



25 YEARS OF UG2 CONCENTRATORS...

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25 YEARS OF UG2 CONCENTRATORS...



Presentation topics

- a *What we knew then...*
 - 2 Developing fundamental understanding of UG2 metallurgy
 - 2 1st UG2-only concentrator at Western Platinum
- a *What have we learned?*
 - 2 Kroondal - late '90s
 - 2 Pilanesberg - 2009
 - 2 Current status of UG2 concentrator design
- a *Future...*
 - 2 Some thoughts on new technology
 - 2 Integration of concentrator design with downstream processes

MINTEK HAS A LONG HISTORY WITH UG2



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

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(Pyrometallurgy Division)

This paper first appeared in August 1985 in the book *Extraction Metallurgy*, pp. 789 to 816, published by the Institution of Mining and Metallurgy of London, and is republished with the kind permission of that Institution. The typesetting has been changed to ensure uniformity within this journal.

SYNOPSIS

The Merensky and UG-2 Reefes are in close proximity to each other, but there are differences in their gangue mineralization and the grain size of the noble metals and sulphides they contain.

These differences and their effect 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 unit operations differ. Although the overall recovery for UG-2 ore is lower than that for Merensky ore at present, there is a potential for improvement. This lies in the preconcentration stage, particularly in the treatment of the coarse fraction of the flotation tailing.



KEITH LIDDELL was born in London in 1958, and obtained entrance to the University of Birmingham in the United Kingdom to study minerals engineering in 1978. He graduated in 1981 and emigrated to South Africa, where he joined the Ore-dressing Division at Mintek. He has been extensively involved in practical work associated with the optimization of the flotation of UG-2 ores and the recovery of gold and uranium using wet high-intensity magnetic separation (WHIMS). He is currently conducting research into the fine milling of pyrite and calcines. Mr Liddell continued his education at the University of the Witwatersrand, and was recently awarded an M.Sc. (Eng.) degree. He is married and has two children. He enjoys football and, occasionally, waterskiing.



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 1964. As a post-graduate student at that University, he lectured in metallurgy until he was awarded the M.Sc. (Eng.) degree. He was appointed as a senior scientist at Mintek in 1969 and was seconded to Mintek's Pyrometallurgy Research Group at the University of the Witwatersrand. Mr McRae is now a chief engineer in the Pyrometallurgy Division at Mintek.

a Since 1970's Mintek has been involved in the integrated disciplines of mineralogy, assaying, flotation chemistry, metallurgy and pyrometallurgy relating to UG2

a 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

a Mintek continues to provide laboratory and pilot facilities for UG2 operations

UG2 FROM A PROCESS PERSPECTIVE



- a UG2 is chromite seam that happens to contain economic quantities of PGMs¹
- a Not much metallurgical similarity to Merensky
- a Chromite spinels generally do not contain significant PGMs unless UG2 has been altered (locally or regionally)
- a PGMs are mostly associated with base metal sulphides (but those which are not lead to losses if not considered in process strategies)
- a BMS² are easily liberated when interstitial to chromite and silicates (but when locked lead to losses and concentrate dilution)
- a 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

SMELTING CHARACTERISTICS



Typical UG2 and Merensky concentrate specifications

	Mass Recovery %	PGM g/t	Cr ₂ O ₃ %	Ni %	Cu %	S %	CaO + MgO %	SiO ₂ %	FeO
UG2	1.3	200 - 400	2 to 5	1 - 2	<1	3 - 5	23	44	12
Merensky	2 to 3	100 - 200	< 0.5	3	2	9	23	41	22

- a UG2 concentrate is notoriously difficult to smelt due to present of chromite, requiring higher temperatures and intensive furnace conditions
- a Low sulphide and base metal content means blending with Merensky, Platreef or other high BMS concentrate is necessary to achieve sufficient matte fall
- a Both rectangular and circular furnaces are used
- a Increasing production of PGM from UG2 will give need for various strategies:
 - 2 Continue concentrator designs to minimise Cr₂O₃ in concentrate
 - 2 Alternative smelting strategies – DC arc smelting such as ConRoast
 - 2 Hydrometallurgical processing of concentrate – Kell Process



