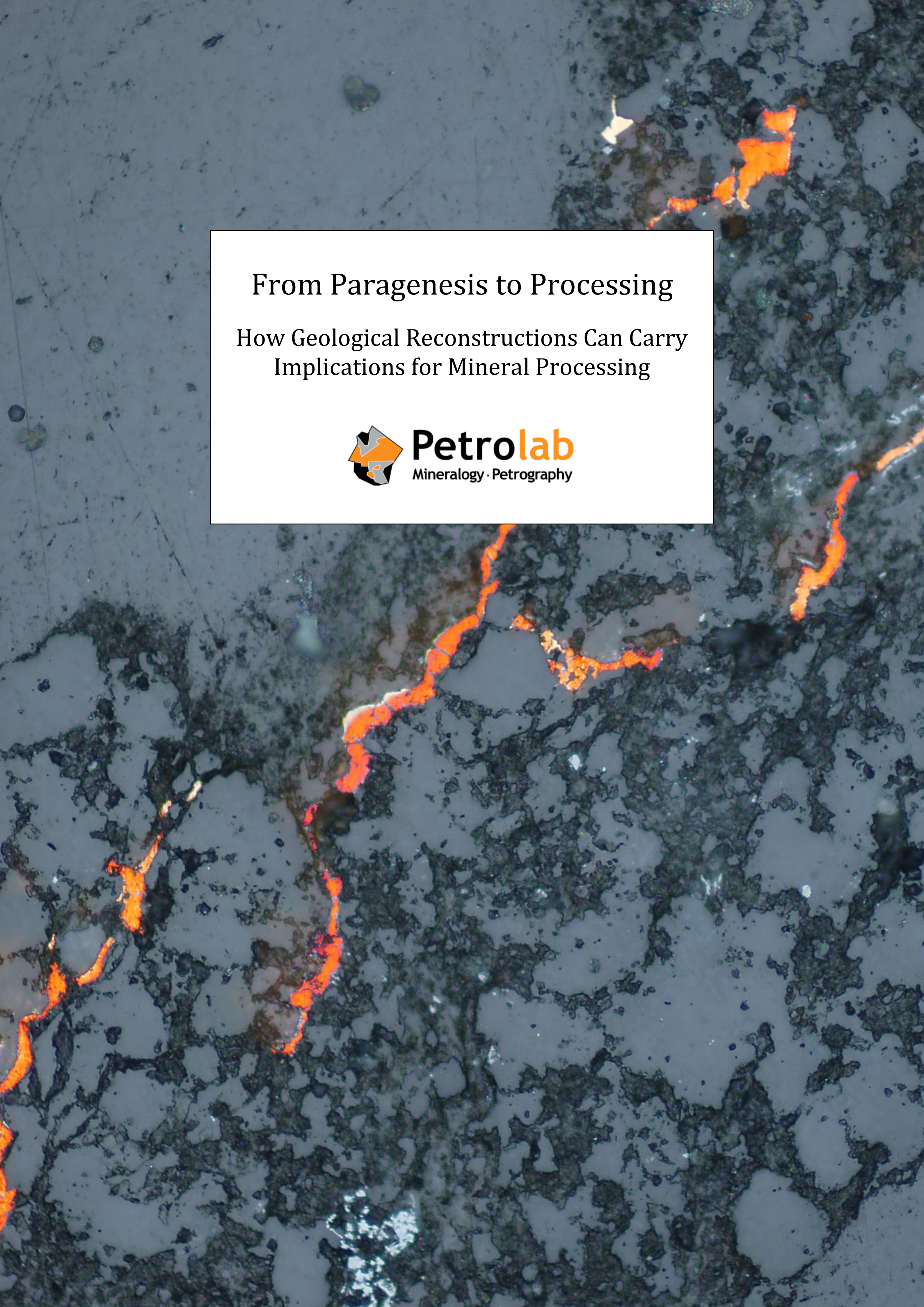

From Paragenesis to Processing

How Geological Reconstructions Can Carry Implications for Mineral Processing

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From Paragenesis to Processing: How Geological Reconstructions Can Carry Implications for Mineral Processing

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Abstract

This case study briefly highlights the potential to derive, in an approximate sense, likely processing behaviour from geological reconstructions. In turn, this information can feed into geometallurgical planning allowing the early stage recognition of potential processing flowpaths that can be used to optimise recovery. The case study is pulled together from analysis undertaken on the Merensky reef at Northam Platinum Ltd in South Africa.

