25 YEARS OF UG2 CONCENTRATORS...

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Presentation topics

What we knew then...
- Developing fundamental understanding of UG2 metallurgy
- 1st UG2-only concentrator at Western Platinum

What have we learned?
- Kroondal - late '90s
- Pilanesberg - 2009
- Current status of UG2 concentrator design

Future...
- Some thoughts on new technology
- Integration of concentrator design with downstream processes
Since 1970’s Mintek has been involved in the integrated disciplines of mineralogy, assaying, flotation chemistry, metallurgy and pyrometallurgy relating to UG2

Liddell, McRae and Dunne’s paper in Extraction Metallurgy ’85 summarised the state of the art as it was in the early 1980’s, and compared UG2 with Merensky

Mintek continues to provide laboratory and pilot facilities for UG2 operations

Process routes for beneficiation of noble metals from Merensky and UG-2 ores

K.S. Liddell, L.B. McRae, and R.C. Dunne
(Pyrometallurgy Division)

This paper first appeared in August 1985 in the book Extraction Metallurgy, pp. 789 to 806, published by the Institution of Mining and Metallurgy of London, and is reprinted with the kind permission of that Institution. The typesetting has been changed to ensure uniformity within this journal.

SYNOPSIS

The Merensky and UG-2 Rovars are close proximities to each other, but there are differences in their mineralogical characteristics and the grade size of the noble metals and sulphides they contain.

These differences and their effects on the behaviour of Merensky and UG-2 ores during treatment are examined. It is shown that, although the same basic processing route is used for both ores, the operating conditions for the extractive stages differ. Although the overall recovery for UG-2 is more than that for Merensky ore at present, there is a potential for improvement. This lies in the preconcentration stage, particularly in the removal of the coarse fraction of the flotation tailing.

KEITH LIDDELL was born in Johannesburg in 1931 and obtained a BSc degree from the University of the Witwatersrand in 1953. He was employed by the University of the Witwatersrand and was recently awarded an MSc (Eng.) degree. He is married and has two children. He enjoys football and occasionally water-skiing.

LAURENCE BRUCE MCRAE was born in Johannesburg and matriculated from the Jeppe High School, Johannesburg, in 1953. He gained practical experience as a technician while working in industry and at the University of the Witwatersrand. After being awarded a bursary by Gold Fields of South Africa Limited, he went on to study metallurgy, and graduated from the University of the Witwatersrand in 1956. As a postgraduate student at that University, he lectured in metallurgy until he was awarded the MSc (Eng.) degree. He was appointed as a senior scientist at Mintek in 1969 and was seconded to Mintek’s Poremetallurgy Research Group at the University of the Witwatersrand. Mr McRae is now a chief engineer in the Pyrometallurgy Division at Mintek.
UG2 FROM A PROCESS PERSPECTIVE

UG2 is chromite seam that happens to contain economic quantities of PGMs

Not much metallurgical similarity to Merensky

Chromite spinels generally do not contain significant PGMs unless UG2 has been altered (locally or regionally)

PGMs are mostly associated with base metal sulphides (but those which are not lead to losses if not considered in process strategies)

BMS are easily liberated when interstitial to chromite and silicates (but when locked lead to losses and concentrate dilution)

UG2 concentrate on its own is not amenable to conventional matte smelting due to low sulphide and high chromite

1. PGMs – Platinum group minerals, 2. BMS – Base metal sulphides

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UG2 concentrate is notoriously difficult to smelt due to present of chromite, requiring higher temperatures and intensive furnace conditions.

Low sulphide and base metal content means blending with Merensky, Platreef or other high BMS concentrate is necessary to achieve sufficient matte fall.

Both rectangular and circular furnaces are used.

