Mine-plan-informed CMC depressant blend selection using QXRD and microflotation of Western Bushveld PGM lithological domains

NJ Shackleton[*a], V Malysiak[a], O Muswadzi[b], and R Madiba[b]

[a]*AECI Mining Chemicals, AECI Place, 24 The Woodlands, Woodlands Drive, Woodmead Sandton, 2191, South Africa*

[b]*AECI Mining Chemicals, P.O. Box 2820, Sasolburg, 1947, South Africa.*

**Corresponding author:* natalie.shackleton@aeciworld.com

ABSTRACT

Depressant selection in PGM flotation is often treated as a reagent-ranking exercise, where the best-performing depressant is selected from tests on a single ore composite. This approach may not be robust where the mining mix changes and the gangue mineralogy entering the plant varies over time. This study reframes CMC depressant selection as a process-mineralogy problem: which CMC chemistry, or CMC blend, best matches the gangue mineral assemblage expected in the plant feed?

Western Bushveld PGM stratigraphic-position composites and lithological endmember samples were characterised by quantitative X-ray diffraction (QXRD) and evaluated using controlled microflotation. Natural floatability was first established using no-depressant tests, followed by CMC screening at 100 g/t using coded CMC chemistries. Depression response was interpreted relative to the natural-floatability baseline and measured gangue mineral assemblage. The QXRD and microflotation results showed that stratigraphic-position composites and lithological endmembers were mineralogically distinct and showed different natural-floatability and CMC depression responses. Footwall, hanging-wall and reef-position composites had natural floatabilities of 3.55%, 8.51% and 7.98%, respectively, confirming different baseline flotation behaviour before depressant addition.

Feldspar-rich domains were generally lower-risk, but feldspar abundance alone did not predict natural floatability; altered silicates, pyroxenes and likely surface exposure also influenced response. The resulting mineralogy–CMC response matrix was used to formulate blends for a representative mine-plan composite containing 60% hanging wall, 20% altered pyroxene-rich material and 20% spotted anorthosite. Blend 2, comprising 50% CMC B and 50% CMC F, gave the strongest microflotation depression response for this composite. Supporting batch flotation tests further showed that selected CMC conditions shifted the recovery–concentrate mass pull balance relative to the CMC C baseline, confirming that final depressant selection should consider recovery, mass recovery and concentrate quality together.

The workflow links QXRD-defined mineralogy, natural floatability, CMC response, planned mining proportions and supporting flotation validation to guide proactive, mine-plan-informed CMC blend selection as feed mineralogy changes.

Keywords: Process mineralogy; geometallurgy; CMC depressants; XRD; microflotation; Western Bushveld; PGM flotation; gangue mineralogy; depressant blend design.

1. Introduction

Depressants are widely used in platinum-group mineral (PGM) flotation to improve selectivity by reducing the recovery of naturally floatable or entrained gangue minerals to the concentrate. In Bushveld PGM ores, gangue minerals such as talc, chlorite, serpentine, pyroxene, feldspar and mica can report to the concentrate and dilute PGM grade. The metallurgical challenge is therefore not only to reduce gangue recovery, but to do so without depressing valuable PGM-bearing particles or compromising flotation kinetics.

CMC depressants are commonly evaluated through comparative screening, where several products are tested under fixed flotation conditions and ranked according to metallurgical response. While useful, this approach may not adequately account for changes in feed mineralogy. In mining operations where the relative contribution of hanging-wall, reef, footwall and altered lithological domains changes over time, the gangue mineral assemblage entering the concentrator may vary significantly. A single depressant selected from one composite may therefore become sub-optimal as the mining mix changes.

Previous work has shown that CMC depressant performance depends on both CMC structure-property characteristics and the gangue mineralogy being treated. CMC products differ in degree of substitution, purity, viscosity, molecular weight and molecular conformation, and these properties can influence interaction with gangue mineral surfaces. Shackleton et al. (2025) showed that CMC response in PGM ores varied with gangue mineral type and that mixtures of CMC depressants may be more effective than a single CMC where ore mineralogy is variable.

