Mineralogical variability of the UG1 chromitite horizon at Bokoni Platinum Mines: Predicted implications for beneficiation.

Boitshepo Masetlha[a], Prof Bjorn Von der Heyden[a], Prof Margreth Tadie[a], Dr Boikanyo Motloba[a]

[a] African Rainbow Minerals Chair in Geometallurgy, Stellenbosch University, Stellenbosch, 7600, Western Cape, South Africa

boitshepomasetlha@gmail.com

bvon@sun.ac.za

mtadie@sun.ac.za

Abstract

The UG1 chromitite seam in the Upper Critical Zone of the Bushveld Complex is an under-exploited source of chromite mineralisation. This study investigates the mineralogical, textural, and geochemical heterogeneity of the UG1 at Bokoni Platinum Mines to predict its beneficiation behaviour using heavy-medium separation. Optical microscopy and mine XRF assays were used to characterise chromite textures, silicate assemblages, and grade. Three different textural classes were identified: massive chromite (>90% chromite; 20–1420 µm), disseminated chromite (~40%), and intercumulus chromite (<30%; both 25–650 µm), with the Cr grade decreasing from an average of 38.2 wt.% in massive chromitite to 8.4 wt.% in intercumulus pyroxenite. The Cr content is typically slightly higher at the base of thicker seams. The texture further suggests that massive chromitite will likely liberate at coarse sizes suited to heavy medium separation, whereas disseminated and intercumulus chromite will likely require grinding below the method's effective range, increasing fines and silicate contamination. These predictions are being tested by TIMA, particle size, XRF and ICP-MS analyses of the completed heavy medium separation products

Keywords: UG1 chromitite, chromite, textural classes, liberation, Bushveld Complex

1. Introduction

Chromium is a key element in modern industry and supports the metallurgical, refractory, and chemical industries (Ulusoy & Atagun, 2023). South Africa is one of the world's leading chromite producers, producing 23,000 thousand metric tons in 2025 (Geological Survey, 2026). The LG6 and MG1 chromitite layers are South Africa's major chromite sources, both hosted within the Lower Critical Zone of the Bushveld Igneous Complex (BIC) (Kruger, 2005). The UG1 chromitite seam, hosted within the Upper Critical Zone (Mukherjee et al., 2017), is an additional, selectively mined but under-exploited chromite source.

The UG1 horizon varies widely in thickness, internal layering, host lithology, and bifurcation. It may occur within anorthosite, orthopyroxenite, or mixed pyroxenite-anorthosite packages

(Mukherjee et al., 2017), and its chromite abundance and composition vary with host-rock type. For example, at Union Mine on the Western Limb of the BIC, the seam is thin and pyroxenite-dominated, whereas slightly further east at Brits it is thicker and associated with noritic-anorthosite lithologies (Scoon & Teigler, 1994).

Chromite is a member of the spinel group, commonly represented as $FeCr_2O_4$, and typically occurs with silicate gangue minerals such as plagioclase, olivine, and orthopyroxene (Pownceby et al., 2023; Voordouw et al., 2009). Although massive chromitites commonly contain 85% modal chromite (Mukherjee et al., 2017), gangue minerals may sometimes constitute 35-40% of the rock, in which case it no longer qualifies as a massive chromitite, but a semi-massive chromitite. These gangue minerals differ in density, hardness, and liberation behaviour, influencing chromitite response to comminution (Polat et al., 2019). Chromite grain size and shape, and associated silicates, are therefore important variables in effective beneficiation.

Despite this variability, information on how the texture of the UG1 affects beneficiation and chromite recovery remains limited. This study characterises the mineralogical, textural, and geochemical heterogeneity of UG1 at Bokoni Platinum Mines and uses these observations to interpret its petrogenesis and predict how chromite texture and silicate gangue influence chromite liberation.

2. Methodology

Chromitite samples were collected from Bokoni Platinum Mines, Limpopo, located along the northern extremities of the Eastern Limb. Three chromitite bulk samples were collected from trenches, and one drill core was selected from 13 boreholes for in-depth mineralogical analysis. The remainder of the boreholes were used for geochemical analyses. From these samples, 26 polished blocks were prepared and analysed using the Zeiss Primotech microscope at Stellenbosch University to identify minerals, determine textural relationships, and assess grain-size and shape distributions. The mine provided XRF data from the remaining drill cores, which were used to assess grade distribution across different lithologies.