Increasing production of PGM from UG2 will give need for various strategies:

- Continue concentrator designs to minimise Cr$_2$O$_3$ in concentrate
- Alternative smelting strategies - DC arc smelting such as ConRoast
- Hydrometallurgical processing of concentrate - Kell Process

<table>
<thead>
<tr>
<th></th>
<th>Mass Recovery %</th>
<th>PGM g/t</th>
<th>Cr$_2$O$_3$ %</th>
<th>Ni %</th>
<th>Cu %</th>
<th>S %</th>
<th>CaO + MgO %</th>
<th>SiO$_2$ %</th>
<th>FeO %</th>
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</thead>
<tbody>
<tr>
<td>UG2</td>
<td>1.3</td>
<td>200-400</td>
<td>2 to 5</td>
<td>1-2</td>
<td>&lt;1</td>
<td>3-5</td>
<td>23</td>
<td>44</td>
<td>12</td>
</tr>
<tr>
<td>Merensky</td>
<td>2 to 3</td>
<td>100-200</td>
<td>&lt;0.5</td>
<td>3</td>
<td>2</td>
<td>9</td>
<td>23</td>
<td>41</td>
<td>22</td>
</tr>
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</table>
**FIRST UG2-ONLY CONCENTRATOR**

Commissioned March 1983 at Western Platinum Mine

**MF1 Circuit:**
- 3 stage crush to <12mm
- Grinding - Rod mill, two parallel closed circuit ball mills
- Flotation - Rougher, 2 stages of closed circuit cleaning
- 73% PGM recovery to concentrate containing 460g/t PGM, 3.05% Cr\(_2\)O\(_3\)

Following intensive investigation of the PGM deportment throughout the plant, subsequent changes made in 1984 included:
- Change mining and blasting practices to reduce fines generation and losses
- Double the cleaner residence time by installing new 1\(^{st}\) stage cleaner using larger volume cells than previously installed
- Convert from 2 to 3 cleaning stages,
- increase power density of cleaner cells and provide forced air
- Split rougher concentrates into primary and secondary and direct to first and second cleaner stages respectively

Thereafter recovery increased by 10% and concentrate Cr\(_2\)O\(_3\) reduced to by 10%

Also investigated was:
- DMS of rod mill feed to remove waste
- Attrition scrubbing of rougher concentrate and cleaner tailing
- Chromite recovery by flotation and gravity concentration
- Screening of tailing at 53-75 \(\mu\)m to recover unliberated PGM and fine milling of silicate
- Improvements to classification
- Reagent regimes
Don’t create fines when you mine!

Minimise fines when blasting, they are lost on underground and surface transfer of run of mine ore

Minimise handling of ore underground and on surface, PGMs abrade from the chromitite when scraped, loaded and stockpiled. Some of these fines are then lost in stopes and on stockpiles

Mine-produced fines oxidise and have lower recoveries in the plant

1. 3PGE+Au assay value, aggregate of Pt, Pd, Rh, +Au

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**WHERE LOSSES OCCUR - CONCENTRATOR**

Don’t slime when you mill, but liberate from silicate!

### Analysis of an MF1 UG2 flotation tailing (1984)

<table>
<thead>
<tr>
<th>Size fraction µm</th>
<th>Cum. mass % finer</th>
<th>3PGE +Au g/t</th>
<th>PGE % in fraction</th>
<th>Colour</th>
<th>Cr$_2$O$_3$ assay %</th>
<th>Relevant mineralisation</th>
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</thead>
<tbody>
<tr>
<td>+150</td>
<td></td>
<td>3.12</td>
<td>11</td>
<td>Brown</td>
<td>4</td>
<td>PGM locked in silicates</td>
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<tr>
<td>-150, +106</td>
<td>96</td>
<td>2.90</td>
<td>21</td>
<td>Brown</td>
<td>7</td>
<td>+ 75 µm fraction has</td>
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<tr>
<td>-106, +75</td>
<td>87</td>
<td>1.42</td>
<td>13</td>
<td>Black</td>
<td>20</td>
<td>45% of PGMs in tailing at</td>
</tr>
<tr>
<td>-75, +53</td>
<td>76</td>
<td>0.66</td>
<td>18</td>
<td>Black</td>
<td>31</td>
<td>grade of 2.25 g/t</td>
</tr>
<tr>
<td>-53, +38</td>
<td>53</td>
<td>0.55</td>
<td>5</td>
<td>Black</td>
<td>34</td>
<td>Chromite predominant,</td>
</tr>
<tr>
<td>-38, +11</td>
<td>42</td>
<td>0.41</td>
<td>10</td>
<td>Black</td>
<td>35</td>
<td>partly liberated and talc</td>
</tr>
<tr>
<td>-11</td>
<td>15</td>
<td>1.52</td>
<td>21</td>
<td>Khaki</td>
<td>28</td>
<td>rimmed BMS/PGMs</td>
</tr>
</tbody>
</table>

