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A geological, petrological and mineralogical study of the UG3 chromitite seam at Modikwa Platinum Mine: Significance to exploration and PGE resources.

The thesis is submitted in partial fulfilment for the requirement for the degree of Master of Science. I declare that this my own unaided work except where reference or suitable acknowledged.

Signature.....Date.....

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Abstract

The UG3 at Modikwa Platinum Mine occurs as a platiniferous, planar chromitite seam. It is stratigraphically located in the Upper Critical Zone of the Eastern Bushveld Complex. Field work study comprise of underground mapping, sampling, surface mapping, borehole core logging, microprobing and microscopic investigations carried out at the Rhodes University.

The UG3 at the Modikwa Platinum Mine is about 22cm thick chromitite seam underlain by a white fine grained anorthosite and overlain by a brown medium grained feldspathic pyroxenite. It is an incomplete cyclic unit consisting of chromite and feldspathic pyroxenite.

The UG3 reef at the Modikwa Platinum Mine lease area represents a Platinum Group Metal resource of 300 million tons of ore at an in situ grade of 2.5g/t. Under the current market conditions the UG3 reef remains unprofitable to mine in an underground operation due to the operational cost involved. However, it has been illustrated that the UG3 chromitite seam can increase profit margins in an open pit operation provided it is mined together with the economic UG2 chromitite seam. The extraction of the UG3 as ore in the four Modikwa UG2 open pits would result in a combined operating cash profit of R330 million.

The UG3 chromitite seam is platiniferous. The platinum-group minerals (PGM) range in size from less than 10 μ m to about 70 μ m. The PGMs are associated with sulphides and are both located in the interstitial silicates and are concentrated in the chromitite seam.

The PGMs show a strong preference to contact boundaries of the silicate grains, the chromite grains and the sulphide phases. In some instances, they are enclosed within the chromite grains in association with sulphides. The general sulphide assemblage comprises pentlandite and chalcopyrite whereas, the PGMs assemblage comprises cooperite, ferroplatinum, laurite, FeRhS and PtRhS.

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1. Introduction

The UG3 occurs stratigraphically 10m above the economic UG2 that is mined at the Modikwa Platinum Mine and it is thus present in all exploration boreholes that were drilled to explore for the UG2 economic horizon at the mine lease area. These intersections provide a perfect vantage point as the UG3 chromitite seam becomes readily available for study purposes.

1.1 Regional Geology and study area

1.1.1 Overview of the Bushveld Large Igneous Province

The Bushveld magmatic province is an unusual massive crustal emplacement of predominantly mafic Mg and Fe rich extrusive and intrusive rocks. It is of a Palaeoproterozoic age (2.06 Ga) and it is undeformed. It is the largest magmatic layered intrusion in the world. The Bushveld magmatic province is located centrally within the northern portion of South Africa (Burger and Coertze, 1975). It comprises in part voluminous volcanics that were predominantly felsic rather than basaltic in composition and it lacks associated dyke swarms.

According to Walraven (1986), the Bushveld magmatic province intruded the Pretoria Group of the Transvaal Supergroup at 2054 ± 2 to 2061 ± 2 Ma. The emplacement of the Bushveld magmatic province is undoubtedly the most important magmatic event on the Kaapvaal Craton (Eales and Cawthorn., 1996). The intrusion is approximately 13000m thick and covers an area of about 65000 km². It literally extends from Zeerust in the west to Burgersfort in the east and from Bethal in the south to Villa Nora in the north. The voluminous magmatism took place over a very short period of less than 10 Ma years. The voluminous magmatism would have involved approximately half a million cubic kilometres (Kinnaird *et al.*, 2004). The Bushveld Complex is larger than the Skaergaard, Stillwater and Sudbury (Arndt *et al.*, 2005).

The Palaeoproterozoic Bushveld Igneous Province in South Africa is comprised of.

- The bimodal but predominantly Rooiberg Group volcanic province. one of the largest pyroclastic provinces on Earth covering at least 50 000 km² and up to 3 km thick (Rooiberg Group comprises a 3500-5000 m thick (Clubley-Armstrong 1977) succession of felsite flows, with subordinate volcanoclastic and sedimentary intercalations (Twist 1985). It is part of the 20 km thick Transvaal Sequence, and crops out only in the central areas of the Transvaal Basin).
- The Rustenburg Layered Suite, the largest mafic layered complex on Earth which covers an area of approximately 65,000 km² and comprises anorthosite, mafic and ultramafic cumulates.
- The tabular Lebowa Granite Suite.
- The Rashedoop Granophyre Suite developed at the contacts between the granites and Rustenburg Layered Suite which is comprised of metamorphosed sediments and intrusive acidic rocks.
- The Molopo Farms and Nkomati – Uitkomst which are isolated smaller mafic intrusions.

The complete array of ultramafic to acid plutonic, hyabysal and volcanic rocks is collectively termed the Bushveld Magmatic Province.

Rustenburg Layered Suite will be described very briefly.

1.1.2 A brief description of the Rustenburg Layered Suite

The Rustenburg Layered Suite comprises rock types ranging from dunite and pyroxenite through norite, gabbro and anorthosite to magnetite and apatite rich diorite. The Suite demonstrates a complete differentiation sequence for basic magma (Cawthorn *et al.*, 2006)

The Rustenburg Layered Suite was emplaced at shallow crustal levels beneath the volcanic pile of Rooiberg felsites and Rashedoop granophyres as sills in the Transvaal Supergroup. The preserved footwall rocks of the emplacement in the Steelpoort-Burgersfort area are the Magelliesberg quartzites. However in the Stoffberg area, the basaltic rocks of the Dullstroom Formation are the preserved footwall rocks. This suggests that the emplacement transgressed upwards through more than 2 km of sediments (Kinnaird *et al.*, 2004).

The outcrop pattern of the Rustenburg Layered Suite is comprised of several limbs namely, the eastern limb in the Steelpoort- Burgersfort area, the western limb in the Rustenburg area, the far western limb in the Groot Marico area, the northern limb in Potgietersrus, and the south-eastern limb in the vicinity of Bethal. Refer to figure 1.

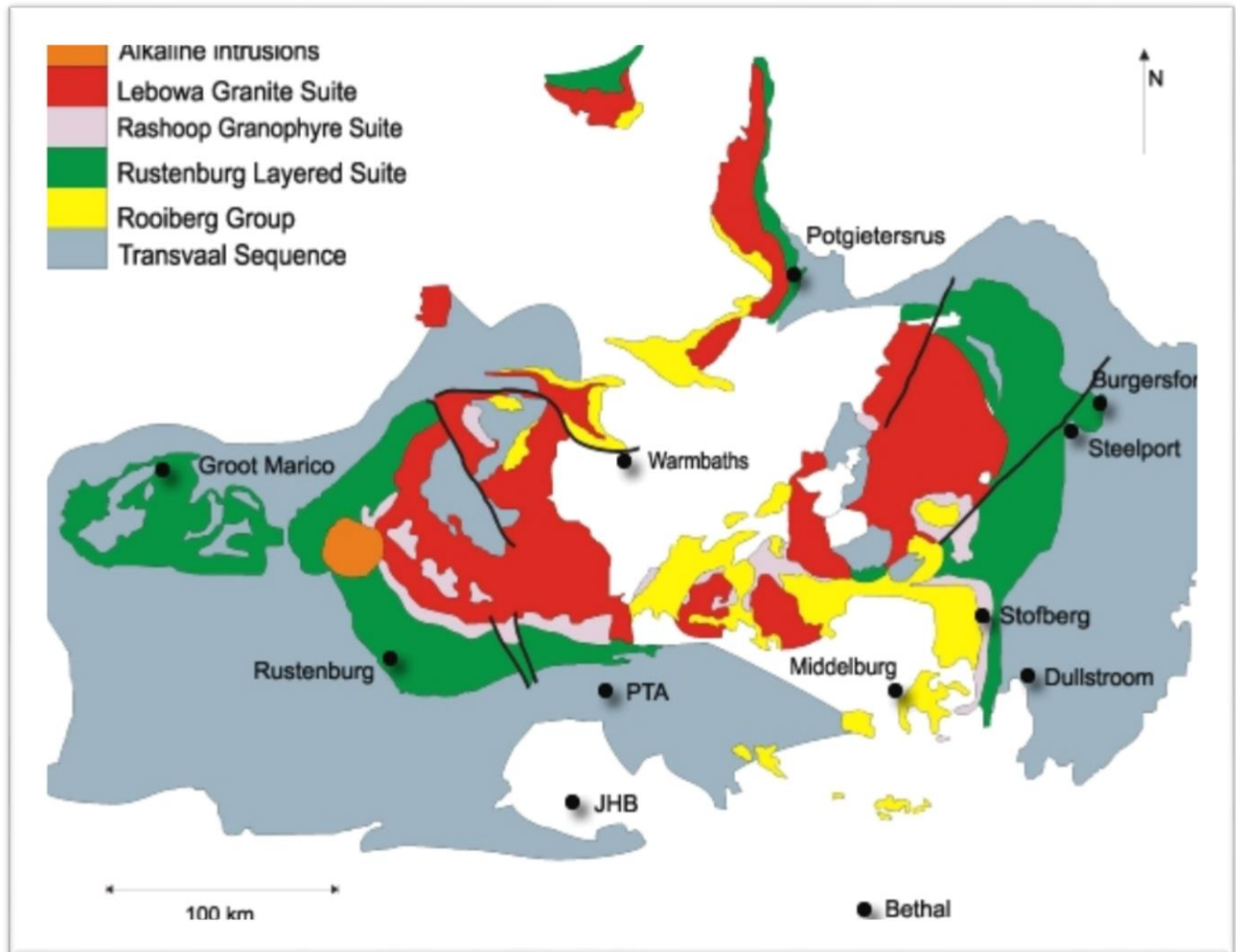


Figure 1. Simplified map of the Bushveld Complex showing the location of the various limbs. the eastern, western, far western and northern limbs and the south-eastern limb, which is obscured by younger cover (Kinnaird et al., 2004).

The Layered Suite is economically important layered mafic portion of the Bushveld Igneous Province. A unique characteristic of the Rustenburg Layered Suite is the extremely well developed, laterally extensive layering which is present on a variety of layers ranging from very thin crystal size stringers up to hundreds of metres thick. According to Hunter et al (2006) the thickness of the Rustenburg Layered Suite is approximately 8km. With the exception of the northern lobe, which dips in an independently westerly direction, the Rustenburg Layered Suite dips inwards towards the central granite and granophyres suites. Despite the separation of the individual limbs from each other, there is a striking similarity in the mineralogical layering amongst the different limbs (Hunter et al., 2006). A recent gravity model of the Bushveld Complex indicates that the western and eastern limbs of the Rustenburg Layered Suite are connected at depth.

The intrusive mechanism of the Rustenburg Layered Suite is suggested by Eales and Cawthorn (1996) to involve a series of magma pulses injected into the chamber from a primitive source. The magma

injections resulted in the formation of consistent and repetitive layering. These repeated injections of magma into the chamber were suggested by Eales and Cawthorn (1996) to be responsible for the formation of cyclic units, within the Rustenburg Layered Suite.

The process involved an injection of primitive magma into the chamber followed by a process of re-equilibration in which the differentiated residue magma in the chamber mixed with new influxes of primitive magma. The injections were closely spaced in time that the previous magma had not cooled and crystallized enough before the next additional magma introduction Cawthorn and Walraven (1998). According to Eales and Cawthorn (1996) the vast lateral extent of the layering within the Rustenburg Layered Suite would require that this process of re-equilibration be extremely efficient. The magma would then gradually be driven towards a more evolved composition by crystallization and fractionation processes. The crystallization and fractionation processes would continue until a new influx of primitive magma is injected into the chamber. The injection of primitive magma will cause a repeat of the process. Cyclic units varying from a few metres up to hundreds of metres thick would be produced by this persistently repetitive process as suggested by Eales and Cawthorn (1996). These cyclic unit patterns are superimposed on an overall normal fractionation trend of the Rustenburg Layered Suite. Major Chromitite seams occur at the base of these cyclic units. As a result the sequence of crystallization of cumulus phases is chromite, orthopyroxene, and plagioclase. The lithologies would therefore be chromitite, harzburgite, olivine orthopyroxenite, orthopyroxenite, melanorite, norite, leuconorite, and anorthosite. Thus the ultramafic cumulate base will be capped with an anorthosite (Scoon *et al.*, 1987)

Consequently the mechanism of formation of the Rustenburg Layered Suite is a multifaceted process involving a subtle interaction between two distinct processes which involved the continuous, repetitive injections of primitive magma into the chamber. The processes were followed by mixing and fractionation resulting in the formation of cyclic layered units.

Eales and Cawthorn (1996) suggested that several types of layering occur in the RLS. The types include modal layering, textural layering, cryptic layering and phase layering. Modal layering refers to layering in which the lithology is homogenous and which gives rise to cyclic units. Textural layering involves changes in crystal size, crystal habit or fabric whereas phase layering is defined by the appearance or disappearance of cumulus phases. Cryptic layering is controlled by mineral composition.