The present study investigates a mineralogy-guided workflow for CMC depressant selection in Western Bushveld PGM lithological domains. Stratigraphic-position composites representing footwall, hanging-wall and reef-position material were tested together with lithological endmember samples, including anorthosite, feldspathic pyroxenite, mottled anorthosite, spotted anorthosite, norite, pyroxenite and pyroxene–serpentine–plagioclase material. QXRD was used to define the principal gangue mineral assemblages, while microflotation was used to establish natural floatability and CMC depression response. The objective was to develop a mineralogy–CMC response matrix that could be linked to expected mining proportions and used to guide CMC blend selection.

2. Experimental approach

The study was conducted on two sample categories: stratigraphic-position composites and lithological endmember samples. The stratigraphic-position composites represented footwall, hanging-wall and reef-position material, while the lithological endmembers represented the principal rock types and alteration domains expected to contribute to the planned plant feed. These two sample categories were included because they provide complementary information: the composites represent operational mining-position domains, while the lithological endmembers provide greater resolution on the mineralogical drivers behind the composite responses.

All samples were crushed, milled and screened to produce a +38 µm to –75 µm microflotation size fraction. QXRD was used to identify and quantify the principal gangue mineral phases in each sample, including feldspar, pyroxene, chromite, talc, chlorite, serpentine and other alteration silicates. The QXRD data were interpreted at both specific mineral-phase level and broader flotation-relevant mineral-group level.

Microflotation tests were conducted using simulated process water. A no-depressant test was first carried out for each sample to establish the natural-floatability baseline. CMC depressant-screening tests were then conducted at a fixed comparative dosage of 100 g/t. Depression response was calculated relative to the no-depressant baseline:

Depression response (%) = [(natural floatability − floatability with depressant) / natural floatability] × 100

The CMC depressants were anonymised as CMC A–CMC F. The purpose of the screening was not to generate a universal reagent ranking, but to determine whether different CMC chemistries responded preferentially to different gangue mineral assemblages.

The mineralogy–CMC response matrix generated from the QXRD and microflotation data was then used to design CMC blends for a representative mine-plan composite. The representative composite contained 60% hanging-wall material, 20% altered pyroxene-rich material and 20% spotted anorthosite. Three CMC blends were tested at 100 g/t total depressant dosage.

3. Results and discussion

3.1 Stratigraphic-position composites are mineralogically distinct

QXRD showed that the footwall, hanging-wall and reef-position composites were mineralogically distinct. The footwall composite contained a mixed albite–anorthite–enstatite assemblage with clinochlore and minor talc. The hanging-wall composite was strongly anorthite-rich, with clinochlore and minor enstatite, while the reef-position composite was enstatite-rich with chromite, anorthite, talc and minor lizardite.

These differences show that operational descriptors such as hanging wall, reef and footwall do not represent a single gangue mineralogy. The hanging-wall composite can be considered a feldspar-rich domain, the reef-position composite a pyroxene-rich domain with chromite and talc modifiers, and the footwall composite a mixed feldspar–pyroxene–chlorite domain. This mineralogical distinction provides the basis for interpreting natural floatability and CMC depression response.

The mineralogical grouping also indicates that flotation response is controlled by a balance between feldspar-rich assemblages and more problematic altered or pyroxene-rich silicate components. Feldspar-rich material is generally expected to be lower-risk, based on previous AECI microflotation experience, but the presence of clinochlore and minor pyroxene means that feldspar abundance alone may not fully predict natural floatability. The QXRD data therefore provide a mineralogical framework, but the natural-floatability test remains necessary to confirm the flotation response.

3.2 Natural floatability and CMC response of stratigraphic-position composites

The no-depressant microflotation tests showed different natural-floatability baselines for the three stratigraphic-position composites. The footwall composite had the lowest natural floatability at 3.55%, while the hanging-wall and reef-position composites showed moderately higher natural floatability of 8.51% and 7.98%, respectively. These values confirm that the composites have different inherent flotation behaviour before depressant addition.

The CMC depression responses also differed between composites. The footwall composite showed the strongest response to CMC A, while the hanging-wall composite showed the strongest response to CMC B. The reef-position composite showed a broader response to CMC C, CMC E and CMC F.