The Merensky Reef at Northam Platinum shows a complex range of reef developments with several distinct reef types that are processed through the run-of-mine. These differences can be related to the paragenetic history of the deposit with the differing mineralogy related to the changing footwall mineralogy at the time of the hanging wall deposition. This case study looks at three of those reef types (the Normal Reef, the transitional Pothole reef and the full Pothole reef) which contain distinct differences in their mineralogical deportment.

The differing mineralogy of the footwall at the time of hanging wall deposition resulted in differences in modal mineralogy, the amount of floatable gangue and the sulphide textural development. These differences in turn led to predictable differences in milling times, mineral liberation and sulphide flotation performance. As the Merensky reef is a platinum-group element (PGE) ore with the majority of the platinum-group minerals contained within sulphides, these differences are crucial.

Background

The Merensky reef, which was discovered in 1924 by Dr Hans Merensky, formed for many years the worlds' premium resource of platinum. It consists of the Merensky Cyclic Unit (MCU) deposited unconformably as a drape over a stratified and mineralogically variable footwall (Figure 1; Viring & Cowell, 1999; Roberts et al., 2007). Mineralisation within the Merensky reef is present at both the base of the MCU and within the upper portion of the footwall. The variability in the footwall mineralogy at Northam Platinum mine during MCU depodition has significant processing implications which will be explored in this article. For further reference, similar research at the Bafokeng Rasimone Platinum mine also shows the effect of geological variations on flotation performance (Smith et al., 2013). All results presented in this article are derived from a laboratory scale set of experiments. The results are therefore presented as a comparison across standardised conditions but are not necessarily completely indicative of the behaviour on a processing plant scale.