3. Results

3.1 Chromite Characterisation

Mineralogical analysis identified three textural classes within the chromitite horizon: massive (chromite-dominated), disseminated and intercumulus chromite. The massive chromitite consists of clustered chromite grains with silicates occupying the small spaces between the chromite grains (Figure 1A). Chromite grains occupy over 90% of the chromitite, while silicates make up the remaining < 10% and mainly consist of plagioclase grains with minor pyroxene grains (Figure 1 C&D). A limited number of chromite grains were observed with plagioclase inclusions (**Error! Reference source not found.**E&F), these are observed in larger chromite grains. Chromite grains are euhedral to subhedral and range from 20–1420 µm, with at least 60% of grains within the diameter size range of between 650 and 1000 µm. Grains larger than 650 µm concentrate in the centre of the chromitite seam and gradually decrease in size toward the lithological contacts, where the texture becomes more disseminated.

The disseminated texture consists of scattered, interconnected chromite grains (Figure 2). The grains range from 25–650 µm and are mostly subhedral to anhedral. The silicates (pyroxenes and plagioclase) occupy approximately 60% of the slide surface area, while chromite grains occupy 40%. The texture occurs as patches in the centre of the chromitite seams (Figure 2A) and towards their contacts (Figure 2C-D), where chromite grains are enclosed in pyroxenites and orthopyroxene (Figure 2C). In pyroxenites, chromite grains form interconnected networks and occupy a larger proportion of the surface area than in the intercumulus texture (Figure 2B).

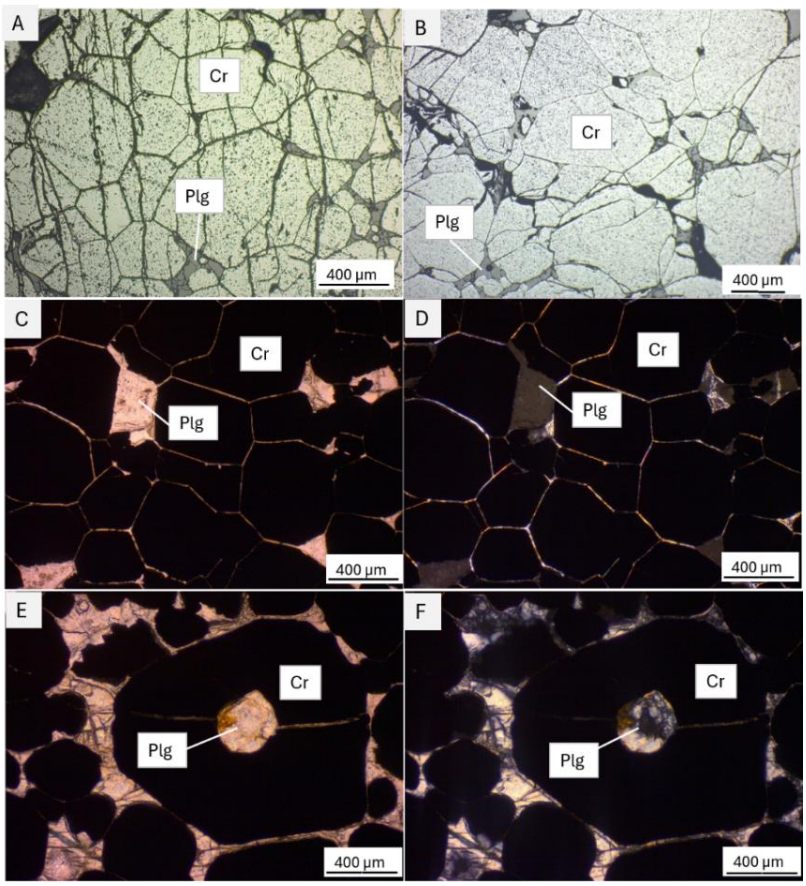

Figure 1. Photomicrograph of the massive texture chromitite sample (A) BH6 and (B) WVS38.1, representing chromite (Cr) grains under reflected and transmitted light samples in (C) ppl (D) xpl (F) chromite (Cr) with plagioclase (Plg) inclusion ppl and (E) xpl.