FIRST UG2-ONLY CONCENTRATOR

Commissioned March 1983 at Western Platinum Mine

- a 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% Cr₂O₃
- a 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 1st 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
- a Thereafter recovery increased by 10% and concentrate Cr₂O₃ reduced to by 10%
- a 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 μ m to recover unliberated PGM and fine milling of silicate
 - Improvements to classification
 - Reagent regimes

WHERE PGM LOSSES OCCUR - MINING



- a Don't create fines when you mine!

PGM distribution in UG2 run of mine ore		
Size fraction, mm	Cum. Mass % passing upper size	Cum. 3PGE+Au ¹ % passing upper size%
<12.5, >1.7	65	63
<1.7, > 0.075	42	33
<0.075	7	19

- a Minimise fines when blasting, they are lost on underground and surface transfer of run of mine ore
- a 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
- a Mine-produced fines oxidise and have lower recoveries in the plant

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

WHERE LOSSES OCCUR - CONCENTRATOR



- a Don't slime when you mill, but liberate from silicate!

Analysis of an MF1 UG2 flotation tailing (1984)

Size fraction μm	Cum. mass % finer	3PGE +Au g/t	PGE% in fraction	Colour	Cr ₂ O ₃ assay %	Relevant mineralisation
+150		3.12	11	Brown	4	PGM locked in silicates + 75 μm fraction has 45% of PGMs in tailing at grade of 2.25 g/t
-150, +106	96	2.90	21	Brown	7	
-106, +75	87	1.42	13	Black	20	
-75, +53	76	0.66	18	Black	31	Chromite predominant, partly liberated and talc rimmed BMS/PGMs
-53, +38	53	0.55	5	Black	34	
-38, +11	42	0.41	10	Black	35	
-11	15	1.52	21	Khaki	28	Slimed PGMs, slow flotation rates