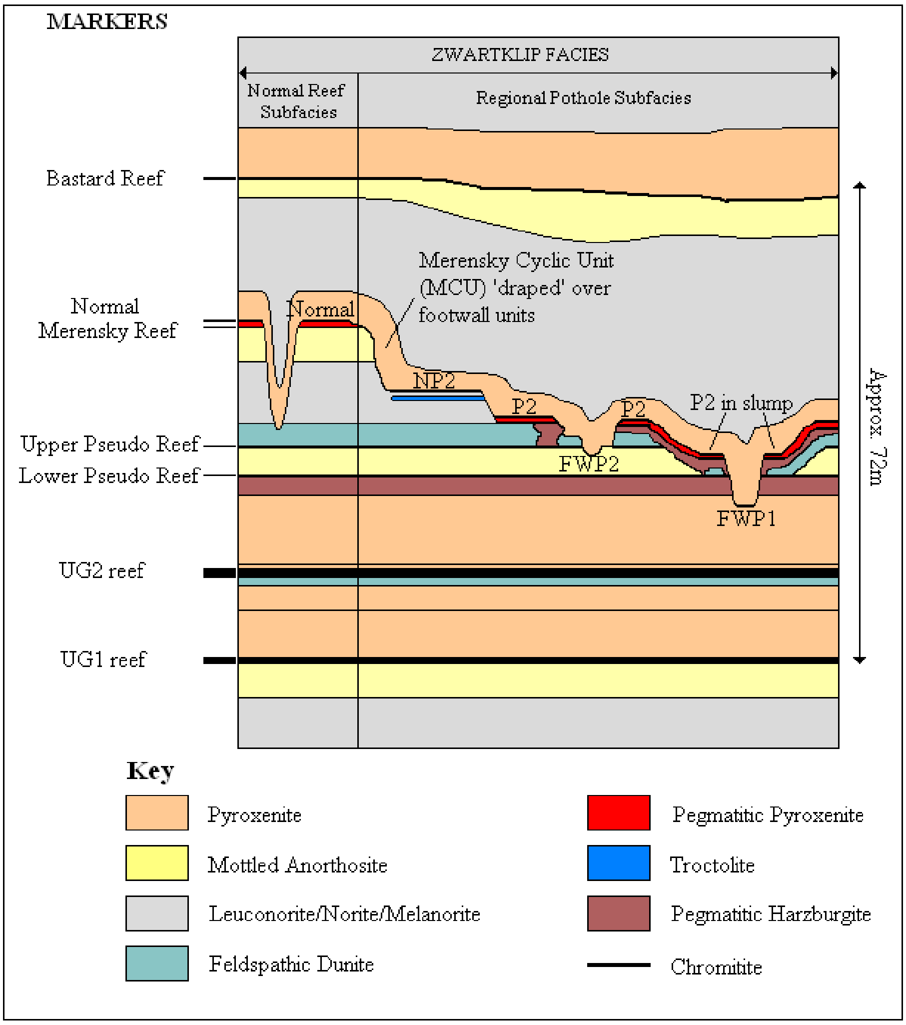

Figure 1: *A schematic cross-section through the upper section of the Upper Critical Zone, showing the hanging wall 'drape' and footwall components to the Merensky reefs at Northam Platinum Mine, South Africa. Adapted from Smith et al., (2004).*

At the Northam Platinum mine variation in the footwall mineralogy has led to development of at least three distinct reef types; Normal, NP2 and P2 reef. The Normal and P2 reefs are broadly mineralogically similar in that the footwall is melanocratic in each case and with the immediate lithology below the MCU chromitite consisting of pegmatitic pyroxenite underlain by another basal chromititic stringer. For the Normal reef this basal chromite stringer is underlain by anorthosite, whilst for the P2 reef the basal stringer is underlain by a more dunitic harzburgite. The NP2 reef is the most mineralogically distinctive of the three reef types consisting of the single MCU chromite overlying a predominantly anorthositic footwall. Within the anorthosite there is the development of a troctolite band which marks the downward extent of fluid infiltration from the MCU (Figure 2; Viring & Cowell, 1999).

