, if the information gathered

for the MG-1, MG-2, and UG-2 Chromitite Layers (i.e. that the PGE-bearing minerals occur preferentially enclosed in the interstitial silicates or between chromite grains) also applies to the LG-6 Chromitite Layer, then it follows that these PGM should become concentrated in the silicate tailings during the purification of the friable chromite ore with spiral concentrators. Completely liberated PGM and base-metal sulphides, although they have a considerably higher density than the chromite, should also be washed to the silicate tailings because of their minute grain size. Microscopic investigations of the LG-6 Chromitite Layer by Cameron¹¹ at Jagdlust Chrome Mine in the eastern Bushveld Complex, and by Von Gruenewaldt and Worst¹² at Zwartkop Chrome Mine in the western Bushveld, have shown the amount of interstitial silicate in the LG-6 Chromitite Layer to be about 5 and 8 per cent respectively. A pure silicate separate from the chromitite layer should therefore contain more than 5 g/t PGE.

Investigation of Tailings

With the above reasoning in mind, samples of silicate-rich tailings from several chromium mines throughout the Bushveld Complex were analysed in duplicate for their noble-metal (PGE + Au), nickel, and copper contents by atomic-absorption spectrometry. The analyses were carried out by B. Cordier of Rio Tinto Laboratories, Johannesburg. Lead oxide was used as a collector for gold, platinum, and palladium, nickel sulphide as a collector for rhodium, ruthenium, and iridium. The detection limits were 0,1 p.p.m. for gold, platinum, palladium, rhodium, and ruthenium, and 0,25 p.p.m. for iridium. The nickel and copper analyses were for the acid-soluble portion of the ore, and therefore reflect the nickel sulphide and copper sulphide values. The detection limit was 10 p.p.m. for these two elements. The analytical results (Table I) indicate that the concentration of iridium and gold in all the samples was below the limit of detection of the analytical technique.

TABLE I

ANALYSES OF SAMPLES FROM THE TAILINGS DUMPS OF CHROMIUM MINES ON THE BUSHVELD COMPLEX

Sample	Pt	Pd	Rh	Ru	ΣPGE	Cu*	Ni*
Properly separated LG-6 tailings							
1	3,20	2,03	0,35	3,40	8,98	130	195
2	4,52	2,80	0,45	2,63	10,40	95	264
3	3,06	1,40	0,16	1,43	6,05	69	119
4	3,17	0,93	0,18	2,14	6,42	50	439
Poorly separated LG-6 tailings							
5	0,25	0,11	0,06	0,60	1,02	17	78
6	0,99	0,45	n.d.	n.d.	>1,44	40	282
Properly separated MG-1 tailings							
7	0,42	0,27	0,03	0,73	1,45	20	86
8	0,57	0,40	0,07	1,11	2,15	35	126
9	1,13	0,36	0,07	0,61	2,17	29	95