The mafic rocks that are collectively termed the Rustenburg Layered Suite can be divided into about five zones. The zones are referred to as the Marginal, Lower, Critical, Main and Upper Zone.

The Marginal zone is generally comprised of fine grained rocks and contains abundant calsilicate xenoliths. The thickness of this zone is highly variable and may be completely absent in some areas. The zone has no known mineralisation.

The marginal Zone is overlain by the Lower Zone. The Lower Zone is dominated by orthopyroxenite with associated olivine rich cumulates in the form of harzburgites and dunites. The commencement of the Critical Zone is marked by the appearance of cumulus chromite layers. The Critical Zone is divided into Lower and Upper Critical zone. The Critical Zone hosts all the chromitite layers and it is characterised by regular cyclic layering. Approximately 25 cyclic units have been identified. The Lower Critical Zone

contains about seven chromitite seams occurring within the pyroxenite. They are termed the Lower Group chromitite seams (LG). Included in the Lower zone are the MG1 and MG2 chromitite layers. Above the MG2 chromitite seam, plagioclase becomes cumulus and marks the commencement of the Upper Critical Zone.

The Critical Zone is approximately 800m thick. The MG3 and MG4 chromitite seams occur at the base of the Upper Critical Zone. The Critical Zone is characterised by a number of cyclic units beginning with narrow pyroxenitic horizons with chromitite layers which invariably pass up into norites, leuconorite and eventually anorthosite. The first important rhythmic layering in the Upper Critical Zone is the UG1 cyclic unit. It is said to be a spectacular unit consisting of chromitite layers with interlayered footwall anorthosite. Another significant cycle is that of the UG2. The UG2 chromitite seam is of considerable importance because it contains economic concentrations of PGE mineralisation. The UG3 chromite seam is 10m above the UG2 chromite seam and is the focal point of this thesis. The Merensky and the Bastard cycles are the uppermost rhythmic units. The Merensky reef is known for its economic PGE concentrations. The top of the Critical Zone is defined by the Giant Mottled Anorthosite. Overlaying the Critical Zone is the Main Zone.

The Main zone consists of norites grading upwards into gabbronorite. Several layers of anorthosite occur in the lower part of the main zone. A distinctive pyroxenite layer, called the Pyroxenite Marker appears two thirds towards the top of the zone. The middle part of the Main Zone is said to be very resistant to erosion and thus have given rise to the Pyramid Hills found in the Southwestern limb of the Rustenburg Layered Suite. The resistant part of the Main Zone is being mined for dimension stones. The Main Zone is overlain by the Upper Zone.

The Upper Zone is characterised by layers of magnetite and its base is marked by the appearance of cumulus magnetite above the Pyroxenite Marker. The zone is approximately 2km thick. The Upper Zone contains between 24-27 magnetite layers, the 4th layer being termed the Main Magnetite Layer is the most prominent. The 4th layer is underlain by an anorthosite and it is mined for its vanadium content in the Eastern and Western Limbs of the Bushveld Complex (Eales and Cawthorn, 1996).

1.2. Previous research

According to Eales (2012) broad and detailed descriptions of the Bushveld Complex are so freely available in the literature. However specific mention of the geological, petrological and mineralogical study of the UG3 chromitite seam in particular is rarely found in the literature.

A common feature of all chromite-rich rocks is that they display high concentrations of platinum group elements irrespective of whether they occur in ophiolitic sequences in Alaska-type ultrabasic complexes or in stratiform intrusions.

The geologic setting of the UG3 chromitite layers on Maandagshoek has been described in detail by Gain (1985). Maandagshoek is situated in the critical zone of the eastern lobe of the Bushveld Complex. The chromitite layer occurs at the base of the UG3 cyclic unit. The UG3 cyclic unit is separated from the Merensky reef by a 300-m-thick monotonous succession of massive to well-layered norite with intercalations of leuconorite and anorthosite at the Maandagshoek farm.

The UG3 chromitite seam crop out on the adjacent properties of Maandagshoek and Hendriksplaats, part of the leasehold of the Modikwa platinum mine, to the west of the Mooihoek pipe (Scoon and Mitchell, 2011).

According to Gain (1985) the UG3 chromitite seam has an average thickness of 0.22m. The seam has a sharp basal contact. The UG3 chromitite seam is underlain by an anorthosite and overlain by a porphyritic melanorite. The UG3 chromitite seam is laterally contiguous (Scoon and Teigler, 1995). The hanging wall of the UG3 chromitite layer consists of porphyritic melanorite, with minor chromite, in which the intercumulus oikocrysts of clinopyroxene form 5 to 10 percent of the mode. The UG3 cyclic unit terminates without the formation of layers of norite or anorthosite.

The seam has an in situ 4e value of 4.7g/t according to the sampling carried out by Gain et al., (1986). The four platinum elements include Pt, Pd Rh and Ru. A summary of the sampling results are provided below.

Table 1. Platinum-Group Elements, Ni, Cu, Co, and S Concentrations in Chromitite Layers of the Bushveld Complex in ppm.

Chromitite layer	Pt	Pd	Rh	Ru	Ni	Cu	Co	S
UG3A	1.58	0.48	0.27	0.70	147	36	15	72
UG3	3.03	0.18	0.38	1.12	86	30	20	46
UG1	1.35	0.83	0.30	0.95	120	32	16	99
MG4a	1.04	0.30	0.20	0.43	84	26	16	17
MG3	0.93	0.45	0.21	0.44	92	21	20	34
MG2a	1.78	0.44	0.02	0.30	165	24	24	62
MG2a/b	0.25	0.11	0.03	0.08	125	30	20	112
MG2a	1.46	0.78	0.06	0.40	116	36	16	63
MG2b	0.46	0.24	0.13	0.76	92	18	16	13
MG1a	0.67	0.21	0.16	0.38	115	24	18	46

The UG3 at Maandagshoek has shown Pd depletion as compared to the UG2 and MG chromitite seam values. It however has an abnormally high Pt/Pd ration of 17. The PGE proportions for Pt, Pd, Rh and Ru were 64.3%, 3.8 equates to 64.3% of Pt, (Gain et al, 1986)

Platinum group element data for the chromitite layers such as the UG3 seam in the Bushveld Complex have been lacking due to the fact that they are not economic to mine. As a result these seams have not been evaluated properly and their significance of the distribution and proportions of platinum-group elements less recorded.

1.3 Objectives of the study

The objective of the project is to document the geology, mineralogy and petrology of the UG3 chromitite seam at the Modikwa Platinum Mine lease area. This data will prove invaluable in understanding both the mechanisms of mineralization and petrogenesis of the UG3 chromitite seam of the Upper Critical zone of the Eastern Limb of the Bushveld Complex. There is very little detail geology, mineralogy and petrology data about the UG3 chromitite seam in the literature. The reason for this is that this chromitite layer has been viewed as being uneconomic despite the fact that it is platiniferous.

It is also envisaged that the volumetric quantity of the UG3 and its grade would be determined, thus its suitability to be classified as an economic ore resource in an open pit operation will also be established. A detailed mapping and sampling of the UG3 will provide PGE data that can be used to determine the PGE distribution and content.

2. Location and Geology of the study Area.

The Modikwa Platinum Mine forms part of the Anglo Platinum group as a joint venture between ARM Mining Consortium and Anglo Platinum.

The Anglo Platinum group is the world's leading producer of Platinum Group Metals. The group is listed on the Johannesburg and London stock exchanges. It is also represented on the Brussels Bourse by means of International Receipts. The Anglo Platinum group accounts for more than half of South Africa's 73% contribution to world primary supplies.

Modikwa Platinum Mine is situated some 15 km N of Burgersfort and 15 Km East of Steelpoort, Limpopo Province, RSA. Sinking of the declines started in 2001, whereas mining operations commenced in May 2002. The mineral lease covers 24.8 Km of strike length on the farms Driekop, Maandagshoek, Heindreksplaas, Onverwacht and Winterveld. Platiniferous reefs identified within the area are the Merensky Reef and the UG2 reef. The Modikwa mines the UG2 reef of the Upper Critical Zone of the Eastern Limb of the Bushveld Igneous Complex at depths of 50-200m below surface.

The Modikwa Mining lease is underlain by rocks of the Main Zone of the Bushveld Igneous Complex. This zone comprises a layered sequence of differentiated units of chromitite, pyroxenite, norite and anorthosite. The layered sequence strikes NNW-SSE and has an average dip of approximately 12 degrees.

Of economic interest are the Merensky Reef, the UG2 Reef as well as a number of dunite pipes such as the Driekop Pipes that has been mined in the past. Throughout the area exploration pits, trenches and adits occur, some of which date back to the early prospecting days of the 1920's. Although the occurrence of the Merensky reef and the Dunite pipes is known, insufficient data exists to quantify any resources contained therein

The UG2 outcrops on surface where it is oxidised and weathered. The UG2 is continuous to a depth of 860 m below the Leolo Mountains at the Western Boundary of the Mining lease.

The UG2 normally occurs as a solid chromitite with an approximate thickness of 60 cm. In places the UG2 is potholed. In these potholes the UG2 reef rolls down into the footwall stratigraphy and is either very thin or not developed at all. The potholes are considered to be unmineable. Gentle undulations of the UG2 with amplitudes of less than 2 metres occur throughout the area. Isolated areas termed slumps have been described. In these areas the UG2 rolls down but remains preserved, and the reef can be mined through extra infrastructure.

The UG3 occurs 10m above the UG2 chromite seam. It forms part of the strata and therefore strikes and dips the same way as the UG2 reef. The UG3 seam has an average thickness of 22cm. it is classified as an uneconomic reef horizon. This chromitite seam only appears in the Eastern Bushveld (Eales and Cawthorn, 1996)

A number of dykes dissect the area. These dykes are readily recognisable from aeromagnetic images, as well as satellite and orthophotographs. The most prominent dykes occur with a NNE-SSW orientation

and have little or no throw (less than 5m) while thicknesses of up to 30m may be reached. Faulting occurs mainly along directions parallel to the main dyke orientation. A number of WNW-ESE less prominent dykes with thicknesses up to 5m and maximum throws of 5m also occur. The area is believed to be more structurally complex closer to the Steelpoort Fault which occurs near the Southern boundary of the mining lease.

Within the mining lease area the most intense faulting has so far been observed in an area on South Mine, known as the South Shaft Gap.

A number of Iron Rich Ultramafic Pegmatoids (IRUP) and replacement pegmatoids been observed, particularly at the Onverwacht Hill area. Where these occur, the succession has been intruded by the above as a result from late stage hydrothermal activity where the UG2 reef is either completely replaced or highly disrupted.

The first few metres from surface are considered to be weathered. Within the weathered zone the rock is more friable and the UG2 is considered to be negatively affected by oxidisation. The bottom part of the weathered zone, known as the regolith is associated with the saturated water table. The regolith may extend to a maximum depth of 40m. The weathered zone and regolith pose a potential safety hazard during underground mining. The one risk is the oxidisation of the UG2, which may have affected metal content and metallurgical recoveries. For this reason the ground between the outcrop and the limit of the regolith is not part of production plans, although it is part of the resources. The second risk associated with the regolith is the possibility of uncontrolled water influxes into the mine's workings. A cover drilling code of practice has been implemented to address this risk. A localized stratigraphic column of the Modikwa Platinum Mine is provided below.