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

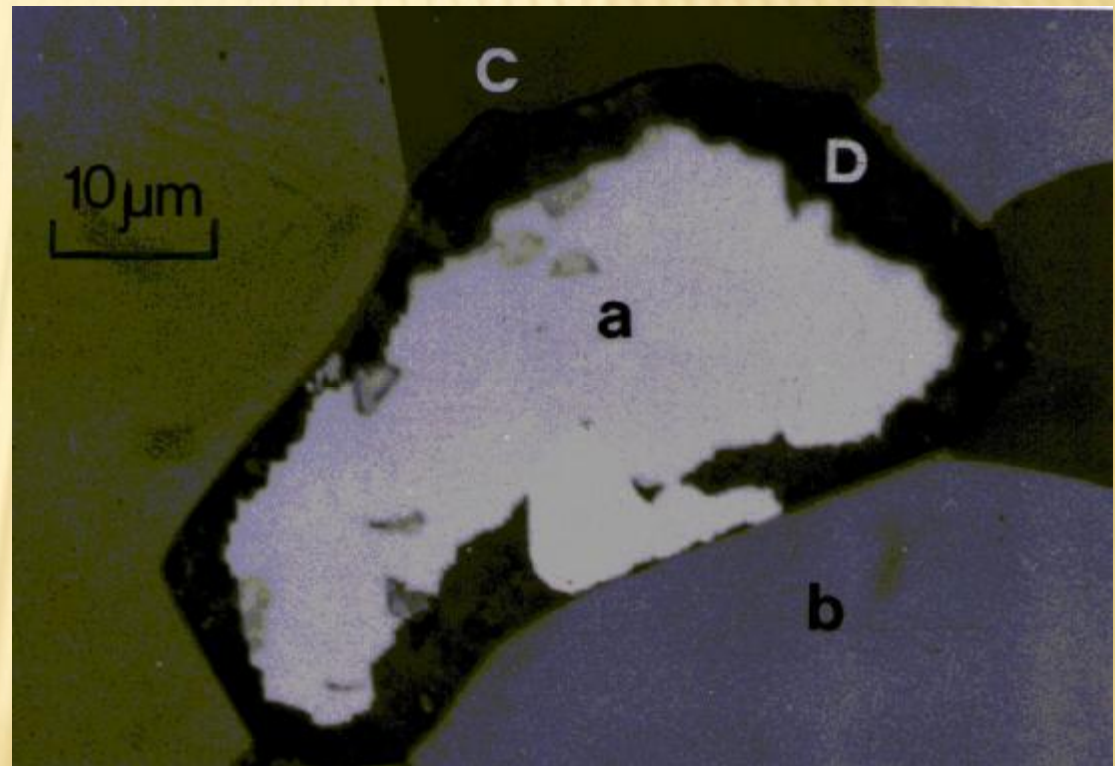
MINERALOGY 25 YEARS AGO



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

Photomicrograph of talc rimmed BMS in UG2 ore (1987)

- a Instance of 1-2 μm talc rims of BMS still under estimated today
- a Fine milling of these particles not necessary, it overgrinds otherwise coarse sulphides
- a Scrubbing suffices