n.d. not determined
* acid soluble

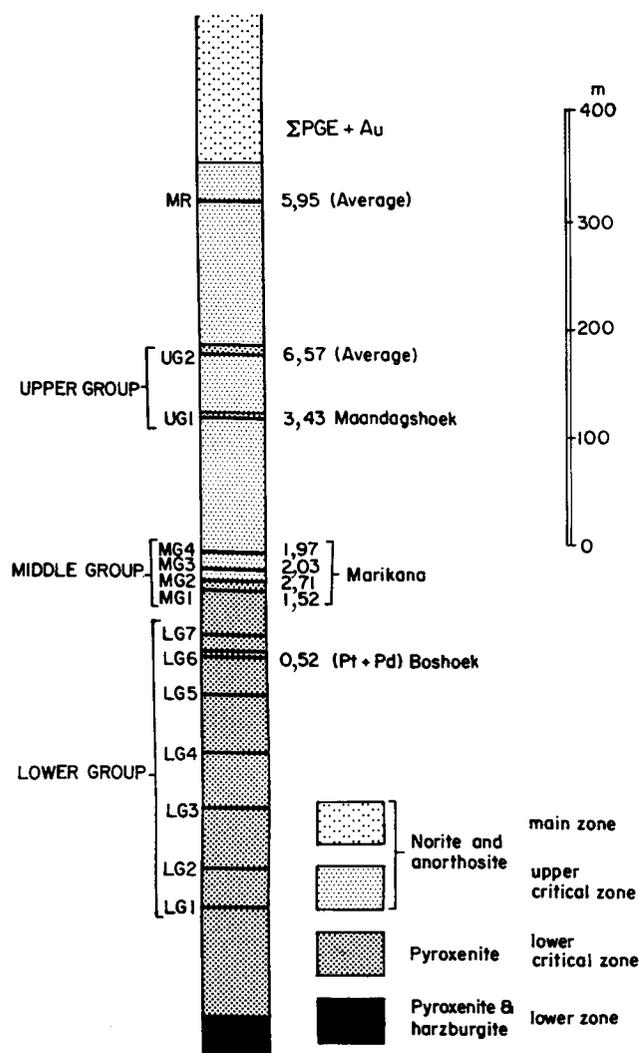


Fig. 1—Generalized columnar section through the Critical Zone in the western Bushveld Complex, showing the position of the various chromitite layers. The PGE + Au values and localities are from Von Gruenewaldt *et al.*¹⁰. Those for the Merensky Reef and the UG-2 Chromitite Layer are average values of available data from the eastern and western Bushveld Complex

Several factors seem to influence the PGE content of the tailings.

(1) *Purity of the Tailings*

The first four samples listed in Table I are from tailings dumps where the chromite and silicates had been efficiently separated with spiral concentrators. In comparison, samples 5 and 6 were obtained from dumps at mines where operations had ceased several years before. These samples contain a very high percentage of chromite (more than 60 per cent) and were taken from fines in which the separation of chromite and silicate had not been very effective. The separation of chromite from such fines would at least double the PGE content of the tailings.

(2) *Type of Chromium Ore*

Three samples (samples 7, 8, and 9, Table I) were taken from tailings dumps of mines in the Marikana area where the lowest chromitite layer of the Middle Group (MG-1) is exploited. Although spiral concentrators are used for the purification of the friable chromium ore, the tailings have a considerably lower PGE content than the properly separated LG-6 tailings. The reason for this is not clear at this stage. All the available analytical data on MG-1 ore (Von Gruenewaldt *et al.*¹⁰, Figure 6 and Table 2) suggest a platinum plus palladium content of about 0,7 to 0,8 p.p.m. from different localities, and a total PGE content in excess of 1,5 p.p.m.; yet the tailings assayed only about 2 p.p.m. Such low values in properly separated tailings suggest that a high proportion of the PGM are contained in chromite grains, or that the samples are not representative of the tailings because of grain-size effects. The difference in the amount of interstitial material in LG-6 and MG-1 ore is too small to produce this effect.

(3) *Grain Size*

The values for sample 1 in Table I are the average values for two samples, a coarse and a fine fraction, of the same tailings dump. It is of interest that the PGE content of the fine fraction is 16,1 p.p.m. compared with 1,9 p.p.m. for the coarse sample. The nickel and copper values for the fine sample are also considerably higher than for the coarse sample, which indicates that the PGM are associated with base-metal sulphides. This suggests that the PGM and associated nickel and copper become concentrated in the fine fraction of the tailings during the separation of the chromite.

(4) *Lateral Variations in the PGE Content of the Layer*

The very limited analytical data on the PGE contents of the tailings do not allow any speculation regarding the lateral homogeneity of the PGE in the chromitite layer, since the variations in the PGE content of individual samples from different dumps could be due to the effect of grain size on the analytical data. Representative data of the PGE content of the tailings in a dump at a particular locality would require an extensive and systematic sampling programme. Lateral variations in the PGE content of the tailings could be due to several reasons, such as variations in the PGE content of the chromitite layer, the

proportion of PGM enclosed in chromite grains, and the proportion of interstitial silicates. There is no reason to believe that the PGE content of a chromitite layer should vary to any great extent laterally. Although fluctuations in the PGE content of individual samples from one area are common, the average values remain remarkably consistent from one area to the next, as was shown for the Middle Group of chromitite layers and the UG-2 Chromitite Layer by Von Gruenewaldt *et al.*¹⁰.

It is of interest to note that the proportions of the PGE differ considerably from those in the Merensky Reef and the UG-2 Chromitite Layer. Values for tailings from the MG-1 and LG-6 are compared with whole-rock data in Table II. Although the platinum-to-palladium ratio of the tailings is similar to values in the Merensky Reef and the UG-2 Chromitite Layer, the proportion of ruthenium is considerably higher in the tailings of both the MG-1 and the LG-6 chromitite. The rhodium values, on the other hand, are less than half those in the UG-2 Chromitite Layer. The proportions quoted by Von Gruenewaldt *et al.*¹⁰ for a whole-rock sample from the MG-1 are, except for rhodium, similar to those in the tailings. This difference is probably due to sampling error, since the information quoted both by Von Gruenewaldt *et al.*¹⁰ and in the present paper is based on very limited sample numbers. Considerably more analytical data are required for a proper evaluation of the PGE proportions both in the tailings and in the chromitite layers from which the tailings are derived.