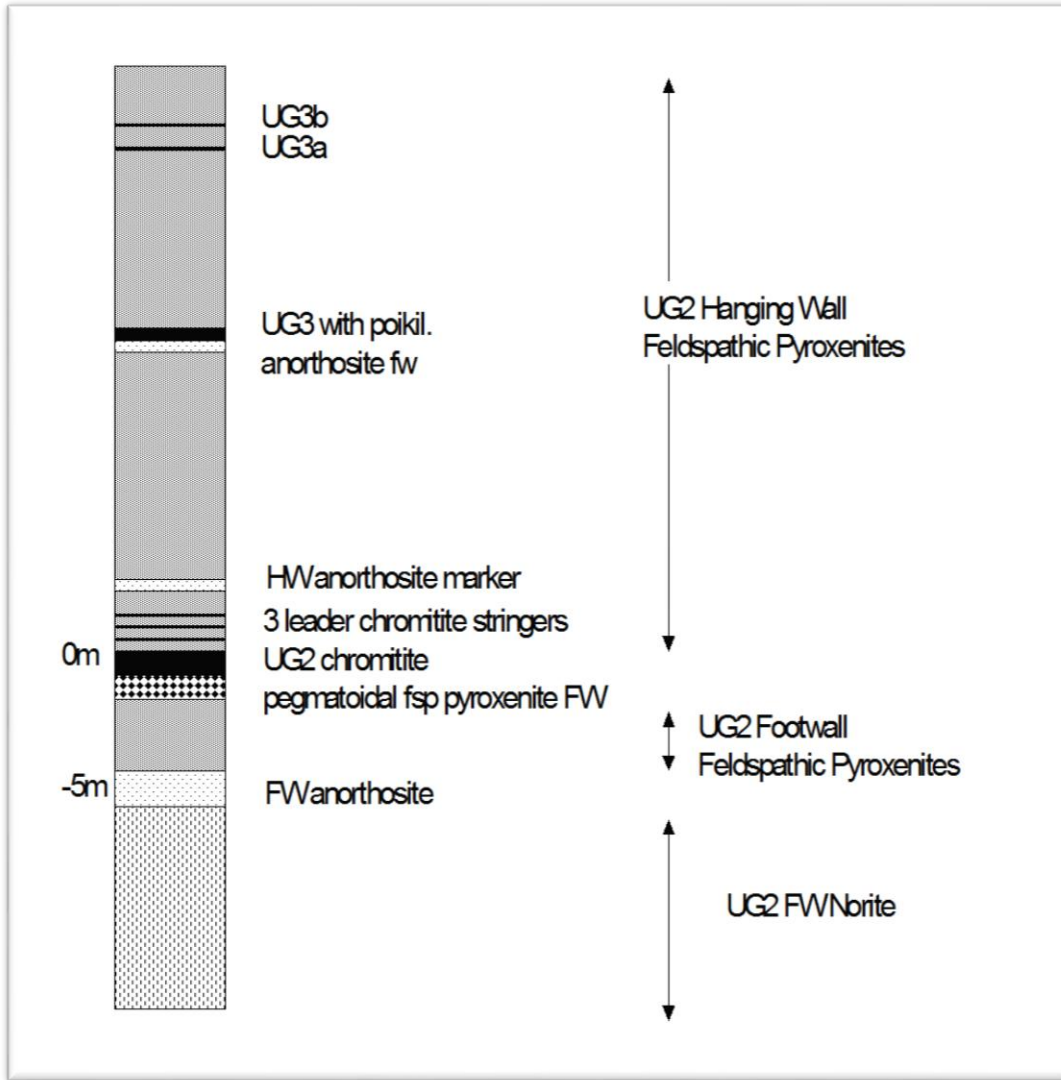


Figure 2. A schematic diagram of the localized stratigraphic column of Modikwa mine.

3. Methodology

The underground and surface mapping of the UG3 chromitite seam was carried out at the Modikwa Platinum Mine lease area. Mapping profiles were created at different locations along the strike of the UG3 chromitite seam. The lithologies in the immediate vicinity of the seam were described in detail. Determinations of colour, grain size, texture, alteration zones, primary mineralogy, nature of contacts as well as structural features was carried out. The colour of the rocks proved to be particularly useful identification mapping tool for example, anorthosite has a distinct white colour and chromitite appears black in colour.

3.1. Drill core study.

The borehole core study was done on a short prospect hole drilled at a primary underground development work place. Core was transported from underground to the core logging facility (core yard) in sealed core containers. At the core yard the borehole core was removed from the containers and laid out onto core trays. The core was marked and oriented appropriately.

The borehole was logged in detail in order to identify the lithologies of the UG3, its immediate hanging and foot wall. The logging involved a visual inspection of the core to ensure that a proper quantitative rock description is carried out. Estimations of colour, grain size, texture, nature of contacts, primary mineralogy and presence of structural features were noted. The presence or absence of core losses were recorded as well.

3.2. Sampling.

An underground exposure of the UG3 chromite seam was sampled. A PGE analysis was carried out for platinum, palladium, rhodium and gold to establish the 4E value of the UG3. The PGE distribution was determined by the fire assay method. Two values were obtained for each major element and the average was used in the calculations. Best practices that ensured the high standards of quality control and assurance were adhered to. The quality control and assurance ensured that the samples were not contaminated and were of the correct size. The samples were taken vertically across the strata and within the same lithology. The samples were correctly labelled and numbered under the supervision of a geologist and sampling tools were cleaned before and after taking a sample to ensure that there is no contamination. A record of the sample number, site location, and date of sampling, lithologies and coordinates were taken.

3.3. Petrographic examinations.

A rock slab extracted near the sampled UG3 chromitite seam was used for petrographic analysis. Four thin sections were petrographically analyzed using the transmitted light microscopy. A camera is attached to the instrument to produce photographic images. Aspects such as crystal size, crystal shape and habit and description of textures were noted. Modal proportions of crystals were estimated as well. Silicates and oxides were identified and characterised.

3.4. Identification of PGMs and sulphide particles.

A reflected light microscopic technique was used to identify the Sulphides and PGM grains as well as the petrology of the samples. The platinum-group minerals and sulphides appeared very bright under reflected light. Once located, the particles were delineated on the thin section by a permanent marker. Refer to figure 3.

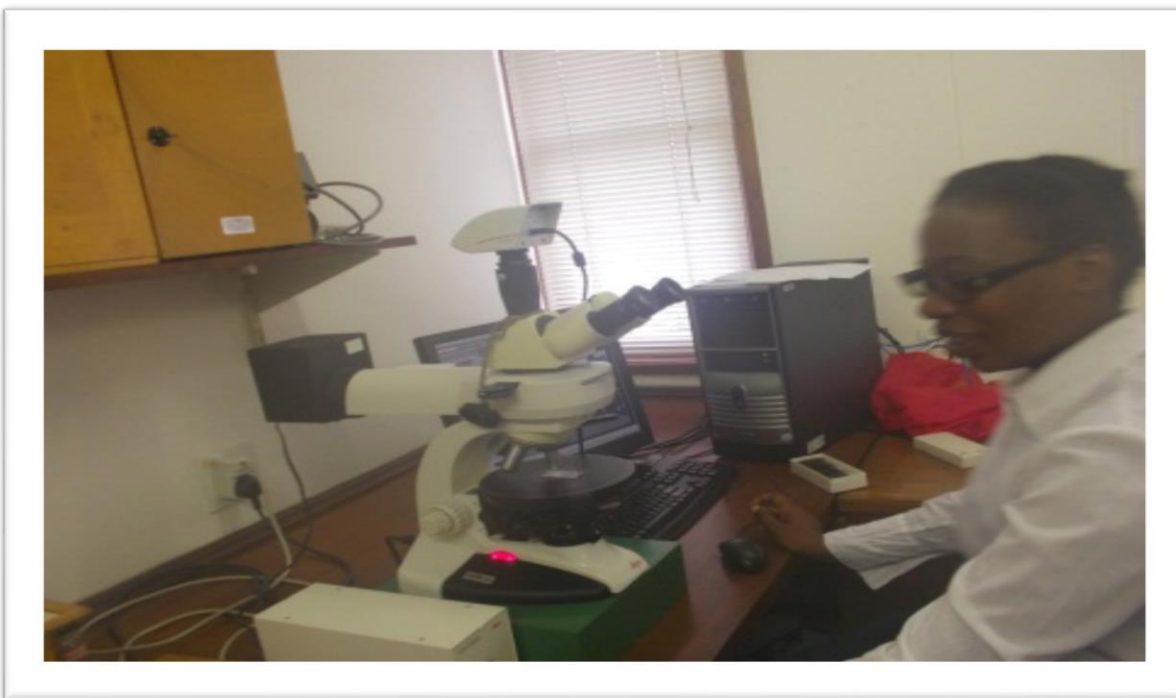


Figure 3. A photographic image of the Leica transmitted light microscope.

3.5. Quantitative analysis.

Quantitative analysis was carried out using the Jeol JXA 8230 Superprobe machine. Amongst other components the equipment has a power supplying cable, electron magnetic lenses that create an electromagnetic field, iron and rotary pumps that create vacuum in the sample chamber, an anode that controls the amount of the positive charge as well as a detector which creates back scatter electron images.

The equipment comprises 4 WD spectrometers. An acceleration voltage of 15kV, a probe current of 20nA and a counting time of 10 seconds on peak and a 5 second on background, and a beam size spot <1 micron were employed for analysis. The ZAF matrix correction method was employed for quantification. The following elements were quantified.

- Platinum-group minerals
- Sulphides

- Silicates
- Oxides

A photographic image the Jeol JXA 8230 Superprobe analyser is provided below.



Figure 4. A photographic image of the Jeol JXA 8230 Superprobe machine.

Natural standards were used for measuring the characteristic X-rays. Prior to the quantification of the Platinum-group minerals, sulphides, silicates and oxides, the Platinum-group minerals and sulphides were located and marked on the samples. Platinum-group minerals are known to occur in trace amounts in the Bushveld Complex ores. The PGMs and sulphides appeared very bright compared to the silicates and oxides. During the quantification process, a beam was pointed towards those bright appearing particles and the reflection thereof would be captured by a censoring device which reports the quantity of the elements by comparison to the calibrated natural standards used. The quantities of the major elements in the specific particle are reported in mass percentages. An inbuilt camera was utilized to capture the images of the sample view.

The Jeol JXA 8230 Superprobe proved invaluable in quantifying and the characterization of the Sulphides and Platinum-group minerals within the UG3 chromitite seam which is the focal point of this thesis.

In order to delineate and characterize the UG3 chromitite seam a mapping, sampling, valuation and microscopic exercises were carried out as well as documented.

4. Results.

Geological mapping was carried out at three sites namely, the UG3 outcrop at a stream near the Driekop exploration core yard, at the Modikwa UG2 open pit and at the South2 material decline. Borehole core and hand specimen from underground workings were examined and sampled.

5. Geological mapping and core logging.

5.1 Geological mapping at the stream near the Driekop exploration core yard.

The UG3 at this site is overlain by a feldspathic pyroxenite. The pyroxenite consists of brown medium grains with scattered large oikocrysts. The oikocrysts comprise of clinopyroxene. The well-formed euhedral clinopyroxene oikocrysts range from a few centimetres to 5cm in size.

The basal contact of the feldspathic pyroxenite is sharp. The UG3 outcrop dips at approximately 12% towards the east and it has a NNE-SSW strike.

The UG3 seam consists of black fine chromite grains. It is 25cm thick. It has a sharp basal contact. Refer to figure 5.

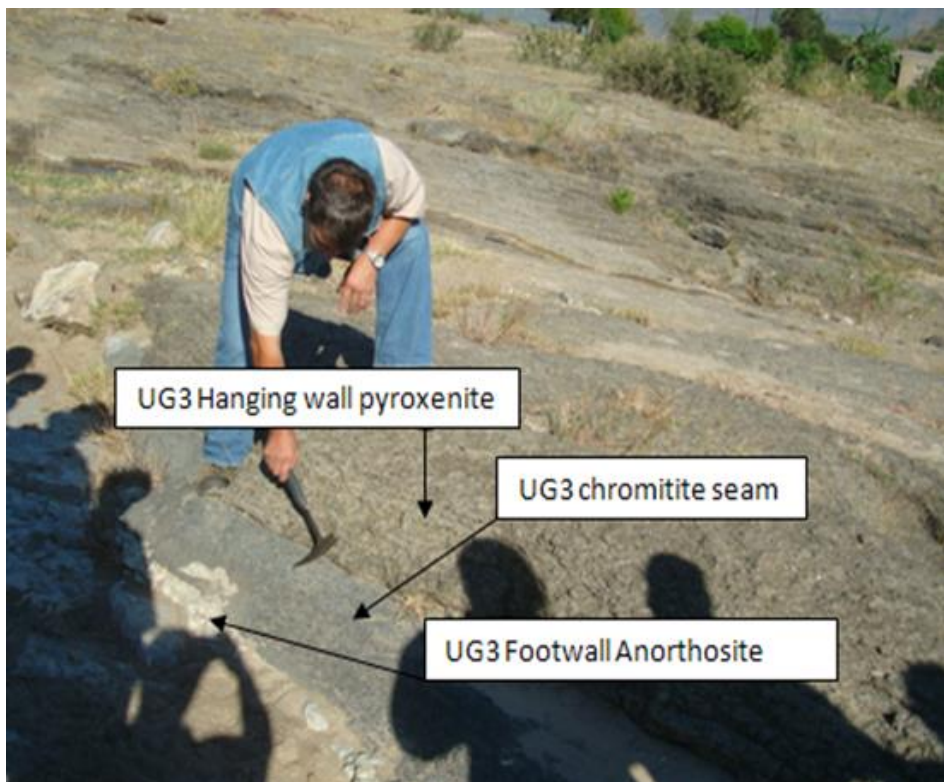


Figure 5. A photographic image of the UG3 chromitite seam outcrop near the Driekop exploration camp.

The UG3 chromitite seam is underlain by a massive anorthosite. The anorthosite has a white-grey colour and it is fine grained. The contact between the anorthosite and the UG3 chromitite seam is sharp.

5.2. The mapping of the UG3 chromitite seam at the Modikwa Platinum Mine open pit.

The UG3 chromitite seam at the Modikwa UG2 open pit lies 10m above the UG2 reef horizon. The chromitite seam is 25cm thick. It is fine grained and has a massive texture. The basal contact of the UG3 chromitite seam is sharp. Refer to figure 6.