These results demonstrate that the depressant requirement changes with stratigraphic-position domain. The footwall, hanging-wall and reef-position composites did not share a common preferred CMC response. A single depressant selected from one composite would therefore not necessarily be robust across changing mining-position contributions. Instead, the CMC requirement is linked to the dominant gangue mineralogy and natural-floatability baseline of each domain.

3.3 Lithological endmembers explain why rock type alone is insufficient

The lithological endmember samples showed substantial mineralogical variability. The anorthosite-family samples were all feldspar-rich, but they differed in detail. Mottled anorthosite was strongly anorthite-rich, anorthosite contained both anorthite and albite with chromite and minor alteration phases, while spotted anorthosite contained substantial feldspar but also elevated clinochlore.

The pyroxenitic and altered samples also differed. Pegmatoidal feldspathic pyroxenite contained high enstatite and anorthite, pyroxenite was enstatite-rich with clinochlore and talc, and the pyroxene–serpentine–plagioclase sample contained elevated clinochlore, talc and vermiculite. These differences confirm that nominal rock type is insufficient to describe flotation-relevant gangue mineralogy.

The microflotation results confirmed that these mineralogical differences translated into different CMC responses. Anorthosite and mottled anorthosite showed their strongest response to CMC B, while spotted anorthosite was more responsive to CMC E. Norite showed a strong response to CMC A, while pyroxenite and pyroxene–serpentine–plagioclase were more responsive to CMC E and/or CMC F.

This behaviour is important because it demonstrates that related lithologies do not necessarily require the same CMC chemistry. For example, anorthosite, mottled anorthosite and spotted anorthosite are all broadly feldspar-rich, but their alteration-silicate content and CMC response differ. The relevant process-mineralogy descriptor is therefore not simply "rock type", but the measured mineral assemblage and its associated natural-floatability and CMC response.

3.4 Feldspar content as a risk modifier, not a standalone predictor

The results indicate that natural floatability is controlled by a mineralogical balance rather than by the presence or absence of a single mineral phase. Previous AECI microflotation work has shown that feldspar-rich material is generally weakly naturally floatable, typically producing less than approximately 4–6% recovery in no-depressant microflotation tests. However, the present hanging-wall composite shows that feldspar abundance alone is not sufficient to predict natural floatability. Although the hanging wall was strongly anorthite-rich, it also contained clinochlore and minor pyroxene and showed moderately higher natural floatability than the footwall.

The feldspar–altered silicate balance should therefore be interpreted as a practical risk indicator rather than a fixed threshold. Feldspar-rich samples may be lower-risk where altered silicates and pyroxenes remain minor or are not strongly exposed, but their natural floatability must still be confirmed experimentally. Where the feldspar contribution decreases and the relative proportion of pyroxene, chlorite, talc, serpentine or vermiculite increases, natural floatability and depressant sensitivity may increase.

PGM head grade was considered as a supporting variable to assess whether the natural-floatability trends were primarily related to valuable mineral content or gangue mineralogy. PGM grade alone did not explain the observed natural floatability. For the stratigraphic-position composites, the hanging-wall sample had the lowest 4E PGM grade but showed natural floatability comparable to the reef-position composite and higher than the footwall composite. Among the lithological endmembers, spotted anorthosite had the lowest PGM grade but the highest natural floatability, while norite and mottled anorthosite had higher PGM grades but lower natural floatability. This supports the interpretation that natural floatability was controlled primarily by gangue mineral assemblage rather than by valuable mineral grade alone.

3.5 Mineralogy–CMC response matrix

The QXRD and microflotation results define a mineralogy–CMC response matrix rather than a universal CMC ranking. The strongest CMC response varied by sample domain. Footwall and noritic material were associated with stronger CMC A response. Hanging-wall and anorthosite-family material were associated with stronger CMC B response. Spotted anorthosite, pyroxenite and pyroxene–serpentine–plagioclase material showed stronger response to CMC E and/or CMC F. Reef-position material showed a broader response to CMC C, CMC E and CMC F.