TABLE II
PROPORTIONS OF ELEMENTS IN THE MERENSKY REEF, THE CHROMITITE LAYERS, AND TAILINGS FROM CHROMIUM MINES^{5,10}

Layer	% by mass				Pt/Pd	Reference
	Pt	Pd	Rh	Ru		
Merensky Reef	61,6	26,9	4	7,5	2,3	1
UG-2 Chromitite (average)	47,6	29,1	8,3	15	1,6	1
UG-1 Chromitite (Maandagshoek)	39,4	24,2	8,7	27,7	1,6	2
MG-4 Chromitite	52,8	15,2	16,2	21,8	3,5	1
MG-3 Chromitite	45,8	22,2	10,3	21,7	2,1	1
MG-2 Chromitite	59,8	22,5	4,8	12,9	2,7	1
MG-1 Chromitite	37,5	15,1	9,9	37,5	2,5	1
MG-1 tailings	37,0	17,7	3,1	42,2	2,1	Table I*
LG-6 tailings	43,8	22,5	3,5	30,2	1,9	Table I†

* Average of samples 7 to 9

† Average of samples 1 to 4

Resource Evaluation

The scattered nature of the chromium mines throughout the eastern and western Bushveld Complex makes the evaluation of resources very difficult. Many mines went into production before the introduction of spiral concentrators, and it is not known to what extent the same tailings dumps were used after spirals had been introduced. Also, some mines exploited chromitite layers below the LG-6 Layer because that ore had a higher Cr₂O₃ content and a better chromium-to-iron ratio. Those layers general-

ly contain a higher proportion of interstitial silicates than the LG-6, so that the mixing of tailings from those layers with tailings from the LG-6 would have resulted in a dilution of the PGE values. Consequently, the resources summarized in Table III are estimates of only the LG-6 and MG-1 tailings.

TABLE III
RESOURCE EVALUATION OF CHROMIUM-MINE TAILINGS DUMPS

	LG-6		MG-1
	Properly separated 7,9	Poorly separated 1,5	1,9
Grade, g/t			
Estimated total tailings	$1,5 \times 10^6$ t	$1,5 \times 10^6$ t	$0,5 \times 10^6$ t
Resource, oz	382 250	72 500	30 500
Proportions			
Pt	43,8		37
Pd	22,5		17,7
Rh	3,5		3,1
Ru	30,2		42,2
Value/oz*		542	495
In situ R value	207×10^6	30×10^6	15×10^6

* Based on the December 1985 prices quoted by Robson⁹

The calculations given in Table III indicate a resource in the tailings dumps of close to 500 000 oz of PGE with a value of more than R250 million at the prices prevailing at the end of 1985. To this, about 38 000 oz of PGE with a value of R20 million are added every year. This figure is based on the assumption that about 150 kt of properly separated LG-6 tailings are added to the dumps annually. Clearly, an integrated approach in which chromite and PGE are extracted simultaneously could contribute significantly to the profitability of mining the chromitite layers in the Bushveld Complex.

The above figures are based on the combined platinum, palladium, rhodium, and ruthenium content of the tailings only. Just as for the PGE deposits of the Merensky Reef and the UG-2 Chromitite Layer, the tailings are bound to contain small quantities of iridium, osmium, and gold, which will further increase the value of this resource. Furthermore, the tailings also contain some nickel and copper sulphides (Table I). The proper recovery of these could yield 700 t of nickel and about 125 t of copper.

As stated above, the poorly separated tailings contain a high percentage of chromite. Further treatment of these tailings could contribute chromite sand as an additional product of substantial value.

Conclusions

The high grade of the tailings produced by thorough washing of the chromitite from the LG-6 Layer is such that the recovery of the PGE appears to be a profitable exercise that could be accomplished with a relatively small capital outlay. However, the scattered nature of the

deposits and the low tonnage at each mine would require several small-scale operations to produce flotation concentrates for further processing of the PGE. For the poorly separated LG-6 tailings, a combined programme of PGE and chromite extraction could, in sum, also be a profitable venture.

However, it must be emphasized that the figures mentioned in this report are based on limited observations, and that considerably more data would be required for a proper evaluation. Research required to ensure the optimal recovery of the PGM from the tailings should include, *inter alia*, studies of the type, grain size, and mode of occurrence of the PGM in the tailings, which would indicate whether additional milling is required to liberate the PGM from the silicates, and which flotation reagents are required to ensure maximum recovery. A study of the vertical distribution of the PGE in the LG-6 and MG-1 Chromitite Layers would show whether or not these elements have a distribution analogous to those in the UG-2 Chromitite Layer, where distinct peaks of mineralization occur at specific levels within the layer. Such knowledge could be of use in selective mining and beneficiation of the ore.

Acknowledgements

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