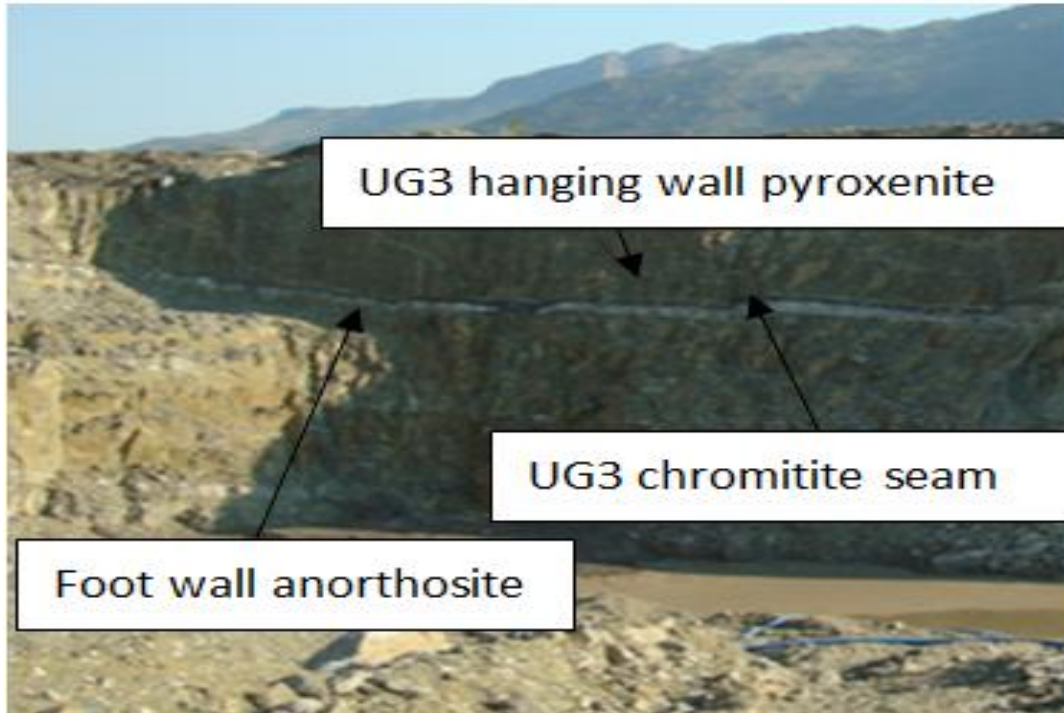


Figure 6. A photographic image of the UG3 chromitite seam at the UG2 open pit at Modikwa Platinum Mine.

The UG3 at this site is overlain by a feldspathic pyroxenite. The pyroxenite consists of brown medium grains with scattered large oikocrysts. The oikocrysts comprise of clinopyroxene. The basal contact of the feldspathic pyroxenite is sharp. The UG3 outcrop dips at approximately 15% towards the east and it has a NNE-SSW strike.

The UG3 chromitite seam is underlain by a massive anorthosite. The anorthosite has a white-grey colour and it is fine grained. Mottles of pyroxenite occur within the anorthosite layer. The mottles range in size from 2cm to about 5cm. The contact between the anorthosite and the UG3 chromitite seam is sharp.

Findings:

- It has been confirmed that the UG3 is laterally extensive throughout the Modikwa Platinum Mine lease area and that it has an average of thickness of 22cm.
- Sharp contact suggests that there was no chemical reaction between the UG3 chromitite seam and the underlying anorthosite.

- The UG3 chromite seam forms the basal layer of the UG3 cyclic unit.
- The UG3 is not a single planar chromitite seam, it consists of at least two chromitite layers fused together.

5.3. Geological mapping at the South2 material decline.

The UG3 chromitite seam has been mapped at a number of underground locations. The primary development work places in which the UG3 has been exposed and mapped are as follows.

- Level 2 South Haulage
- Return Air Way South Haulage
- South 2 Material Decline and Chair Lift

Attention will be paid to the UG3 chromitite seam that has been exposed at the South 2 Material Decline. Modikwa platinum mine has two operational shafts namely, North shaft and South shaft. The ore reserves at South shaft are being exhausted and as a result a replacement will be required in a few years' time, hence the development of a new shaft named South2. Refer to figure 7.

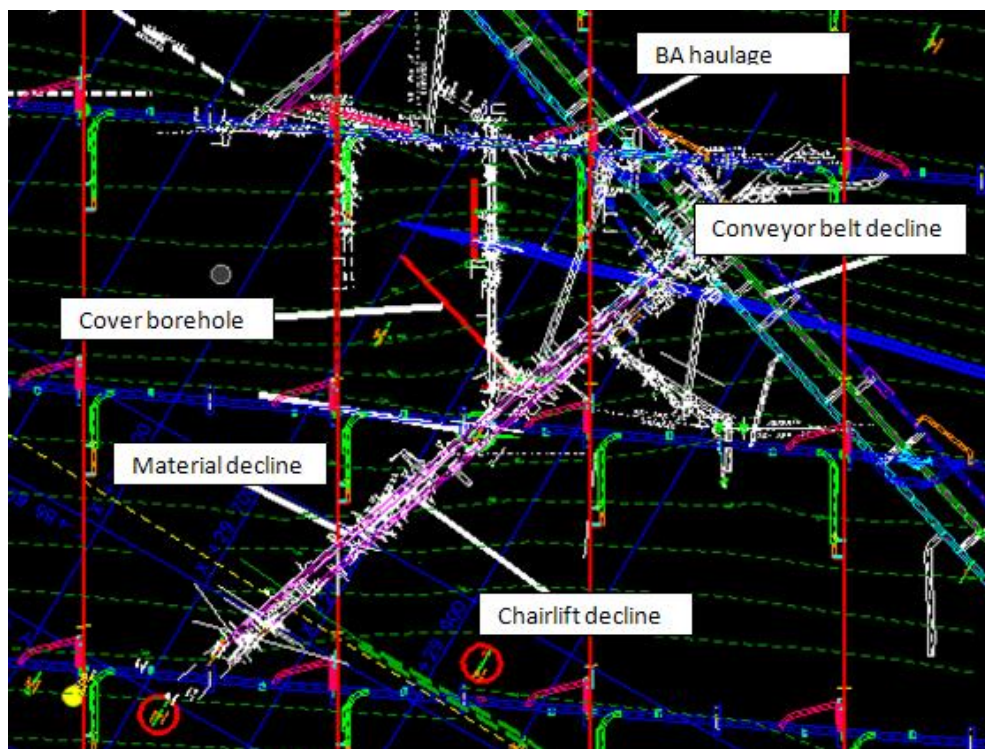


Figure 7. The plan view of the material decline.

During the development of the South2 material decline, the UG3 chromitite seam was intersected. It occurs 10m above the UG2 chromite seam.

The UG3 at the material decline is overlain by a feldspathic pyroxenite. The pyroxenite consists of brown medium grains with scattered large oikocrysts. The oikocrysts comprise of clinopyroxene. The feldspathic pyroxenite has a sharp basal contact. The UG3 outcrop dips at approximately 15% towards the east and it has a NNE-SSW strike.

The UG3 chromitite seam is underlain by a massive anorthosite layer. The anorthosite has a white-grey colour and it is fine grained. The contact between the anorthosite and the UG3 chromitite seam is sharp.

Findings:

- The existence of a pyroxenite lens below the UG3 chromitite seam suggest that a cyclic unit was completely melted during the intrusion of the UG3 cyclic unit. The pyroxenite lens is actually only a remnant of the missing cyclic unit.

5.4 Borehole core examinations from underground workings.

A short prospect hole that was drilled at the BA Haulage South was selected for the study purpose of the UG3 chromitite seam. The BA Haulage is a primary development intended to access virgin ground. These development haulages are usually located approximately 20m below the UG2 reef horizon.

The prospect hole was drilled at an inclination of 90* and the total length of hole was 30m. The bore hole intersected the UG2 at 14m and the UG3 at 24m. The detailed borehole log is provided below.

DISTANCE		Logged by. Nkateko Machumele	Date.
FROM	TO	DESCRIPTION	STRATIGRAPHY
0	10	Grey medium grained norite	NORITE
10	11	White fine grained anorthosite layer	ANORTHOSITE
11	14	Brown, phaneritic and medium grained	PYROXENITE
14	14.6	Black fine grained seam	UG2 REEF
14.6	15.8	Brown, phaneritic and medium grained	FELDSPATHIC PYROXENITE
15.8	16	White massive fine grained anorthosite	HANGING WALL ANORTHOSITE
16	23.8	Brown, phaneritic, medium grained	FELDSPATHIC PYROXENITE
23.8	24	White ,massive and fine grained layer	ANORTHOSITE
24	24.225	Black massive and fine grained seam	UG3 REEF

24.225	24.226	White massive fine grained anorthosite lens	ANORTHOSITE LENS
24.226	24.235	Black massive and fine grained layer	UG3 REEF
24.25	30	Brown, phaneritic and medium grained	FELDSPATHIC PYROXENITE

The UG3 chromitite seam in the bore hole is 24cm thick and consists of black fine grains of chromite. It has a massive texture. A thin anorthositic lens occurs towards the top contact of the UG3 seam. The seam has a sharp basal contact. Chromite is the dominant cumulus primary mineral. Refer to figure 8.

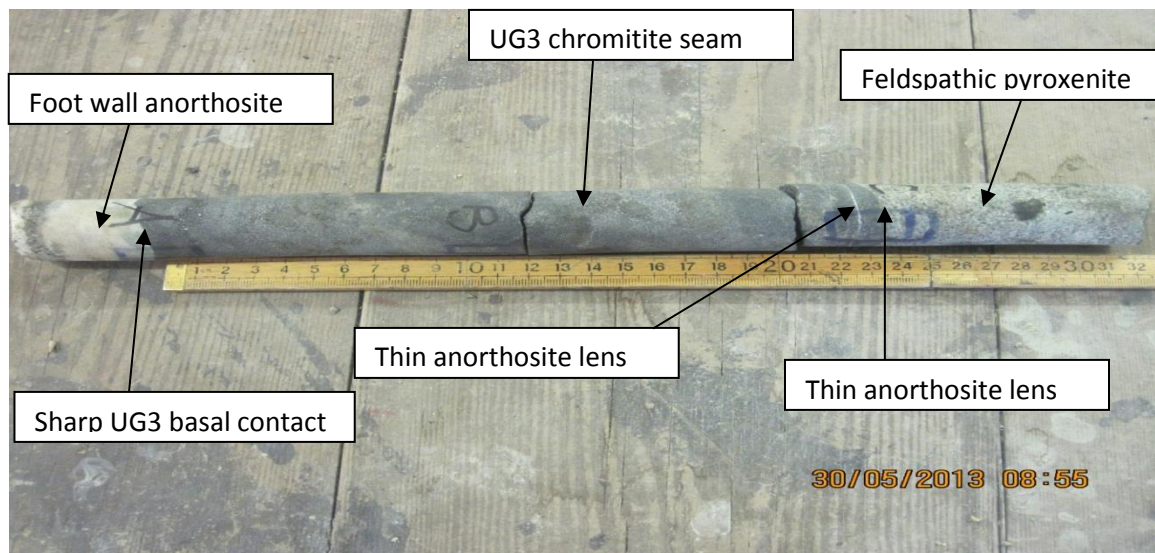


Figure 8. A photographic image of the UG3 chromitite seam intersected in borehole CHS006.

The UG3 chromitite seam is overlain by a feldspathic pyroxenite. The pyroxenite has brown medium grains and scattered clinopyroxene oikocrysts. The oikocrysts range in size from a few centimetres to 5cm. The pyroxenite has a phaneritic texture. Pyroxene is the dominant cumulus primary mineral. The feldspathic pyroxenite has a sharp basal contact.

Underlying the UG3 chromitite seam is the foot wall anorthosite. The anorthosite is white in colour and it has very fine grains. It has a sharp basal contact. The anorthosite consists mainly of cumulus plagioclase.

Findings:

- The thin anorthosite lens suggests that the UG3 chromitite seam is not a single solid chromitite seam. It consists of more than one chromitite unit.

6. The sampling of the UG3 chromitite seam at South2 material decline.

The UG3 chromitite seam was sampled in order to determine its 4E value i.e. Pt, Pd, Au and Rh. The fire assay method was used and the results are tabled below.

Table 2. Showing UG3 sampling results.

TICKETS NO	Pt	Pd	Au	Rh	Total 4E
MDSU10000905	0.1	0.05	0.02	0	0.17
MDSU10000906	5.75	0.14	0.02	0.48	6.39
MDSU10000907	2.54	0.1	0.02	0.24	2.9
MDSU10000908	2.865	0.2	0.02	0.335	3.42
MDSU10000909	1.86	0.065	0.02	0.19	2.135
MDSU10000910	2.735	0.165	0.02	0.31	3.23

The centime grams per ton of the UG3 chromite seam was determine using the 4E values obtained from each sample. The calculation is as follows.