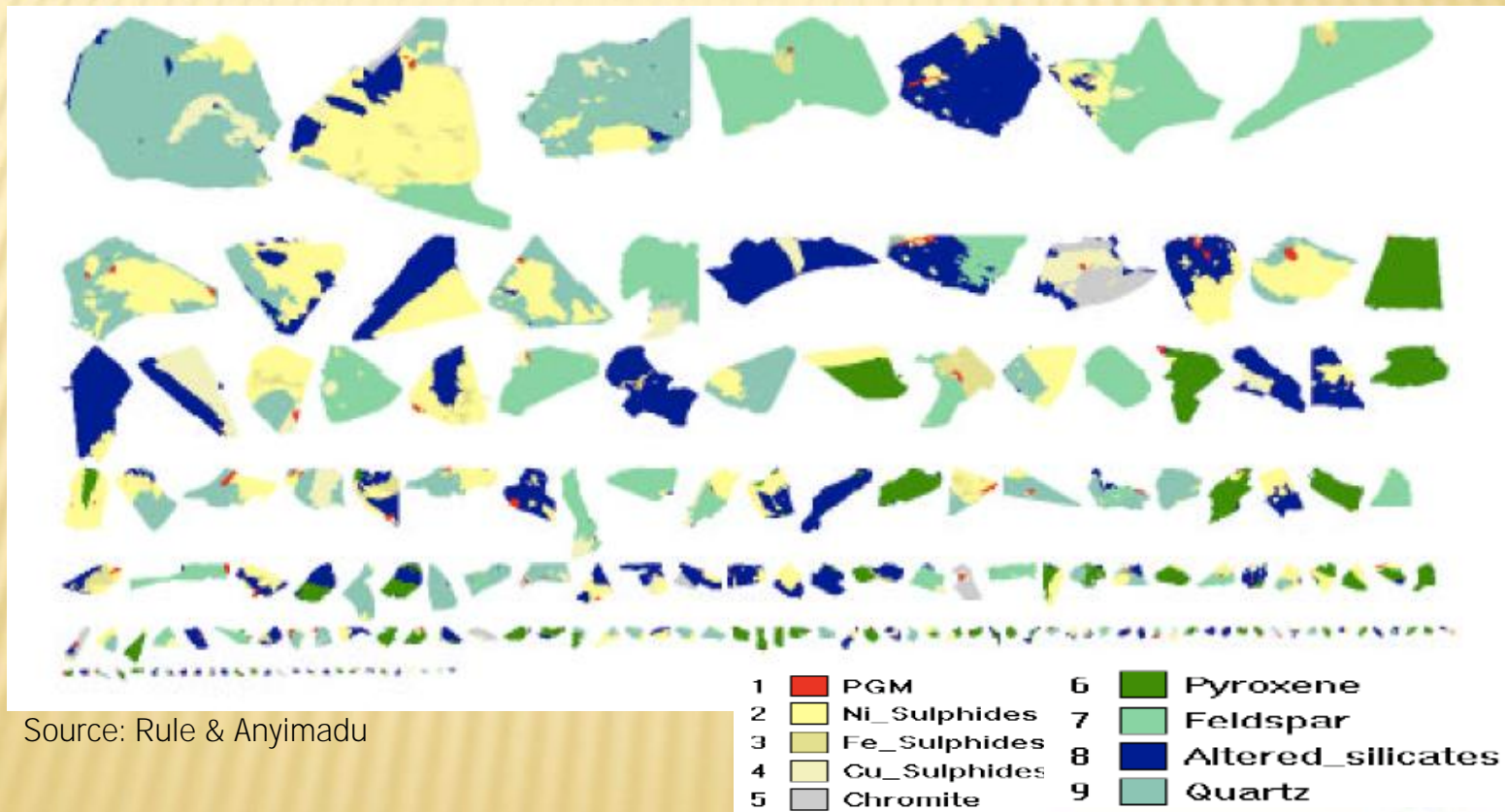


A – Chalcopyrite B – Chromitite
C – Silicate D - Talc rim on chalcopyrite

MINERALOGY NOW



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



Source: Rule & Anyimadu

LIBERATION ANALYSIS = MILL DESIGN



Understanding liberation requirements is key to comminution design and energy and recovery efficiencies

- a Mineralogical associations and liberation analysis define the comminution strategy
- a Must regard UG2 milling as a 2 stage liberation process:
 - 2 1. Primary stage is to liberate clean chromite from BM/PGMs and silicates while minimising chromite breakage and keeping PGMs locked to BMs
 - 2 2. Secondary stage is to liberate BM/PGMs from silicates
 - 2 Completely different comminution processes needed for stages 1 and 2
- a Classification methods are equally important in mill circuit design
 - 2 Hydrocyclones tend to slime chromite, wasting energy and increasing Cr_2O_3 entrainment whilst not effectively grinding silicates to liberate PGMs and BMS



DENSE MEDIA SEPARATION



- a Removes silicate waste from run of mine ore
- a Provides more flexible mining methods
- a Reduces capex and opex when DMS is applicable
- a UG2 chromitite has much higher density than silicate waste ensuring efficient separation curves
- a 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
- a Not applicable to all locations – simple laboratory and pilot testing will determine suitability
- a Waste has higher energy consumption for crushing and milling
 - Waste Bond WI >20 kWh/t
 - UG2 chromitite Bond WI <10 kWh/t
- a Waste can be detrimental to UG2 flotation



KROONDAL – LOWEST COST PRODUCER



*CONCIEVED IN 1997, DESIGN INTEGRATED MINING,
PROCESSING, CONCENTRATE SALES AND SHAREHOLDER
RETURN*

- a Wide reef mining room & pillar as in chromite mining – cheaper & safer, recovers UG2 and leader reefs
- a Semi mechanised operation – less handling of ore
- a DMS to remove waste resulting from wide reef mining
- a Rod mills liberate clean chromite with minimal sliming
- a MF1 (40% <75 μ m) installed first (maximum shareholder NPV, saleable concentrate, mid 70's % recovery), then MF2 (80% <75 μ m) ~2 years later once debt free
- a Thicken rougher concentrate, scrub and 3 stage cleaning – provides high grade MF1 concentrate (up to 900 g/t PGM) with low chromite (<2% Cr₂O₃)
- a Recover clean chromite from float tails – provides revenue stream and lower mass for tails disposal