This matrix is the key technical outcome of the study. It shifts interpretation from "which CMC is best overall?" to "which CMC chemistry best matches the mineral assemblage expected in the feed?" This is important for operations where the mining mix changes over time. If the expected plant feed shifts toward footwall, hanging-wall, reef or altered lithological domains, the CMC blend ratio can be adjusted accordingly.

3.6 Blend validation on representative mine-plan composite

A representative mine-plan composite was prepared to test whether the mineralogy–CMC response matrix could guide CMC blend selection. The composite contained 60% hanging-wall material, 20% altered pyroxene-rich material and 20% spotted anorthosite. This composition represented a hanging-wall-dominant feed with significant altered and naturally floatable gangue contributions.

The representative composite had a no-depressant natural floatability of approximately 18%, which was higher than the individual stratigraphic-position composites. This confirms that blending lithological components can generate a composite response that is not equivalent to any single domain. It also highlights the need to test representative mine-plan composites rather than relying only on individual rock or stratigraphic-position responses.

Three CMC blends were tested at a total depressant dosage of 100 g/t. Blend 1 contained 50% CMC B and 50% CMC E. Blend 2 contained 50% CMC B and 50% CMC F. Blend 3 contained 50% CMC B, 25% CMC E and 25% CMC F. Blend 2 gave the highest depression response, at approximately 52%, followed by Blend 1 at approximately 46% and Blend 3 at approximately 45%.

The improved response of Blend 2 suggests that CMC F provided more effective support than CMC E for this specific hanging-wall-dominant composite containing altered pyroxene-rich and spotted anorthosite components. The result supports the central hypothesis that CMC blend selection can be guided by expected mineralogical composition. However, the result should be interpreted as composite-specific rather than universal. If the mining mix shifts toward higher footwall, reef, pyroxenitic or altered-silicate contribution, the required CMC blend ratio may also change.

3.7 Supporting batch flotation comparison

Supporting batch flotation tests were used to compare selected anonymised CMC conditions against a baseline CMC C condition under more plant-relevant flotation conditions. The results showed that changes in CMC chemistry and blend composition affected the recovery–concentrate mass pull balance. CMC G produced a similar 4E PGM recovery to the baseline but at lower mass recovery, indicating improved selectivity. Other blend conditions increased PGM recovery but also increased mass recovery, confirming that depressant selection should not be based on recovery alone. These results support the microflotation-derived mineralogy–CMC response matrix, but also show that final blend selection must consider recovery, concentrate mass pull and concentrate grade together.

5. Conclusions

This study demonstrates that CMC depressant selection for Western Bushveld PGM ores should be treated as a process-mineralogy decision rather than a simple reagent-ranking exercise. The combined use of QXRD and microflotation provides a practical workflow for linking gangue mineralogy, natural floatability and CMC depression response.

The main conclusions are:

1. **Stratigraphic-position composites and lithological endmembers were mineralogically distinct.** Hanging-wall, reef and footwall samples represent operational mining-position composites, while the lithological endmembers provide greater resolution on the mineralogical drivers behind the composite responses.
2. **Lithological name alone was not sufficient to predict flotation behaviour.** Samples within the same broad rock family, such as anorthosite, mottled anorthosite and spotted anorthosite, showed different mineralogical characteristics and different CMC responses.
3. **Feldspar content is a useful risk modifier, but not a standalone predictor of natural floatability.** Feldspar-rich domains are generally expected to be lower-risk, but natural floatability can still increase where altered silicates or pyroxenes are sufficiently abundant or exposed.
4. **Natural floatability is an essential baseline for interpreting CMC depression response.** The footwall composite had the lowest natural floatability, while hanging-wall and reef-position composites showed moderately higher natural floatability. Depression response should therefore be interpreted relative to the inherent floatability of each domain.
5. **CMC response was mineralogy-dependent.** No single CMC was optimal across all mineralogical domains. Footwall and noritic material favoured CMC A, hanging-wall and

anorthosite-family material favoured CMC B, and altered or pyroxenitic domains favoured CMC E and/or CMC F.

6. **Mine-plan-informed CMC blend selection is feasible.** The representative mine-plan composite test showed that CMC blend performance could be linked to expected mineralogical composition. For the tested composite containing 60% hanging wall, 20% altered pyroxene-rich material and 20% spotted anorthosite, Blend 2, comprising 50% CMC B and 50% CMC F, gave the strongest depression response.