Table 3. Showing individual PGE value of each lithology.

Ticket	Lithology	Thickness in cm	Value in g/t	Centimetres grams per ton
908	UG3 chrm + ospy	11	3.42	37.62
907	UG3 chromitite	10	2.9	29
906	UG3 chrm + ospy	10	6.39	63.9
905	FW anorthosite	11	0.17	1.87
Total		42		132.39

Oxpy = orthopyroxenite

In situ value = 132.39cmg/t divided by 42cm = 3.15g/t

Findings:

- The in situ 4E value of the UG3 chromitite seam at the South2 material decline is 3.15g/t .
- The mining of the UG3 in an underground operation at a stope width of 1m would render a value of 1.32g/t and is uneconomic.
- The UG3 chromitite seam is bottom loaded.

The footwall anorthosite yielded a 4 PGE value of 1.87 confirming that it has very low PGE values as compared to the chromitite seam. Silicate cumulates adjacent to the chromitites generally have much lower PGE values (Scoon and Teigler, 1994).

7. UG3 chromitite seam exploration sampling data.

A number of exploration boreholes which were drilled to explore for the UG2 chromitite seam were selected for UG3 sampling to determine the 4 PGE values within this chromitite seam. The locations of the holes are spread throughout the following farms: Maandagshoek, Driekop, Heindreksplaas, Onverwacht and Winterveld. Refer to table 3.

Table 4. A summary of the UG3 chromitite seam exploration boreholes with 4 PGE values.

Borehole ID	Inclination	From	To	UG3 thickness	4 PGE value
DC3	-90	42.78	43.29	0.51	0.34
DKP13	-90	68.06	68.26	0.20	3.50
DKP7	-90	190.98	191.21	0.23	2.70
HDP89	-90	97.82	97.98	0.16	3.31
M17	-90	489.36	489.51	0.15	4.00
M17	-90	496.46	496.67	0.21	2.10
MN60	-90	35.53	35.75	0.22	0.20
MS30	-90	20.4	20.64	0.24	2.95
MS35	-90	22.85	23.09	0.24	2.90
MS40	-90	31.72	31.98	0.26	2.77
MS60	-90	48.17	48.38	0.21	2.89
MS65	-90	51.97	52.22	0.25	4.30
OV1	-90	153.68	153.94	0.26	3.20
OV717A	-90	352.97	353.11	0.28	2.12
OVC1	-90	73.56	73.68	0.12	4.46
OVC2	-90	55.49	55.62	0.13	5.83
OVC3	-90	26.22	26.35	0.13	0.20
OVC4	-90	33.91	34.04	0.13	4.11
V2A	-90	128.32	128.52	0.20	1.83
V8	-90	81.6	81.8	0.20	0.82
WV1	-90	219.33	219.58	0.25	3.30
WV114	-90	124.55	124.8	0.25	0.03
WV2	-90	264.89	265.18	0.29	3.40
WV3	-90	182.5	182.77	0.27	4.20
			Average	0.22m	2.54g/t

8. A petrographic analysis and rock type descriptions.

All the lithologies encountered in the vicinity of the UG3 have been described using the Leica transmitted light microscopy. Their modal mineral compositions were estimated by visual examinations. Samples from individual lithologies were examined in order to identify any variations in modal mineralogy and textural characteristics.

The MAY B, C and D samples were selected for the examinations, wherein sample B was taken at the basal contact of the UG3 while C and D were taken from the chromitite seam itself. Refer to figure 9. Thin sections were prepared from these samples and viewed by a microscope to determine their modal mineralogy and textural characteristics.

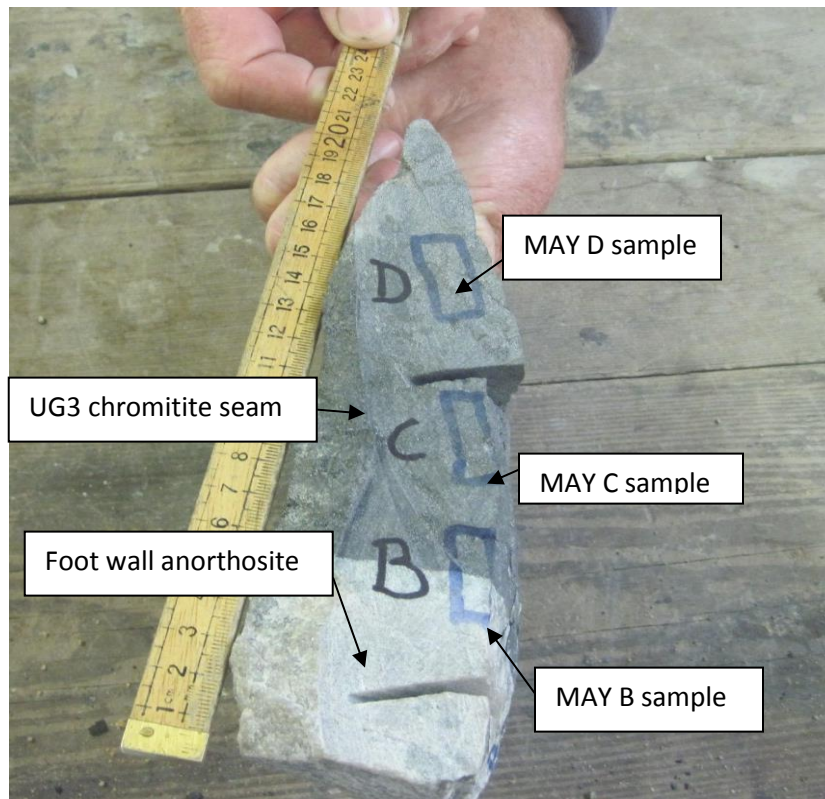


Figure 9. A photographic image of a slab from which the samples were taken.

The MAY B sample was taken at the base of the UG3 chromitite seam. The petrographic description of the sample is as follows.

Sample label

MAY B

Rock lithology type

- Anorthosite.

Stratigraphic name

- This unit forms the UG3 foot wall.

Modal composition

- 99% Plagioclase.
- 1% Orthopyroxene

Refer to figure 10.

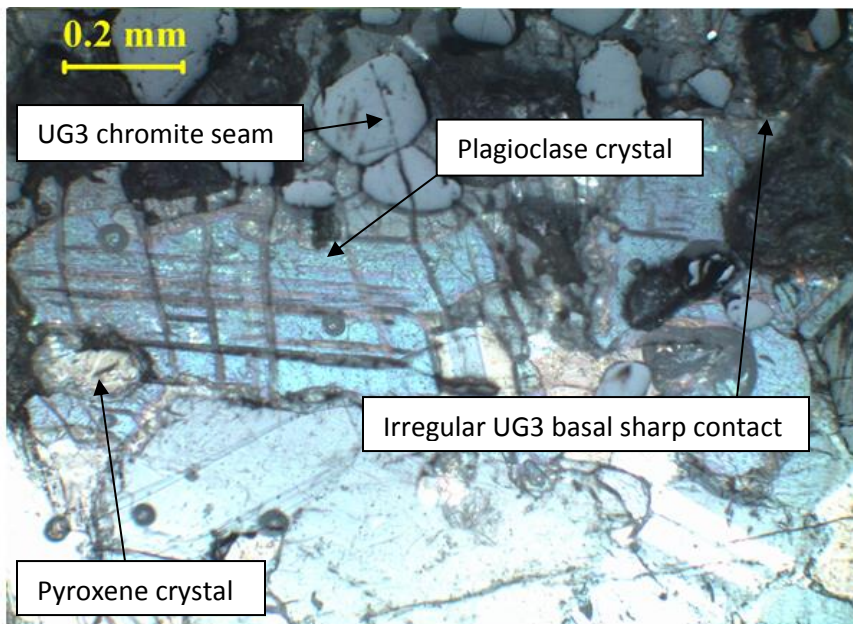


Figure 10. A microscopic image of the UG3 foot wall anorthosite consisting of plagioclase at sample MAY B under transmitted light.

The plagioclase crystals exhibit distinct twinning characteristics. The crystals do not display any preferred orientation. They appear elongated with a diameter of approximately 0.8mm and are euhedral. Pyroxene has a sub-rounded shape and has diameter of about 0.18m. The pyroxene crystal is surrounded by cumulus plagioclase. The chromite-plagioclase contact is irregular thus suggesting that there was a thermo-chemical reaction on contact. This phenomenon was recognised by Mathez and Mey, (2005).

The MAY C sample was taken at the middle portion of the UG3 chromitite seam. The petrography of the interstitial matrix that binds the chromitite grains of the UG3 chromitite seam is the focus of this examination. The petrographic description of the interstitial matrix is as follows.

Sample label

MAY C

Rock type

- This unit forms the interstitial matrix of the UG3 Chromitite seam.

Stratigraphic name

- UG3 Chromite horizon.

Modal composition

- 60% Plagioclase
- 38% Chromite
- 2% Pyroxene

Refer to figure 11.

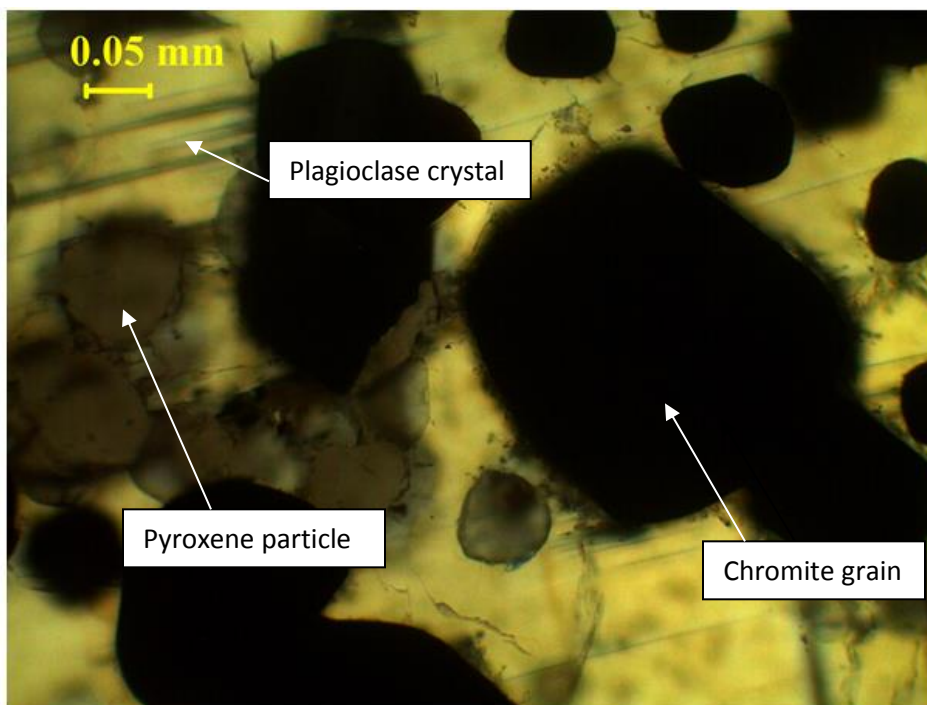


Figure 11. A transmitted light microscopic image of the UG3 chromitite seam at sample MAY C.

The plagioclase is the interstitial matrix that binds the chromite grains. The plagioclase crystals exhibit distinct twinning characteristics. No preferred orientation of crystals was observed. The crystals are elongated, have a diameter of approximately 0.2mm and are euhedral. The pyroxene crystals appear as a cluster, suggesting that this could be a mottle of pyroxene that usually occurs in the cumulus plagioclase of massive anorthosite units. Pyroxene crystals have a sub-rounded shape and has diameter of about 0.18m. The pyroxene crystal is surrounded by cumulus plagioclase.

The MAY D sample represents the top portion of the UG3 chromitite seam. The petrographic description of the anorthosite is as follows.

Sample label

MAY D

Rock type

- Chromitite seam

Stratigraphic name

- UG3 reef horizon

Modal composition

- 95% chromite grains
- 5% interstitial plagioclase and minor orthopyroxene.

Refer to figure 12.

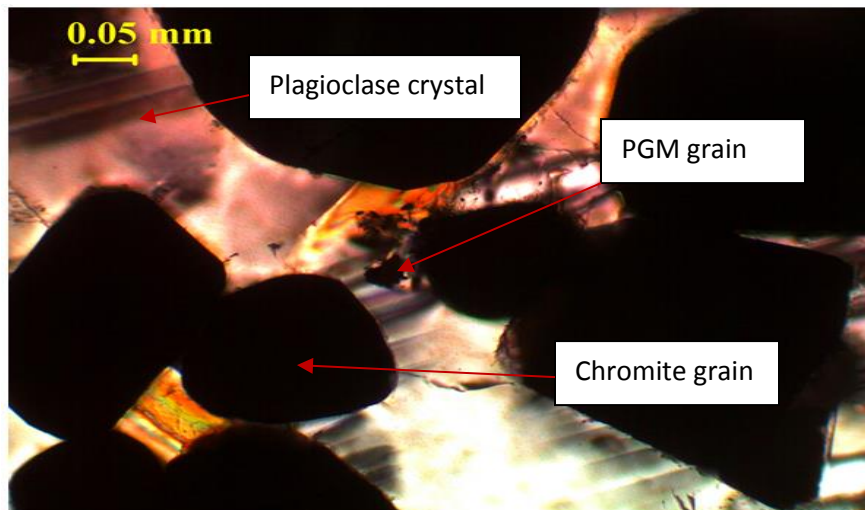


Figure 12. A microscopic image of the interstitial plagioclase within the UG3 chromitite seam at sample MAY D under transmitted light.