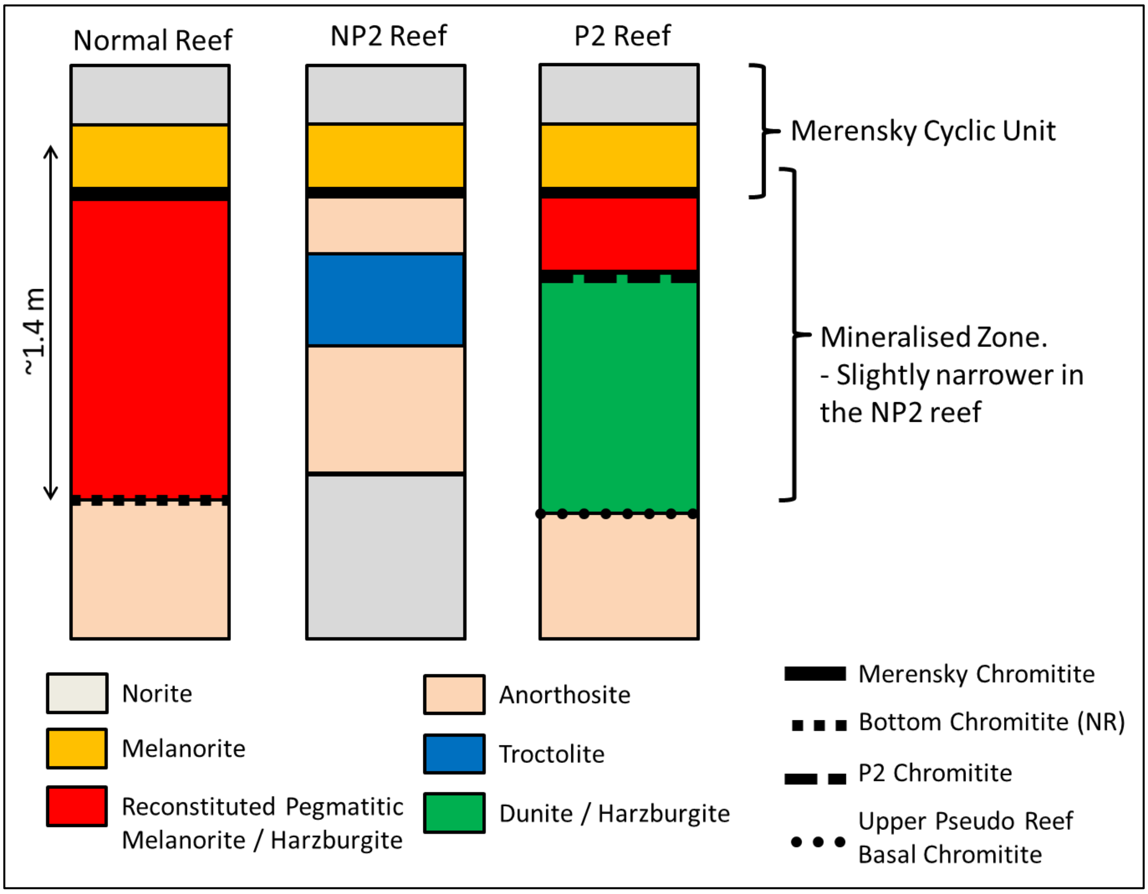

Figure 2: *Schematic of the three reef types.*

Critically, the difference in footwall mineralogy, particularly of the NP2 reef effects the modal mineralogy (Table 1), the degree of floatable gangue, the sulphide textural development (Figure 3), expected milling times (Table 2), as well as sulphide grades and recoveries during flotation (Figure 4). The focus on factors affecting the sulphide development is key because platinum group minerals (PGM) show an intimate association with base-metal sulphides in the Merensky Reef (Becker et al., 2008; Brough et al., 2010), though this does not necessarily hold for the other reef types present within the Bushveld Complex (i.e. the UG2 and Platreef).

Modal Mineralogy

QEMSCAN analysis of the milled feeds of the three reef types show distinct differences in their modal mineralogy (Table 1). In comparison to the NP2 reef which is plagioclase rich (62.6 wt%), the Normal and P2 reef are plagioclase poor (16.7 wt% and 7.2 wt%, respectively). With relatively little plagioclase the principal gangue mineral in the Normal and P2 reefs is orthopyroxene (51.2 wt% and 68.6 wt%, respectively), which constitutes just 25.4 wt% in the NP2 reef. There are also differences in the total proportions of alteration minerals (defined as the sum of the minerals amphibole, serpentine, talc, chlorite as well as magnetite). The Normal reef contains the highest amount of alteration minerals (2.3 wt%), followed by the P2 reef (1.8 wt%) and lastly the NP2 reef (1.0 wt%). Biotite which may be primary or secondary is also greatest within the Normal reef (1.8 wt%) compared to the P2 (0.9 wt%) and NP2 reefs (1.1 wt%). The relative proportions of low-temperature alteration minerals such as talc are important since they are naturally floatable and may induce inadvertent gangue flotation if they are associated with other common gangue minerals (Becker et al., 2009; Jasieniak and Smart, 2009).

Table 1: *Percentage abundance of minerals in weight% within each reef as calculated by QEMSCAN. Total alteration is the summative value of amphibole, serpentine, talc, chlorite, other silicates and magnetite (Brough et al., 2010).*

Mineral	Normal Reef (wt%)	NP2 Reef (wt%)	P2 Reef (wt%)
Orthopyroxene	51.2	25.4	68.6
Clinopyroxene	4.4	3.2	5.4
Plagioclase	16.7	62.6	7.2
Olivine	17.3	1.7	8.7
Mica	1.8	1.1	0.9
Quartz	0.7	0.4	0.4
Amphibole	0.5	0.3	0.6
Serpentine	0.3	0.2	0.4
Talc	0.3	0.1	0.3
Chlorite	0.6	0.1	0.1
Other Silicates	0.5	0.2	0.1
Chromite	3.3	2.7	3.9
Magnetite	0.6	0.3	0.3
Pentlandite	0.6	0.5	0.9
Pyrrhotite	0.5	0.5	0.7
Chalcopyrite	0.2	0.2	0.3
Pyrite	0.1	0.1	0.2
Other Sulphides	0.2	0.1	0.3
Other	0.3	0.4	0.5
Total Sulphides	1.6	1.4	2.4
Total Alteration Minerals	2.3	1.0	1.8