KROONDAL – MF2 CONFIGURATION



PRESENT DESIGN OF CONCENTRATORS



- a MF2 circuit is current standard circuit design
- a Moving to 3 stage milling with fine grinding as tertiary stage using horizontal and vertical stirred mills (Anglo Platinum mines, Pilanesberg Platinum, Platinum Mile)
- a 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
- a Classification still by hydrocyclone which overgrinds chromite – no solution yet found
- a Tank cells standard for flotation
- a In stream X-ray analysis of concentrates used for process control
- a BUT – chromite content of secondary concentrates not being dealt with effectively, and will increase as fine milling becomes more prevalent

PILANESBERG PLATINUM – MARCH 2009



PGM industry's newest mine, processing UG2, Merensky and Pseudo reefs

- a Open pit mining gives low UG2 waste dilution (<8% waste)
- a MF2 with tertiary fine milling "MFM2F"
- a Open circuit primary ball mill – grind 40% <75 μ m
- a Open circuit secondary ball mill with 2-stage cycloning of mill feed – grind 80% <75 μ m
- a Isa mill of cyclone u/f from secondary mill discharge – grind 95% <75 μ m
- a All flotation in tank cells
- a 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?...



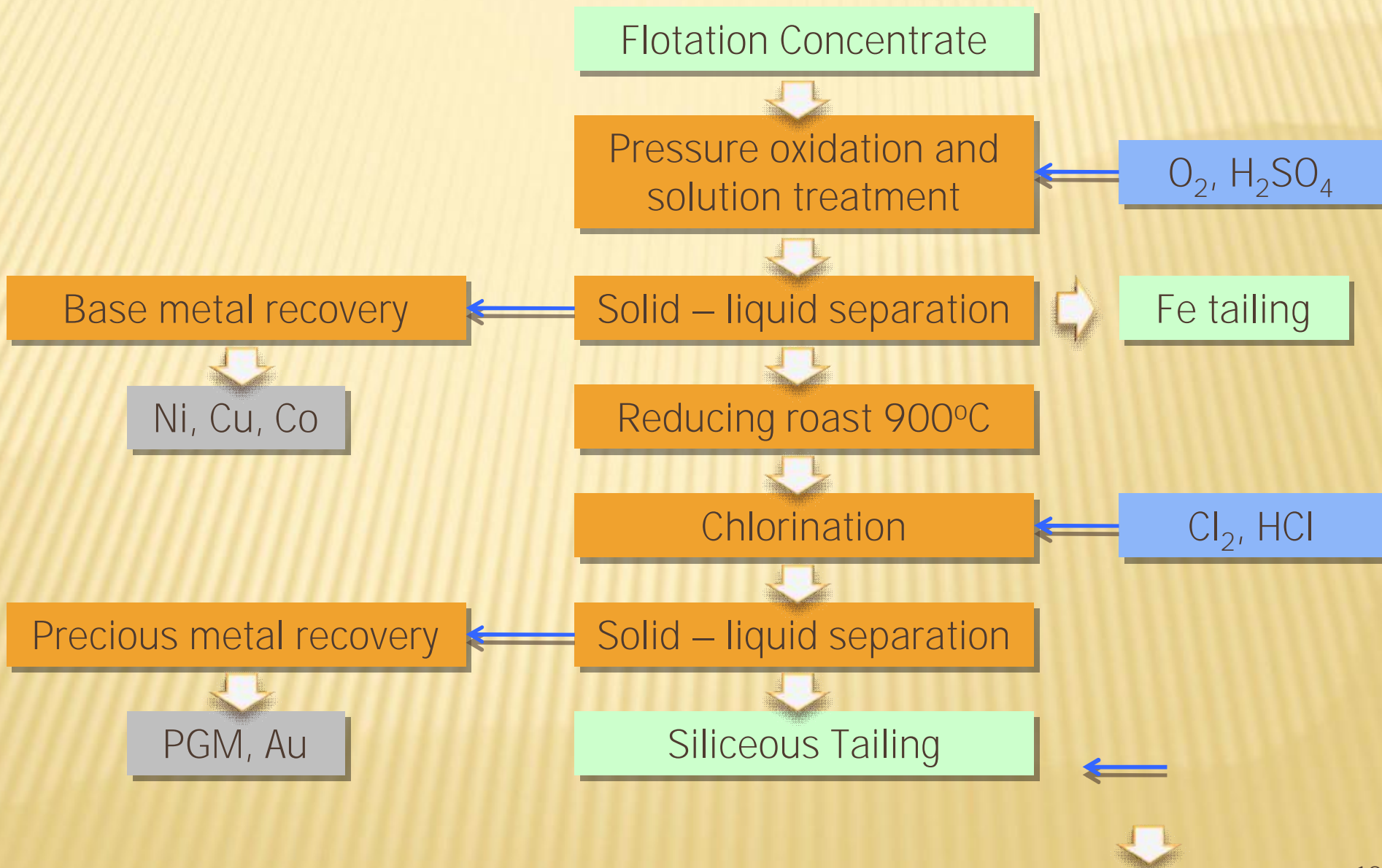
- a Fine grinding technology and high pressure grinding rolls have matured. Major breakthrough for UG2
- a Fine milling will be increasingly applied as tertiary and regrind stages (Anglo Platinum lead the field)
- a High pressure grinding rolls will find increased application as primary stage liberation tool (Northam is first UG2 use of HPGR crushing <32mm feed to 75% passing 1mm)
 - 2 Liberates chromite grains from silicates and BMS by interparticle crushing along grain boundaries
 - 2 Reduced overall energy consumption
 - 2 Reduction of chromite fines
- a 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)
- a Final cleaning stage with column cells to reduce chromite in final concentrate
- a Attrition scrubbing of rougher concentrates is a cheap way to improve grade and reduce chromite in concentrates is under utilised