The rock forming mineral that constitutes the interstitial matrix that binds the chromite grains has been identified as plagioclase. The plagioclase crystals exhibit distinct twinning characteristics with no preferred orientation. The crystals are elongated, have a diameter of approximately 0.2mm and are euhedral. The silicate at this location comprises solely of cumulus plagioclase and no other cumulus minerals are present.

The petrographic characteristics of the samples MAY B, MAY C and MAY D suggest that there are two lithologies namely the anorthosite footwall and interstitial matrix of the UG3 chromitite seam.

The footwall anorthosite consists of predominately plagioclase with minor orthopyroxene. Plagioclase occurs as a cumulus mineral while orthopyroxene is cumulus. Similarly, the interstitial silicates in the UG3 chromitite seam comprise of cumulus plagioclase with minor cumulus orthopyroxene as well.

Plagioclase was distinguished by its twinning characteristics. Plagioclase crystals exhibit poly-synthetic twinning tendencies under microscopic transmitted light. (Raith et al., 2005)

8.1. The textural characteristics of the UG3 chromitite seam.

Textural mineral characteristics of the UG3 chromitite seam are as important as its other attributes. Microscopic photos will be used to document the textural characteristics of the UG3. The selected microscopic photos included The MAY B sample taken from the UG3 basal contact, MAY C and MAY D represents the chromitite seam.

The chromite grains range in size from less than 0.02 to approximately 0.6mm at the MAY B sample. Sample MAY B exhibits an open packing structure or matrix supported. A number of large grains appear to be scattered randomly within the medium and small chromitite grains. Refer to figure 13.

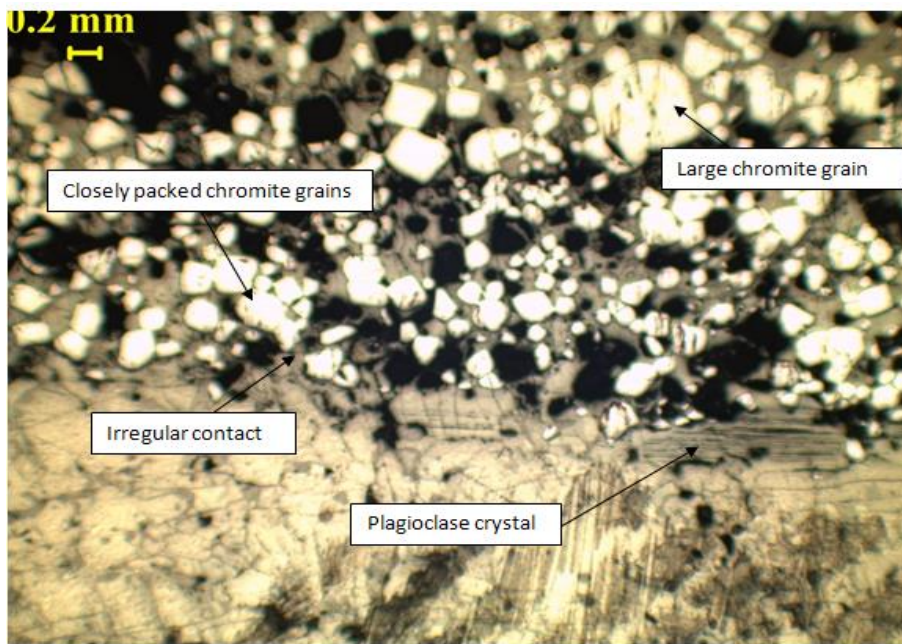


Figure 13. A microscopic image of matrix supported chromite grains within the MAY B sample under transmitted light.

The texture in the MAY B sample comprises a matrix-supported chromite packing structure. The chromites are fine to medium grained with a number of larger grains randomly scattered.

The basal contact of the chromitite seam is irregular. An irregular contact suggests that there has been a thermo-chemical reaction between the two lithologies (Mathez and Mey, 2005)

The textural characteristics of the UG3 chromitite seam was carried out in the MAY C sample and it was established that the chromite grains range in size from less than 0.1 to approximately 0.8mm. Approximately 70% of the sample exhibits an open packing structure and about 30% of the chromite

grains appear to be closely packed. The closely packed grains form a zone in the middle of the sample view. Refer to figure 14.

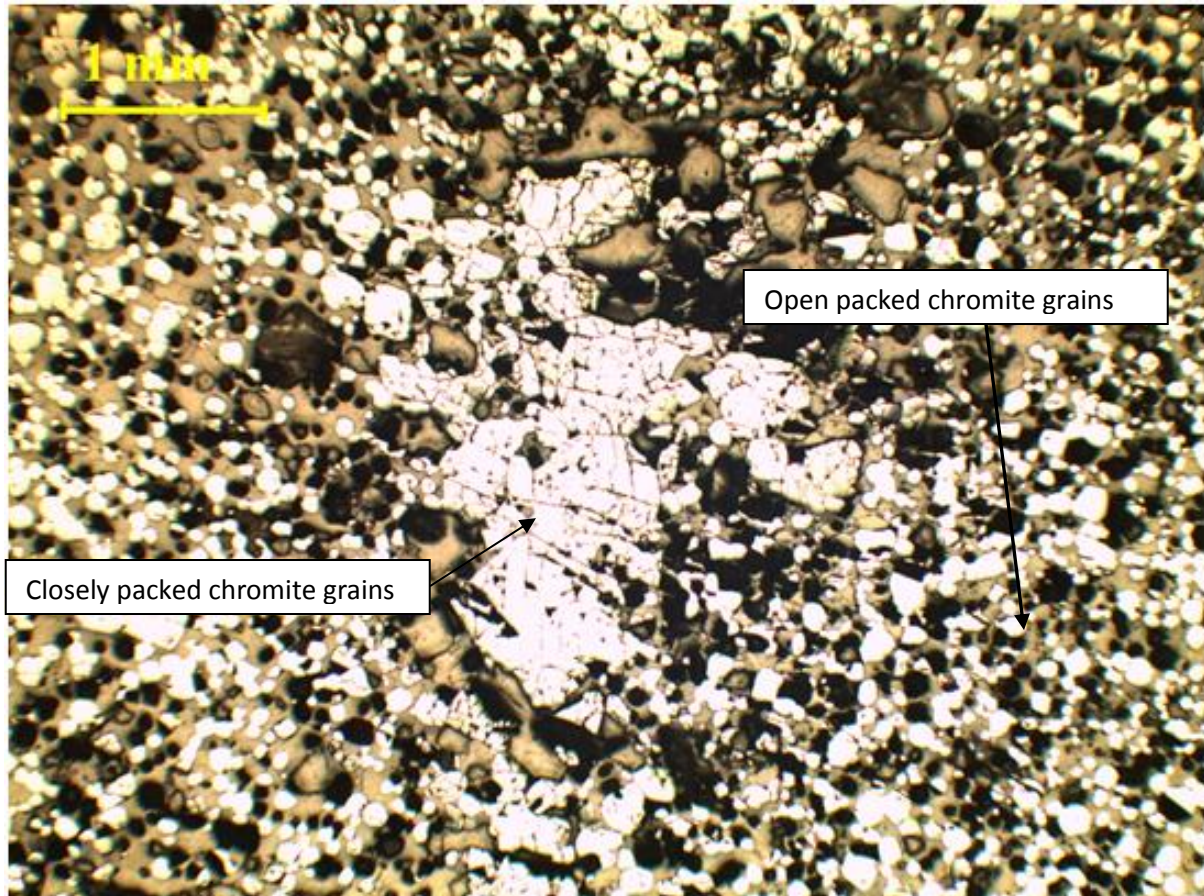


Figure 14. A transmitted light microscopic image of matrix supported chromite grains within the MAY B sample and a closely packed structure at the middle of the image.

In general the textural characteristic of the chromitite seam is matrix supported with a distinct grain supported zone in the middle. The closely packed zone is likely comprising a number of chromite nodules or super grains. Thus three types of textures may exist in this sample namely the open packing, the close packing and the nodular texture.

The chromite grains range in size from less than 0.1 to approximately 0.6mm in the MAY D sample. The sample exhibits a well-developed open packing structure. A fracture appears to be cutting across the sample. Refer to figure 15.

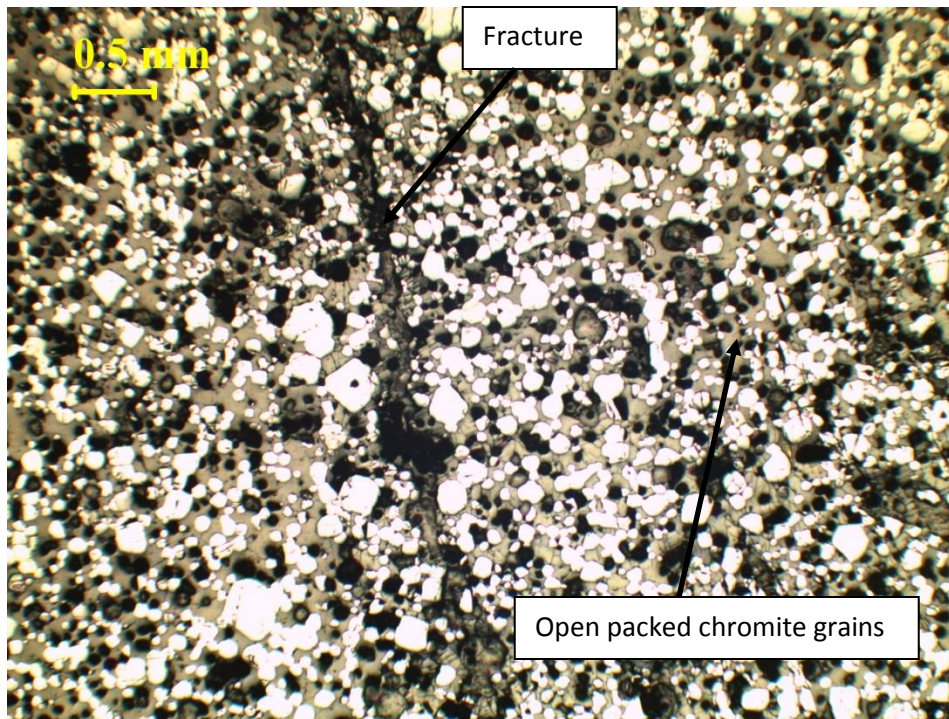


Figure 15. A transmitted light microscopic image of matrix supported chromite grains within the MAY B sample with a fracture cutting across the chromitite seam.

The packing structure in the MAY B sample ranges from a more common matrix supported profile, a less common chromite supported structure as well as a very rare nodular texture. Thus the UG3 chromitite seam consists of a network of cumulus chromite grains within the interstitial silicate matrix comprising of dominantly cumulus plagioclase with minor intercumulus orthopyroxene.

9. An electron microprobe quantitative analysis of the UG3 chromitite samples.

Four thin sections were selected for the microscopic examinations in order to establish the PGMs textural characteristics and associations. The relative location and quantity of PGMs were also determined. The four thin sections namely MAY A batch, MAY B batch, MAY C batch and MAY D batch are described in detail below.

9.1 A brief description of the textural characteristics and associations of the Platinum Group Metals in MAY A1-MAY4, MAYB and MAYD samples.

The PGM quantitative analysis was carried out at Points 24 to 30 within sampleMAYA1. Refer to figure 11. The results of the quantitative analysis are provided in table 5.

Table 5. The results of the quantitative analysis of the Platinum Group Metals.

Pnt	Name	As%	S%	Rh%	Fe%	Cu%	Pt%	Ru%	Pd%	Total%
24	Cooperite	0	16.523	0.297	1.213	0	79.02	0	0.668	97.721
26	Cooperite	0	16.099	0.335	0.968	0.25	78.89	0	0.062	96.604

The PGM particle that was analyzed at Points 24 and 26 has been identified as a Cooperite (PtS). At Points 27 to 30 unnamed PGM phases were also observed. These are composite phases of the PGM within the sample. The position of the analytical points is shown in figure 16.