Floatable Gangue

The basic gangue minerals are the same for each reef type (orthopyroxene, plagioclase, olivine, clinopyroxene, chromite and alteration phases) but relative to the NP2 reef, the Normal and P2 reef contain a far higher abundance of primary ferromagnesian minerals and their alteration phases. One important alteration phase is talc which is present in slightly greater abundance in both the Normal and P2 reefs. Talc is a highly floatable gangue mineral, capable of not only entering the concentrate through true flotation but also of carrying other gangue minerals such as orthopyroxene through association (Becker *et al.,* 2009). Furthermore, talc has a froth stabilising effect promoting increased water recovery and therefore mass recovery by entrainment.

This increased quantity of floatable gangue has two main effects. The first is to lower base-metal sulphide (BMS) grades and this is seen for the Normal and P2 reefs, where initial grades are lower than the NP2 reef (Figure 4). The second is to slow the rate of BMS recovery and thereby reduce total BMS recovery (Figure 4). It is worth noting that this latter effect is only key in batch floats which are froth limiting and that the plant response may not be identical.

Sulphide Textures

Across the three reef types there is one main sulphide texture and three subsidiary textures; the main sulphide texture is fine to medium grained (0.5-5mm), composites (Figure 3a), predominantly of pyrrhotite, pentlandite and chalcopyrite, but also with minor amounts of bornite, cubanite and possibly mackinawite. The three subsidiary textures are: fine grained (<0.2mm), largely monomineralic inclusions in the major silicate phases (Figure 3b) and chromite; sulphides concentrated within microfractures that occurred during brittle deformation (Figure 3c); and very fine unidentifiable sulphides located within secondary silicate minerals such as paragonite and serpentine (Figure 3d).