**Understanding PGM and chromite liberation and flotation rates gave rise to implementation of MF2 circuits**

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Optical microscopy was main mineralogical tool
SEM and QEMSEM were emerging
Interaction between Mintek Ore Dressing and Mineralogy Divisions was key to understanding UG2 processing needs

Photomicrograph of talc rimmed BMS in UG2 ore (1987)

Instance of 1-2 μm talc rims of BMS still under estimated today
Fine milling of these particles not necessary, it overgrinds otherwise coarse sulphides
Scrubbing suffices
Mineral liberation analysis using combined SEM and X-ray techniques in one instrument provide a tool to investigate PGM deportment in ore and process streams.

Photomicrograph below shows association of PGM minerals with gangue in a UG2 plant flotation tailing over wide range of particle sizes.

Source: Rule & Anyimadu
Understanding liberation requirements is key to comminution design and energy and recovery efficiencies.

Mineralogical associations and liberation analysis define the comminution strategy.

Must regard UG2 milling as a 2 stage liberation process:

- 1. Primary stage is to liberate clean chromite from BM/PGMs and silicates while minimising chromite breakage and keeping PGMs locked to BMs.
- 2. Secondary stage is to liberate BM/PGMs from silicates.

Completely different comminution processes needed for stages 1 and 2.

Classification methods are equally important in mill circuit design.

- Hydrocyclones tend to slime chromite, wasting energy and increasing \( \text{Cr}_2\text{O}_3 \) entrainment whilst not effectively grinding silicates to liberate PGMs and BMS.
DENSE MEDIA SEPARATION

- Removes silicate waste from run of mine ore
- Provides more flexible mining methods
- Reduces capex and opex when DMS is applicable
- UG2 chromitite has much higher density than silicate waste ensuring efficient separation curves
- Design to minimise locked particles in DMS low density product (“clean float - dirty sinks” strategy). PGM grade of floats should be less than float tails
- Not applicable to all locations - simple laboratory and pilot testing will determine suitability
- Waste has higher energy consumption for crushing and milling
  - Waste Bond WI >20 kWh/t
  - UG2 chromitite Bond WI <10 kWh/t
- Waste can be detrimental to UG2 flotation
CONCEIVED IN 1997, DESIGN INTEGRATED MINING, PROCESSING, CONCENTRATE SALES AND SHAREHOLDER RETURN

- Wide reef mining room & pillar as in chromite mining - cheaper & safer, recovers UG2 and leader reefs
- Semi mechanised operation - less handling of ore
- DMS to remove waste resulting from wide reef mining
- Rod mills liberate clean chromite with minimal sliming
- MF1 (40% <75\,\mu m) installed first (maximum shareholder NPV, saleable concentrate, mid 70’s % recovery), then MF2 (80% <75\,\mu m) ~2 years later once debt free
- Thicken rougher concentrate, scrub and 3 stage cleaning - provides high grade MF1 concentrate (up to 900 \, g/\, t PGM) with low chromite (<2\% Cr_2O_3)
- Recover clean chromite from float tails - provides revenue stream and lower mass for tails disposal
Primary rod mills, 2 in parallel
Dense medium separation
Chromite spirals on primary rougher tail
Secondary ball mill
Rougher cells
Cleaner cells
Concentrate thickeners
Concentrate load out
Chromite concentrate
MF2 circuit is current standard circuit design

Moving to 3 stage milling with fine grinding as tertiary stage using horizontal and vertical stirred mills (Anglo Platinum mines, Pilanesberg Platinum, Platinum Mile)

Open circuit ball mills (ROM or crushed ore) preferred as primary mills over rod mills. Rod mills better from liberation perspective, but higher capex, length limitation of rods, rod culling and rod cost mitigate against widespread use

Classification still by hydrocyclone which overgrinds chromite - no solution yet found