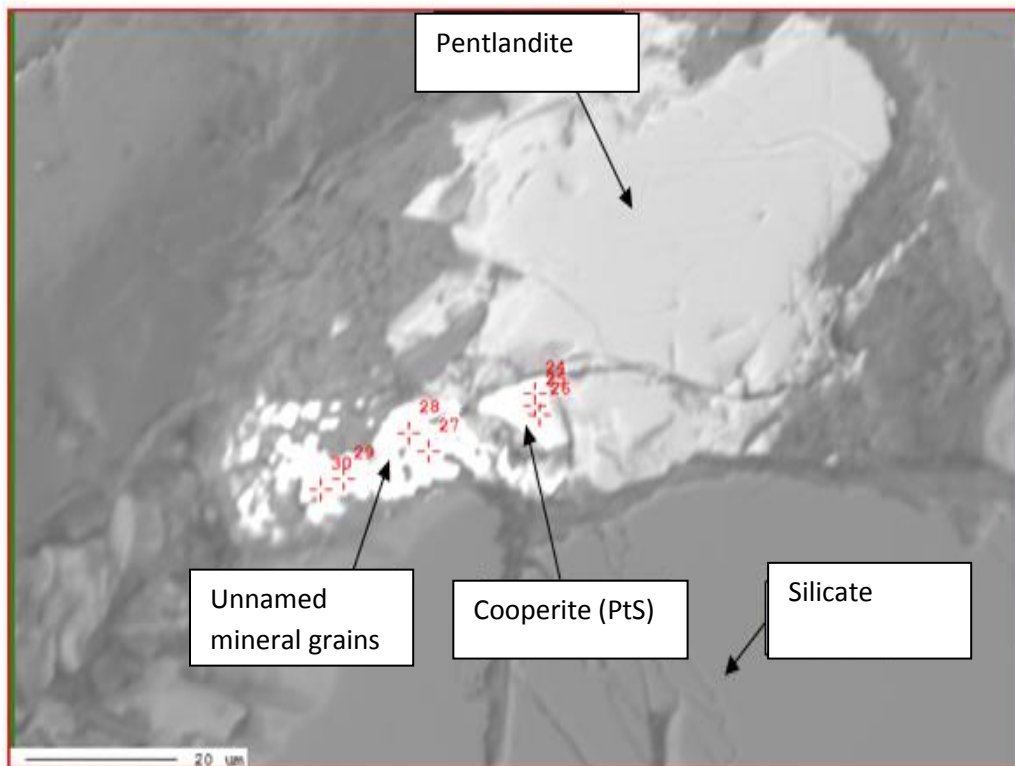


Figure 16. A backscattered electron image of PGMs occurrence within sample MAY 1.

The cooperite is preferentially located near the edges of the sulphide grains. It is approximately 15μm in size. The cooperite is well formed and euhedral. It is closely associated with the pentlandite. The location, size and association suggest a magmatic texture which is a compliant with PGMs that have not been reworked or altered by secondary fluids. It is evident that the cooperite formed from the original PGM assemblage.

An unnamed phase occurs at the boundary of the cooperite. It resembles the brain texture. The particles are irregular and occur in contorted zones of PGM surrounded by silicates. It is located within the interstitial silicates and is separate from the cooperite. The size of the mineral grains of this phase

ranges from less than 5µm to approximately 30µm. The fact that the large and well developed phases are separated from the PGM crystal suggests that they formed the original PGM assemblage.

The PGM quantitative analysis was carried out at Points 39 to 48 within the MAY2 sample. The texture and location of the PGMs were determined and the results of the quantitative analysis are provided in table 6.

Table 6. Showing the PGM quantitative results of the MAY A2 sample.

Pnt	Name	As%	S%	Rh%	Fe%	Cu%	Pt%	Ru%	Pd%	Total%
39	Ferroplatinum	0	0.073	0.261	9.315	0.118	86.541	0	1.108	97.416
40	Ferroplatinum	0	0.025	0.201	9.289	0	87.666	0	0.554	97.735
41	Ferroplatinum	0	0.078	0.356	9.312	0.454	87.047	0	0.199	97.446
44	Ferroplatinum	0	0.038	0.477	9.698	0.319	89.325	0	0.3	100.157
45	Ferroplatinum	0	0.057	0.375	9.294	0.287	84.943	0	3.084	98.04
46	Ferroplatinum	0.004	0.094	0.231	9.974	0.062	90.518	0	0.138	101.021
47	Ferroplatinum	0	0.116	0.466	9.296	0	88.599	0	0.111	98.588
48	Ferroplatinum	0.011	0.156	0.511	9.669	0.32	86.546	0	0.974	98.187

The PGM particle that was analyzed at Points 39 to 48 has been identified as a ferroplatinum alloy. The positions of the analytical points are shown in figure 17.

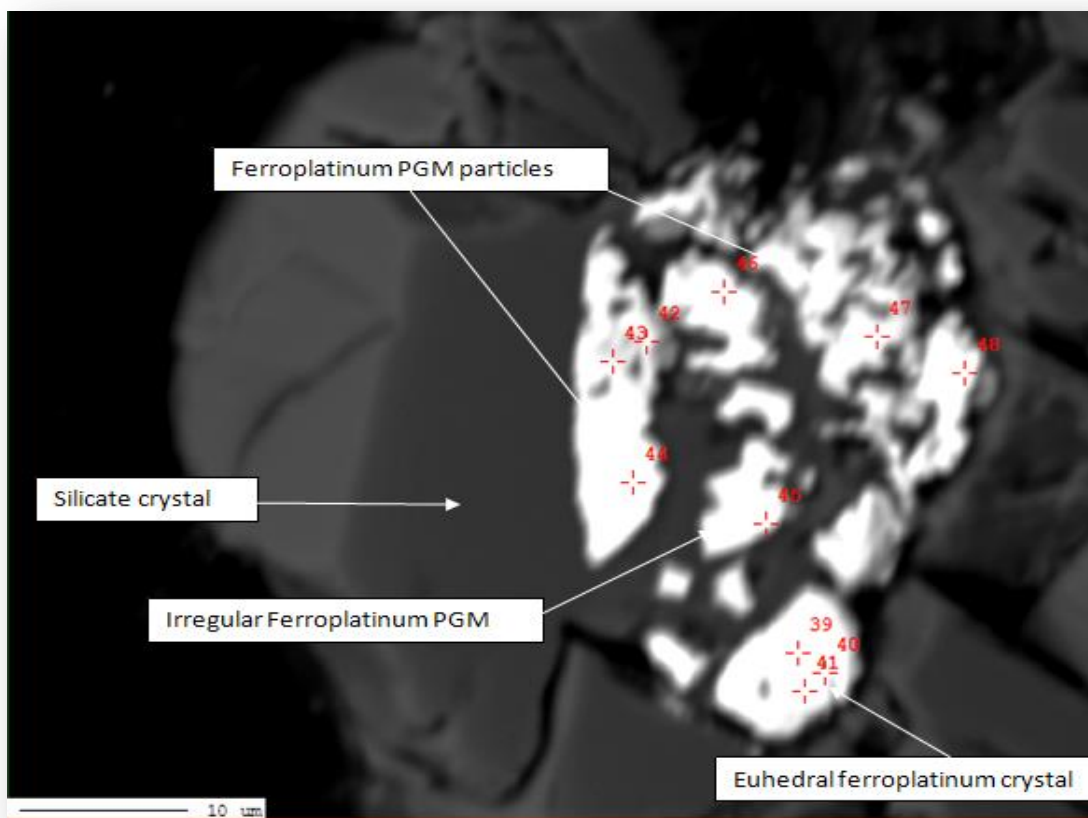


Figure 17. A backscattered electron image of PGM occurrence within sample MAY A2.

The PGM has an intricate pattern that resembles a brain texture. The PGM particles are irregular and occur in contorted zones of PGM surrounded by silicates. The PGM particles within the cluster range from less than 10 μ m to about 30 μ m in size. The cluster of PGM particles, together accumulatively constitutes a sub-rounded very large euhedral grain of ferroplatinum occurring in the interstitial silicates. This typical texture and configuration would suggest that the PGM is of primary nature.

Another PGM quantitative analysis was carried out at Points 34 to 38 within the MAY A3 sample and the results of the quantitative analysis are provided in table 7.

Table 7. The results of the quantitative analysis of the platinum-group minerals.

Pnt	Name	As%	S%	Rh%	Fe%	Cu%	Pt%	Ru%	Pd%	Total%
34	Laurite	3.461	40.054	4.54	0.44	0.087	0.957	51.131	2.339	103.009
35	Laurite	3.269	39.857	5.579	0.491	0.124	1.032	49.666	1.927	101.945
36	Laurite	3.149	39.369	5.731	0.459	0	1.044	50.173	1.855	101.78

According to the Quantitative analysis, Points 34, 35 and 36 represents the element called laurite. The PGM particle that was analyzed at Points 37 and 38 has been identified as the FeRhS mineral. Refer to figure 18.

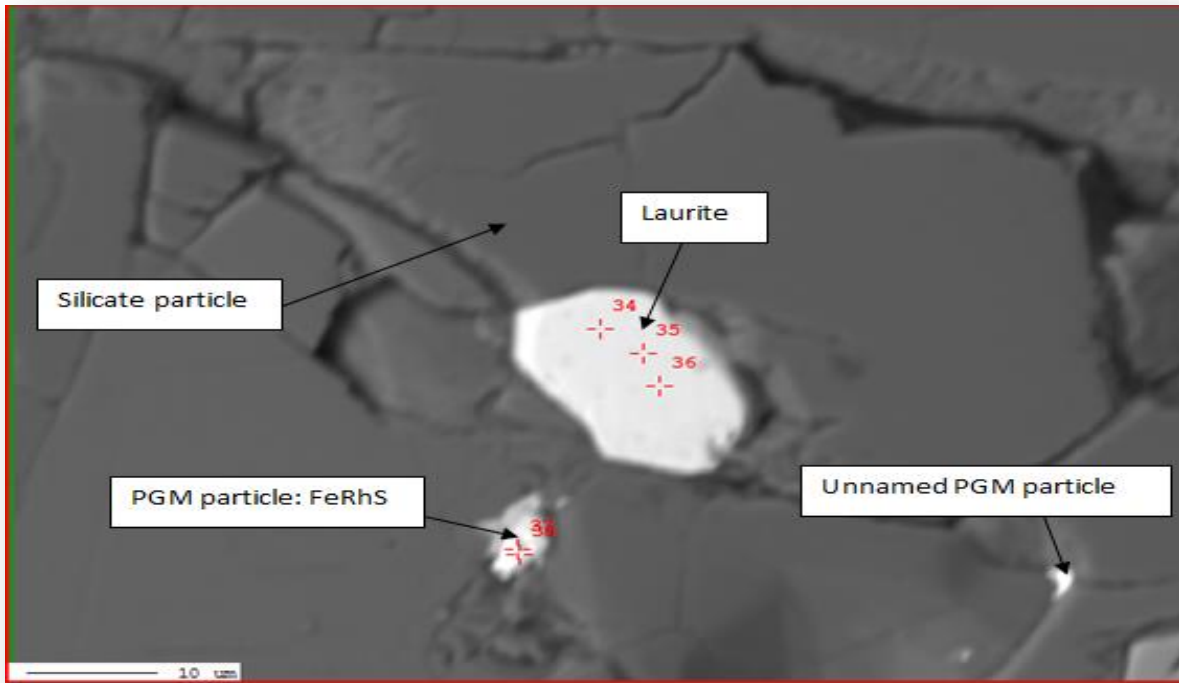


Figure 18. A backscattered electron image of PGM occurrence within sample MAY A3.

The laurite is well formed and euhedral. It is approximately 25µm in size. The laurite is preferentially located the boundary edges of the interstitial silicates. The size, location and configuration tend to suggest that the laurite is of primary magmatic origin.

In the proximal vicinity of the laurite, a relatively small PGM particle occurs. It is about 5µm in size and it has been identified as a FeRhPtS alloy. It is located within the interstitial silicates.

Unlike the rest of the platinum-group minerals analyzed in this section, the grains within the MAY B samples is multi-phased. The quantitative analysis results of the sample are provided below.

Table 8. PGM quantitative results of sample MAY B at points 1-16.

Points	Name	As%	S%	Rh%	Fe%	Cu%	Pt%	Ru %	Pd%	Total%
1	PtRhS	0	28.455	18.721	0.221	13.541	40.874	0	0	101.812
2	PtRhS	0	27.775	18.104	0.013	13.555	41.146	0	0.018	100.611

3	PtRhS	0	26.626	18.532	0.085	14.071	39.49	0	0	98.804
4	PtRhS	0	28.226	18.696	0.034	12.823	40.75	0	0	100.529
5	Cooperite(PtS)	0.022	14.849	0.321	0.07	0	84.206	0	0.129	99.597
6	Cooperite(PtS)	0	14.928	0.326	0	0	85.755	0	0.17	101.179
7	Cooperite(PtS)	0	15.192	0.349	0	0	84.786	0	0.087	100.414
8	Cooperite(PtS)	0	15.148	0.29	0.085	0.217	82.978	0	0.14	98.858
9	Cooperite(PtS)	0.014	15.182	0.376	0	0	84.934	0	0.148	100.654
10	Cooperite(PtS)	0	14.912	0.306	0.101	0	84.431	0	0.132	99.882
11	Cooperite(PtS)	0.004	15.162	0.435	0.214	0.247	84.237	0	0.042	100.341
12	Cooperite(PtS)	0	15.561	0.296	0.07	0.153	84.164	0	0.068	100.312
13	Ferroplatinum(FePt)	0.006	0.065	0.287	9.817	0.236	87.763	0	0.116	98.29
14	Ferroplatinum(FePt)	0.018	0.057	0.292	9.28	0.028	87.402	0	0.343	97.42
15	Cooperite(PtS)	0	10.517	0.232	2.614	0	83.86	0	0.163	97.386
16	Ferroplatinum(FePt)	0	0.207	0.222	10.037	0	88.501	0	0.153	99.12

The PGM occurs as a multi-phase grains consisting of cooperite (PtS), ferroplatinum (FePt) and a PtRhS phase.