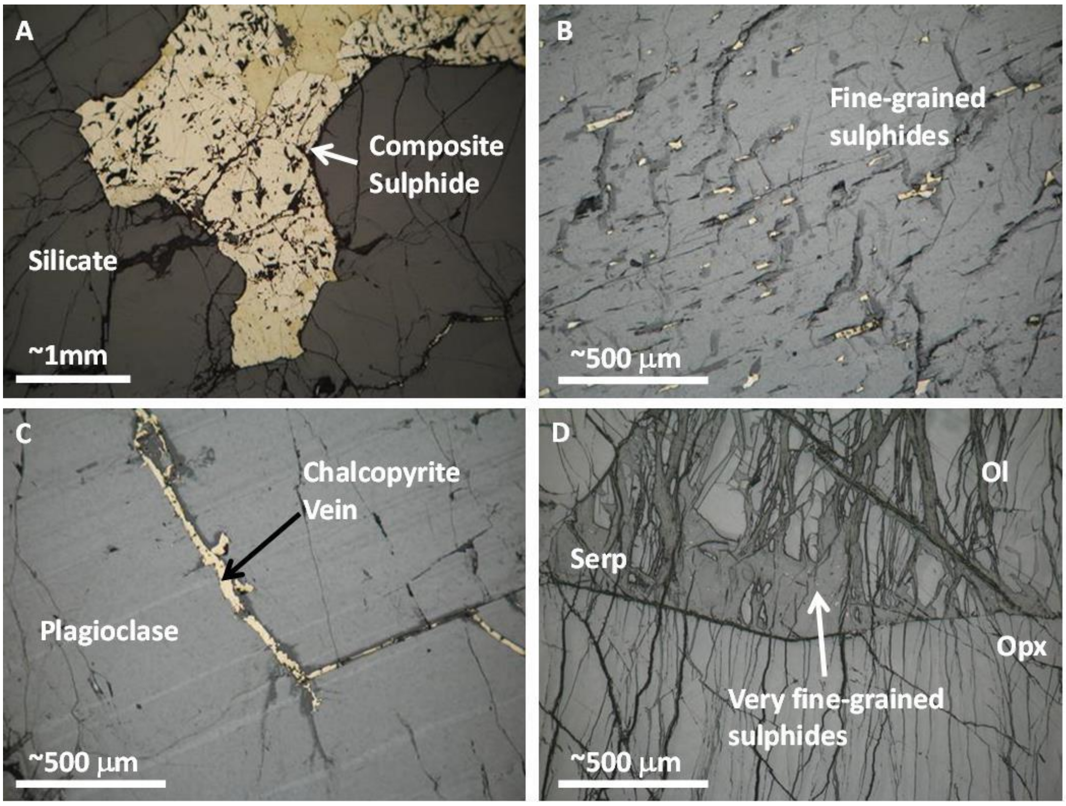

Figure 3: *Sulphide textures. a. composite sulphide about 2mm across. b. Fine grained sulphides locked in an orthopyroxene megacryst. c. sulphide vein within plagioclase grain. d. Very fine grained sulphides enclosed in serpentine (Adapted from Brough et al., 2010).*

The Normal and P2 reefs contain all four sulphide textures, whereas the NP2 reef contains only composite sulphides (Figure 3a) and fine-grained sulphides (Figure 3b). The lack of very fine sulphide development and sulphide veining suggests that sulphides within the NP2 reef will be the easiest to liberate as is the case for chalcopyrite, pyrrhotite and the composite BMS (Brough *et al.,* 2010).

The reason for this difference between the NP2 reef and the Normal and P2 reefs is the pegmatitic nature of the footwall, which is related to the initial 'pre-MCU event' footwall. Since the footwall to the Normal and P2 reef was melanocratic, the subsequent deposition of a new hot magma pulse (the MCU), led to reconstitution and grain coarsening. This encouraged the development of coarse composites as well as complex secondary remobilisation of sulphides, generating three subsidiary textures. In contrast the leucocratic NP2 footwall responded very differently to the deposition of the MCU. Rather than grain coarsening, the magma infiltrated between the plagioclase grains occasionally reacting with rare orthopyroxene grains. The result was largely undisturbed anorthositic or leucocratic layers within which a thin troctolized layer represents the downward extent of magma infiltration.

Milling Times

Milling times for the three reefs suggest that the NP2 reef is the softest, relative to the Normal and P2 reefs, with the P2 reef being the hardest (Table 2). This difference in hardness can be attributed to mineralogy, texture and degree of alteration. It implies that the plagioclase rich rocks (i.e. the NP2 reef) are softer that the orthopyroxene rich rocks (i.e. the Normal and P2 reefs). Furthermore, since the mineralogy of the Normal and P2 reefs are similar the role of alteration and texture are also critical. The Normal reef is slightly more altered that the P2 reef, and contains a much thicker inter-chromitite pegmatite (~150 cm, compared with ~40 cm). This suggests that the increased alteration and pegmatitic character of the Normal reef decreases its milling time relative to the P2 reef. The major implication of this is the expected ore throughput, with the NP2 reef capable of being processed quicker than either the Normal of P2 reefs (Brough *et al.,* 2010).

Table 2: *Milling times given in minutes for the standard and fine grinds for each of the three reef types. Milling was undertaken on an Erietz laboratory stainless steel rod mill.*

Grind	%<75 μm	Normal Reef	NP2 Reef	P2 Reef
Standard	60	19.5	18.0	23.0
Fine	80	26.5	25.0	30.0

Sulphide Grade and Recovery

The variations in sulphide development described above can be linked in with observed variations in liberation and grade recovery. Firstly, the dominance within all reef types of medium grained composite sulphides results in excellent liberation (>80%) for all BMS at both grind sizes (Brough et al., 2008). Since PGM are invariably associated with sulphides, any such PGM associated with the major composite sulphides can also be expected to be recovered.

Secondly, the presence of fine-grained BMS locked within primary orthomagmatic (e.g. orthopyroxene) minerals explains why sulphide recovery is not optimised for each of the three reefs. This is because after grinding the fine-grained sulphides will be locked or only partially liberated, and being trapped within hydrophilic minerals will be retained in the pulp. The lower sulphide recoveries observed within the Normal and P2 reefs values will partly be a function of the greater quantity of fine grained sulphides minerals present (Figure 4).