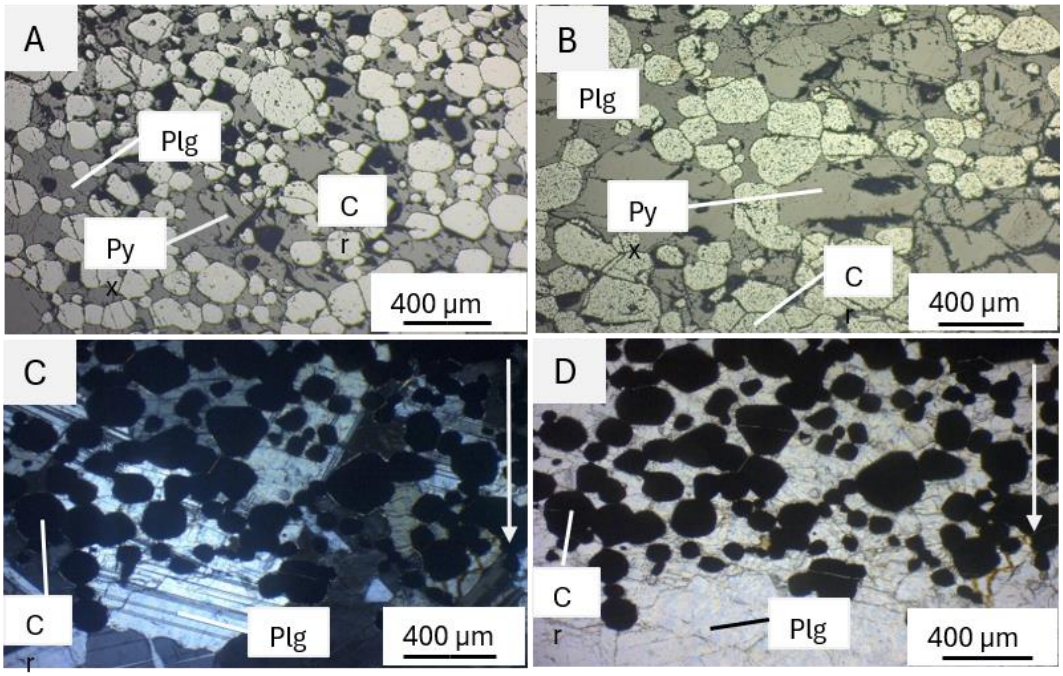

Figure 2. Photomicrographs of the disseminated texture found (A) as the disseminated patch in the centre of a chromitite seam, (B) in a chromitiferous pyroxenite and (C) at the margin of a chromitite seam in transmitted light (ppl) and (D) xpl.

The intercumulus texture occurs only in pyroxenites, where chromite occupies interstitial spaces between pyroxene grains and constitutes less than 30% of the modal mineralogy (Figure 3). Chromite grains range from 25-650 µm and occur in two ways; in the first, they lack distinct grain boundaries and form lobes around the pyroxene grains, with less than 15% of the space occupied by plagioclase (Figure 3A). In the second, chromite forms well-defined, interconnected grains with variable grain size, while plagioclase occupies more than 15% of the space (Figure 3B).