Tank cells standard for flotation

In stream X-ray analysis of concentrates used for process control

BUT - chromite content of secondary concentrates not being dealt with effectively, and will increase as fine milling becomes more prevalent
PGM industry’s newest mine, processing UG2, Merensky and Pseudo reefs

Open pit mining gives low UG2 waste dilution (<8% waste)

MF2 with tertiary fine milling “MFM2F”

Open circuit primary ball mill - grind 40% <75μm

Open circuit secondary ball mill with 2-stage cycloning of mill feed - grind 80% <75μm

Isa mill of cyclone u/f from secondary mill discharge - grind 95% <75μm

All flotation in tank cells

Concentrate blended with Merensky plant concentrate, providing ability to maximise UG2 recovery without primary constraint of Cr₂O₃ content in UG2 concentrate
WHAT NEXT FOR CONCENTRATORS?

- Fine grinding technology and high pressure grinding rolls have matured. Major breakthrough for UG2
- Fine milling will be increasingly applied as tertiary and regrind stages (Anglo Platinum lead the field)
- High pressure grinding rolls will find increased application as primary stage liberation tool (Northam is first UG2 use of HPGR crushing <32mm feed to 75% passing 1mm)
  - Liberates chromite grains from silicates and BMS by interparticle crushing along grain boundaries
  - Reduced overall energy consumption
  - Reduction of chromite fines
- Over last 25 years classification technology has not progressed beyond hydrocyclones (screening technologies such as Pansep & Microscreens failed due to mechanical challenges not being overcome)
- Final cleaning stage with column cells to reduce chromite in final concentrate
- Attrition scrubbing of rougher concentrates is a cheap way to improve grade and reduce chromite in concentrates is under utilised
Hydrometallurgical process developed specifically by Liddell for UG2 concentrate, also applicable to Merensky and Platreef

Process consists of proven unit operations combined to separate sulphate and chloride circuits

Provides high 90%’s PGM and base metal recoveries

Low energy consumption (<50%) relative to smelting, very relevant in light of Eskom power price increases and capacity constraints

Process insensitive to $\text{Cr}_2\text{O}_3$ content & $\text{S}^2-$ and PGM grades

Produces separate PGM and BM streams for downstream refining using industry standard methods

PGM product suitable as PGM refinery feed or straight to metals/salts

Logical for low grade - high chromite secondary concentrates that are difficult to smelt

Patents granted in RSA, USA & Canada
KELL PROCESS – SIMPLIFIED BLOCK FLOW

Flotation Concentrate

Pressure oxidation and solution treatment

O₂, H₂SO₄

Base metal recovery

Ni, Cu, Co

Solid - liquid separation

Fe tailing

Reducing roast 900°C

Cl₂, HCl

Chlorination

Precious metal recovery

PGM, Au

Solid - liquid separation

Siliceous Tailing
Next steps for development:

- Further testing on "unsmeltable" secondary concentrates and those from tailing retreatment operations
- Demonstration pilot plant

Site-based licensing means individual operations can process their own concentrates to high value products and metals, with more rapid revenue generation.

Allows smaller producers to practice their own beneficiation of concentrate for their own benefit.

Allows the majors an alternative to adding further smelting capacity and moving part of their production away from an energy intensive process.
Thoughts on application of technology to future UG2 plants:

- DMS if ROM contains >15% waste
  - Reduces overall energy consumption & removes barren silicates from tertiary milling
- HPGR after primary crushing (particularly after DMS)
- Low power intensity primary milling in open circuit ball mill
- Primary flotation, with high PGM grade, low Cr$_2$O$_3$ concentrate to smelter
- Chromite recovery from primary float tails (UG2 is presently an under-utilised chromite resource)
- Secondary and tertiary milling of chromite recovery tailing - now a silicate-rich stream - to 100% <75 µm
- Secondary flotation of PGMs, final cleaning possibly in column cells
- On-site hydrometallurgical treatment of secondary concentrate
- Approximately 50:50 split of recovery to primary and secondary circuits
Selected bibliography


The Successful Development of an Industrial Process or the Recovery of Platinum-Group Metals from the UG-2 Reef, Application Report No.1, Mintek, 1987


Forest, S., SFA Oxford, Private Communication, November 2008

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