7. **Supporting batch flotation confirmed that final depressant selection must consider metallurgical trade-offs.** Selected CMC conditions shifted the recovery–concentrate mass pull response relative to the CMC C baseline. CMC G gave comparable PGM recovery at lower mass recovery, while some blends increased PGM recovery but also increased mass pull. This confirms that blend selection should consider recovery, concentrate mass recovery and concentrate quality together, rather than recovery or depression response alone.

Overall, the results support a practical workflow in which mine schedule, lithological proportions, QXRD mineralogy, natural floatability, CMC response and supporting flotation validation are combined to guide proactive depressant blend selection. This provides a basis for adjusting CMC strategy as feed mineralogy changes, rather than relying on a fixed single-depressant approach

6. Acknowledgements

The authors would like to thank AECI Mining Chemicals management for support during the study and for permission to publish this paper.

7. References

Becker, M., Harris, P.J., Wiese, J.G. and Bradshaw, D.J., 2009. Mineralogical characterisation of naturally floatable gangue in Merensky Reef ore flotation. *International Journal of Mineral Processing*, 93(3–4), 246–255. https://doi.org/10.1016/j.minpro.2009.10.004

Cawthorn, R.G., 2010. The platinum group element deposits of the Bushveld Complex in South Africa. *Platinum Metals Review*, 54(4), 205–215. https://doi.org/10.1595/147106710X520222

Dzvinamurungu, T., Viljoen, K.S., Knoper, M.W. and Mulaba-Bafubiandi, A., 2013. Geometallurgical characterisation of Merensky Reef and UG2 at the Marikana Mine, Bushveld Complex, South Africa. *Minerals Engineering*, 52, 74–81. https://doi.org/10.1016/j.mineng.2013.04.010

Khraisheh, M., Holland, C., Creany, C., Harris, P. and Parolis, L., 2005. Effect of molecular weight and concentration on the adsorption of CMC onto talc at different ionic strengths. *International Journal of Mineral Processing*, 75(3–4), 197–206. https://doi.org/10.1016/j.minpro.2004.08.012

Lotter, N.O., Kormos, L.J., Oliveira, J., Fragomeni, D. and Whiteman, E., 2011. Modern process mineralogy: An integrated multi-disciplined approach to flowsheeting. *Minerals Engineering*, 24(12), 1229–1237. https://doi.org/10.1016/j.mineng.2011.03.004

Lotter, N.O., Baum, W., Reeves, S., Arrué, C. and Bradshaw, D.J., 2018. The business value of best practice process mineralogy. *Minerals Engineering*, 116, 226–238. https://doi.org/10.1016/j.mineng.2017.05.008

Mierczynska-Vasilev, A. and Beattie, D.A., 2010. Adsorption of tailored carboxymethyl cellulose polymers on talc and chalcopyrite: Correlation between coverage, wettability, and flotation. *Minerals Engineering*, 23(11–13), 985–993. https://doi.org/10.1016/j.mineng.2010.03.025

Parolis, L.A.S., van der Merwe, R., Groenmeyer, G.V. and Harris, P.J., 2008. The influence of metal cations on the behaviour of carboxymethyl celluloses as talc depressants. *Journal of Colloid and Interface Science*, 317(1), 109–115.

Schouwstra, R.P., Kinloch, E.D. and Lee, C.A., 2000. A short geological review of the Bushveld Complex. *Platinum Metals Review*, 44(1), 33–39. https://doi.org/10.1595/003214000X4413339

Shackleton, N.J., Malysiak, V., Moshabeshe, L. and Mphahlele, F., 2025. Insights into gangue reagent interactions using process mineralogy. *Minerals Engineering*, 232, 109515.

Wang, J. and Somasundaran, P., 2005. Adsorption and conformation of carboxymethyl cellulose at solid–liquid interfaces using spectroscopic, AFM and allied techniques. *Journal of Colloid and Interface Science*, 291(1), 75–83. https://doi.org/10.1016/j.jcis.2005.04.095