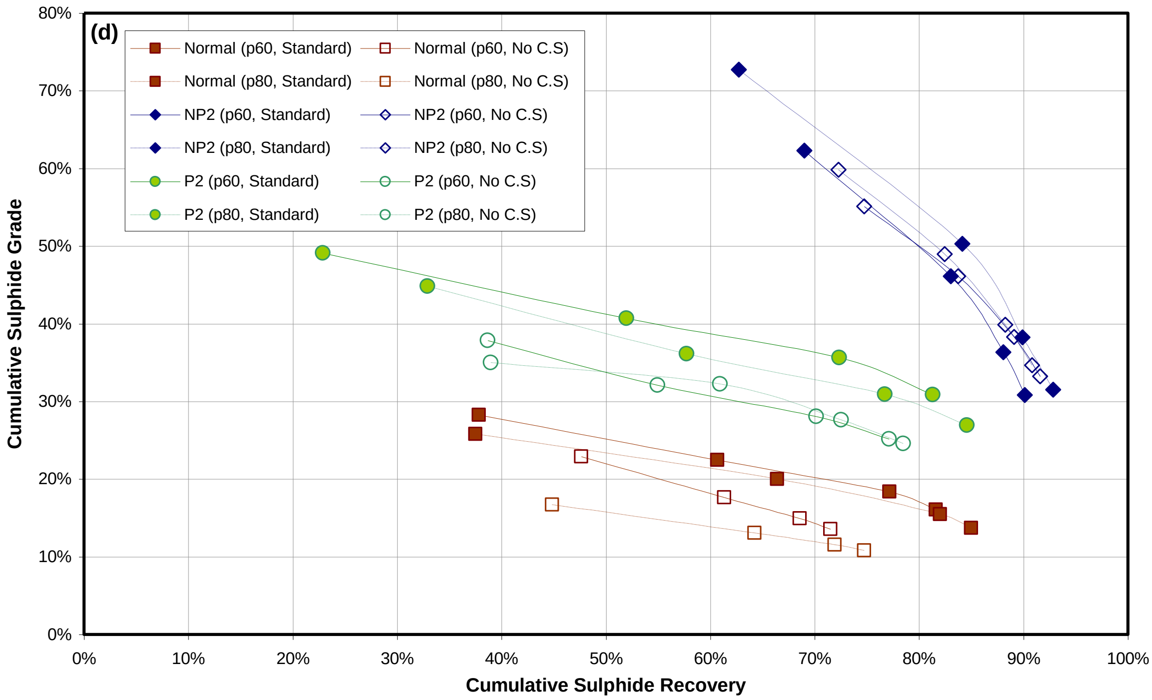

Figure 4: *Total sulphide grade-recovery Curves. Standard applies to flotation conditions using copper sulfate as an activator whilst 'No C.S.' refers to flotation conditions without the addition of copper sulfate as an activator. Two grind sizes are shown which are p60 and p80 passing 75 μm (Taken from Brough et al., 2010).*

Conclusion

From this particular study the NP2 reef is the easiest of the three reefs to process, producing optimum sulphide recoveries and the highest sulphide grades and that these differences in performance can be traced back to the conditions at the time of formation. The different footwall conditions during MCU deposition resulted in a different modal and textural mineralogy. These mineralogical differences ultimately controlled the processing performance, having a direct effect on milling times, floatable gangue and sulphide liberation. Essentially, the paragenesis controlled the processing requirements. This case study shows the potential that accurate geological reconstructions have to impact on geometallurgical considerations.

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Christopher Brough is a consultant mineralogist at Petrolab, Cornwall. He specialises in the application of mineralogy to a range of mining problems including the characterisation of acid-generating and acid-neutralising minerals with implications for acid rock drainage and metal leaching (ARDML) together with the characterisation of ore and gangue mineralogy with their implications for potential processing problems. He has an MEarthSc from Oxford University, an MRes from the University of Cape Town and obtained his PhD in PGE and chromite geochemistry from Cardiff University in 2011.

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Contact:

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