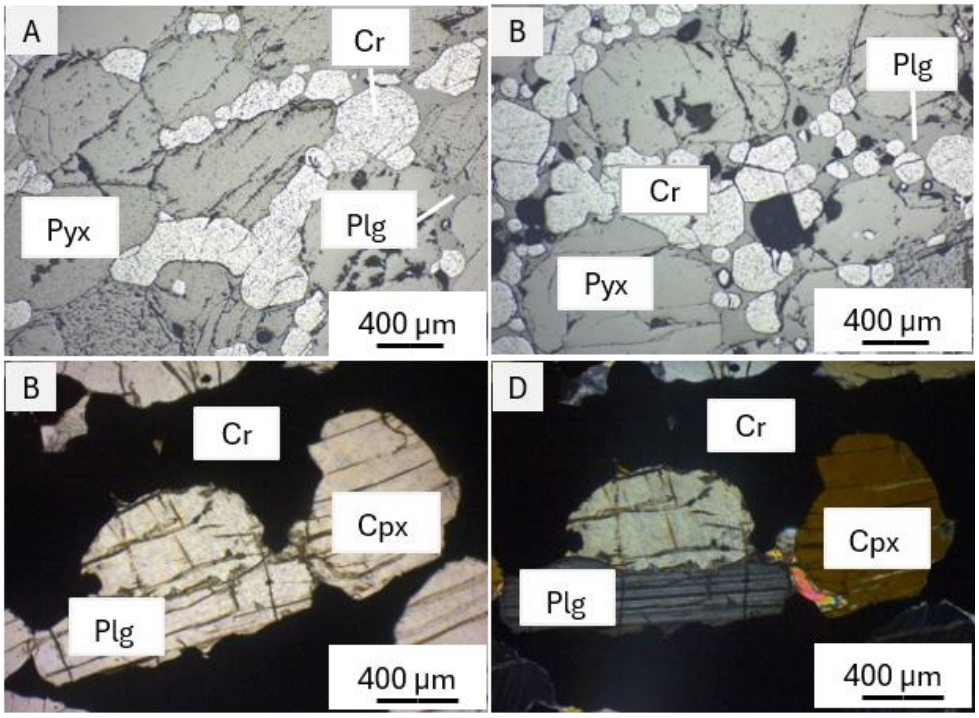

Figure 3 Photomicrographs of the intercumulus texture as (A) lobes without distinct grain shape, (B) linked chromite grains of various shapes and sizes (C) ppl and (D) xpl images of the chromitite lobes.

3.2 Geochemistry

Chromitite seams across the study area average 38.2 wt.% Cr_2O_3, with 11 of the 13 chromitite seams containing more than 40% Cr_2O_3 (Table 1). One such seam, represented by sampling blocks 2 and 3 (borehole WVS37; Figure 4) illustrates the vertical variability observed in thicker seams across all boreholes: Cr_2O_3 is lower in the upper section (block 2) than in the lower section (block 3), indicating a slight decrease in grade up the stratigraphy. A similar upward decrease occurs in associated lithologies, such as the chromitiferous pyroxenite in blocks 9 and 10. This chromitiferous pyroxenite contains approximately 10 wt.% less Cr_2O_3 than massive chromitite. Chromitiferous norite occurs in several boreholes

but is absent in the sampled borehole for petrography and contains approximately 5 wt.% less Cr_2O_3 compared to massive chromitite (Table 1).

Table 1 Average oxide content of multiple lithological seams intersected in the 13 boreholes.

Rock type and associated textural class	**Number of seams**	**Average Cr/Fe**	**Average Cr_2O_3%**	**Average Fe_2O_3 %**	**Average Al_2O_3%**	**Average SiO_2%**	**Average MgO**
Chromitite (Massive)	13	1.40	38.20 **Min**: 35.24 **Max**: 44.32	28.78	15.45	4.78	8.77
Chromitiferous norite	1	1.27	33.58	25.81	16.28	9.74	9.88
Chromitiferous anorthosite (Disseminated)	4	1.37	26.12 **Min**: 23.84 **Max**: 26.12	19.13	18.95	16.938	7.19
Chromitiferous pyroxenite (Disseminated)	13	0.75	13.51 **Min**: 4.62 **Max**: 33.26	18.02	8.50	32.52	17.52
Pyroxenite (Intercumulus)	22	0.52	8.40 **Min**: 1.45 **Max**: 8.40	15.23	8.35	43.13	18.47