KELL PROCESS FOR PGM CONCENTRATES



- a Hydrometallurgical process developed specifically by Liddell for UG2 concentrate, also applicable to Merensky and Platreef
- a Process consists of proven unit operations combined to separate sulphate and chloride circuits
- a Provides high 90%'s PGM and base metal recoveries
- a Low energy consumption (<50%) relative to smelting, very relevant in light of Eskom power price increases and capacity constraints
- a Process insensitive to Cr_2O_3 content & S^{2-} and PGM grades
- a Produces separate PGM and BM streams for downstream refining using industry standard methods
- a PGM product suitable as PGM refinery feed or straight to metals/salts
- a Logical for low grade – high chromite secondary concentrates that are difficult to smelt
- a Patents granted in RSA, USA & Canada

KELL PROCESS – SIMPLIFIED BLOCK FLOW



KELL PROCESS: SMELT THE SMELTABLE, LEACH THE REST



- a Next steps for development:
 - 2 Further testing on “unsmeltable” secondary concentrates and those from tailing retreatment operations
 - 2 Demonstration pilot plant
- a Site-based licensing means individual operations can process their own concentrates to high value products and metals, with more rapid revenue generation
- a Allows smaller producers to practice their own beneficiation of concentrate for their own benefit
- a Allows the majors an alternative to adding further smelting capacity and moving part of their production away from an energy intensive process

FUTURE UG2 CONCENTRATOR?



Thoughts on application of technology to future UG2 plants:

- a DMS if ROM contains >15% waste
 - z Reduces overall energy consumption & removes barren silicates from tertiary milling
- a HPGR after primary crushing (particularly after DMS)
- a Low power intensity primary milling in open circuit ball mill
- a Primary flotation, with high PGM grade, low Cr_2O_3 concentrate to smelter
- a Chromite recovery from primary float tails (UG2 is presently an under-utilised chromite resource)
- a Secondary and tertiary milling of chromite recovery tailing – now a silicate-rich stream – to 100% <75 μm
- a Secondary flotation of PGMs, final cleaning possibly in column cells
- a On-site hydrometallurgical treatment of secondary concentrate
- a Approximately 50:50 split of recovery to primary and secondary circuits

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