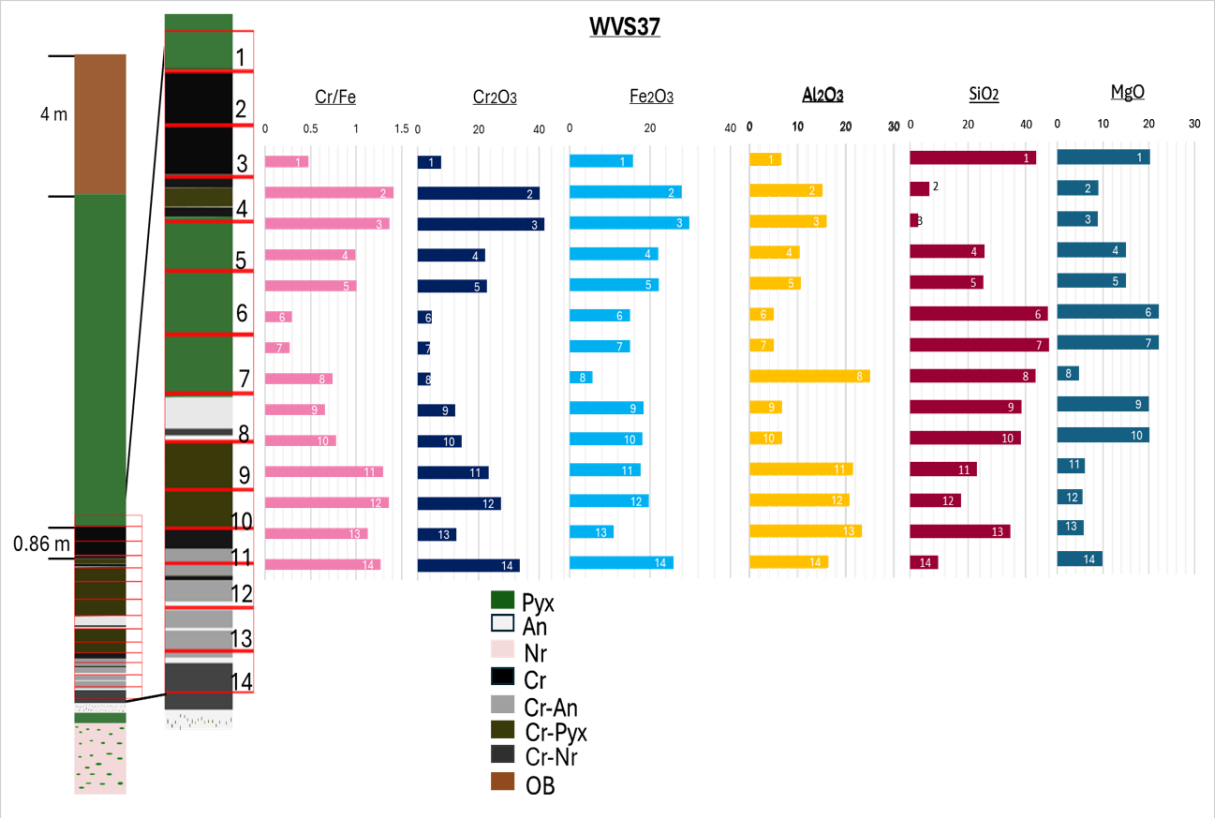

Figure 4 Borehole WVS37, one of the boreholes in the study area, showing detailed vertical oxide variation. Pyroxenite (Pyx), Anorthosite (An), Norite (Nr), chromite (Cr), chromitiferous anorthosite (Cr-An), chromitiferous pyroxenite (Cr-Pyx), chromitiferous norite and overburden (OB).

4. Discussion

4.1 Possible implications of particle size and liberation on grade recovery

The amenability of the UG1 chromitite to heavy medium separation depends on the density contrasts between chromite (~4.6 g/cm^3; Moslim, 2013) and its gangue, and on how the two are intergrown. Plagioclase (~2.7 g/cm^3) contrasts strongly with chromite, whereas orthopyroxene (3.3–3.6 g/cm^3; Moslim, 2013) is close, so its rejection is likely to be less efficient. Because the massive texture is coarse-grained (Section 3.1) and its plagioclase occurs only as small interstitial grains, it is expected to liberate at coarse sizes and report to the sinks as high-grade material. Moslim (2013) reported liberation at approximately 500 µm and the highest-grade concentration through heavy medium separation in the -1180+500 µm fraction. Plagioclase inclusions within coarse chromite are unlikely to liberate, which may limit grade.

Disseminated and intercumulus chromite (25-650 µm) is finer and enclosed in or intergrown with plagioclase and pyroxene, so it likely requires finer grinding. Al-Tigani et al. (2019) estimated a liberation size of 50-300 µm for disseminated chromite and treated the -212+75 µm fraction by laboratory heavy-liquid separation, a size range below the effective range of plant-scale dense medium separation (Moslim, 2013). Grinding blended feed to this size would likely liberate most chromite grains but overgrind coarse massive chromite, producing fines that could be lost during concentration (Murthy et al., 2011). Where the gangue is pyroxene, as in chromitiferous and intercumulus pyroxenite (8.4 wt% Cr2O3), the smaller density contrasts may further limit upgrading.

5. Conclusion

The UG1 chromitite seams at Bokoni Platinum Mines are mineralogically and texturally heterogeneous, with chromite occurring as massive, disseminated and intercumulus textures. The massive texture likely produces the highest grade, followed by the disseminated and intercumulus textures, reflecting a progressive decrease in chromite abundance and an increase in silicates across textural and lithological categories. The Cr_2O_3 also decreases from the lower to the upper sections of the thicker seams, indicating compositional variability within seams. This textural heterogeneity is expected to affect chromite liberation and recovery; therefore, UG1 may require site-specific characterisation and should not be treated as a uniform feed source.

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