The PtRhS particle is large, euhedral and well formed. It is approximately 70µm in size. The PGM particle is located amongst numerous grains of cooperite and silicates. Refer to figure 19.

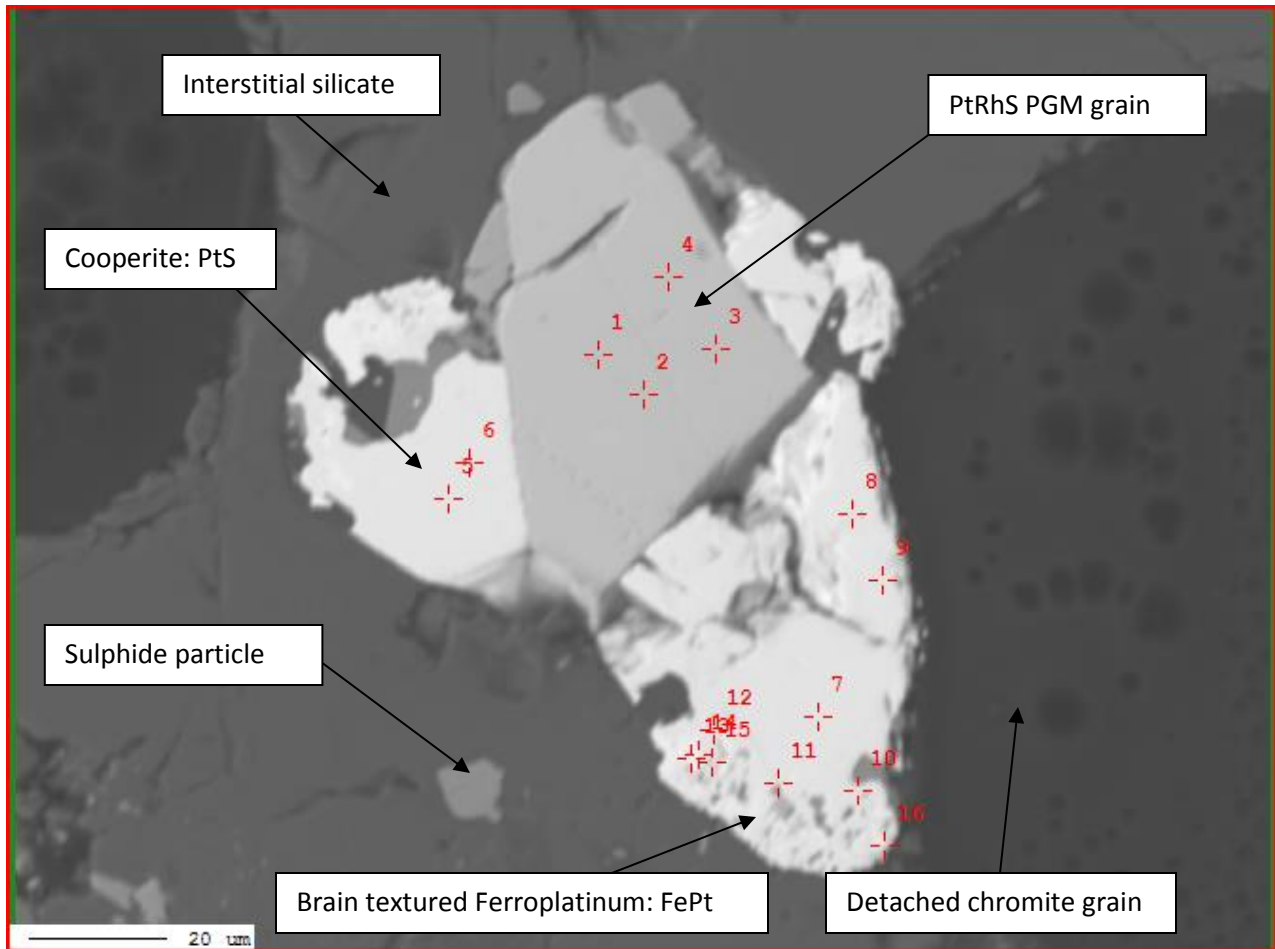


Figure 19. A backscattered electron image of cooperite, RhS and ferroplatinum phases in sample May B.

The fact that the RhS PGM phase is large, well formed and is preferential to boundaries, points to a distinct primary magmatic origin.

The cooperite phases tend to surround the PtRhS particle. The sizes of the cooperite particles range from less than 10 μm to approximately 40 μm . The particles are well formed and occur along the boundaries of a chromite grain, silicate grains and RhS the particle. These intricate textures suggest that the cooperite phases are of primary magmatic nature. Thus the cooperite phases have not been affected by secondary fluids.

A distinct texture has been identified on the lower portion of the cooperite phase. The PGM particles are irregular and are separated by contorted zones of silicates. Refer to figure 20.

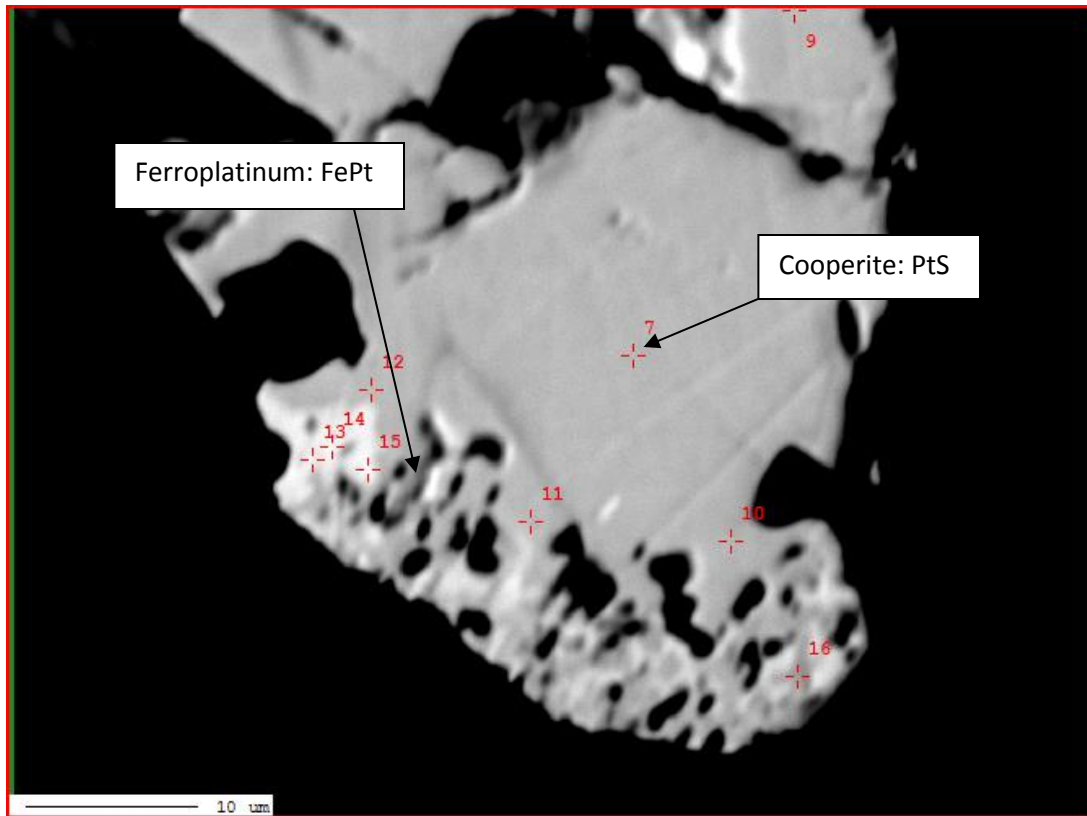


Figure 20. A zoomed in backscattered electron image of the edge of PGM phase within sample MAY B.

The cooperite at this location is euhedral, is approximately 30 μ m in size and well formed. A well-developed exsolution zonation comprising a cooperite core and a ferroplatinum rim occurs at this site.

At the MAY D sample, the PGM quantitative analysis was carried out at Points 52, 53 and 54. The results of the quantitative analysis are provided in table 9.

Table 9. Showing the PGM quantitative results of the MAY D2 sample.

Pnt	Name	As%	S%	Rh%	Fe%	Cu%	Pt%	Ru%	Pd%	Total%
52	Laurite	2.627	39.658	0.978	0.645	0	1.546	53.611	2.446	101.511
53	Laurite	2.749	39.498	1.345	0.96	0.509	1.468	53.833	2.225	102.587
54	Laurite	2.752	38.691	0.97	0.77	0	1.467	51.772	2.374	98.796

The PGM is fully enclosed in a chromite grain. The particle is approximately 20 μ m in size. It has been identified as a laurite. Refer to figure 22. The laurite occurs as a single phase and no association relationship has been established.

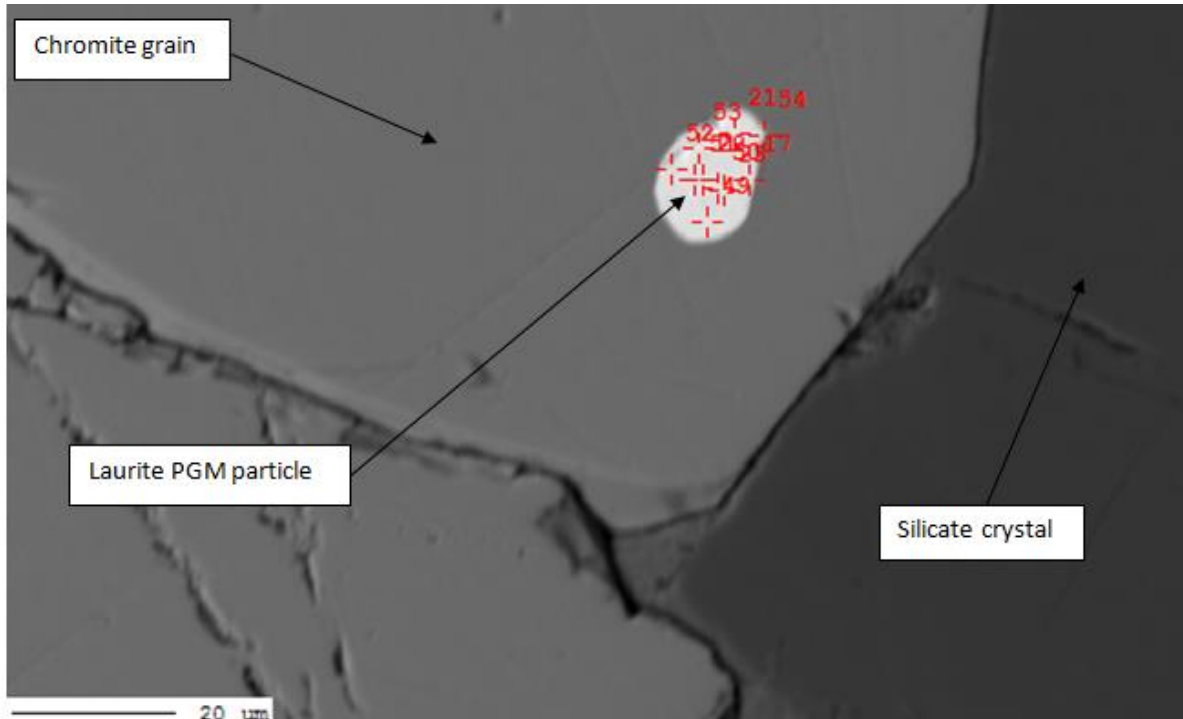


Figure 21. A backscattered electron image of the enclosed Laurite PGM particle within sample MAY D.

Findings:

The platinum-group minerals are concentrated in the chromite seam. This is consistent with the findings of Maier, (2005) who established the PGE enrichments is associated with chromitites and the ultramafic portions of layered intrusions.

9.2 The textural characteristic and quantification of sulphide phases.

The association and textural characteristics of the sulphides will be discussed briefly. The documentation will be based on the imagery and quantitative microprobe analysis of the UG3 samples.

The MAY A sample was analyzed at three points namely, Points 11, 12 and 13 in order to determine the composition of pentlandite. Refer to figure 23 and table 10.

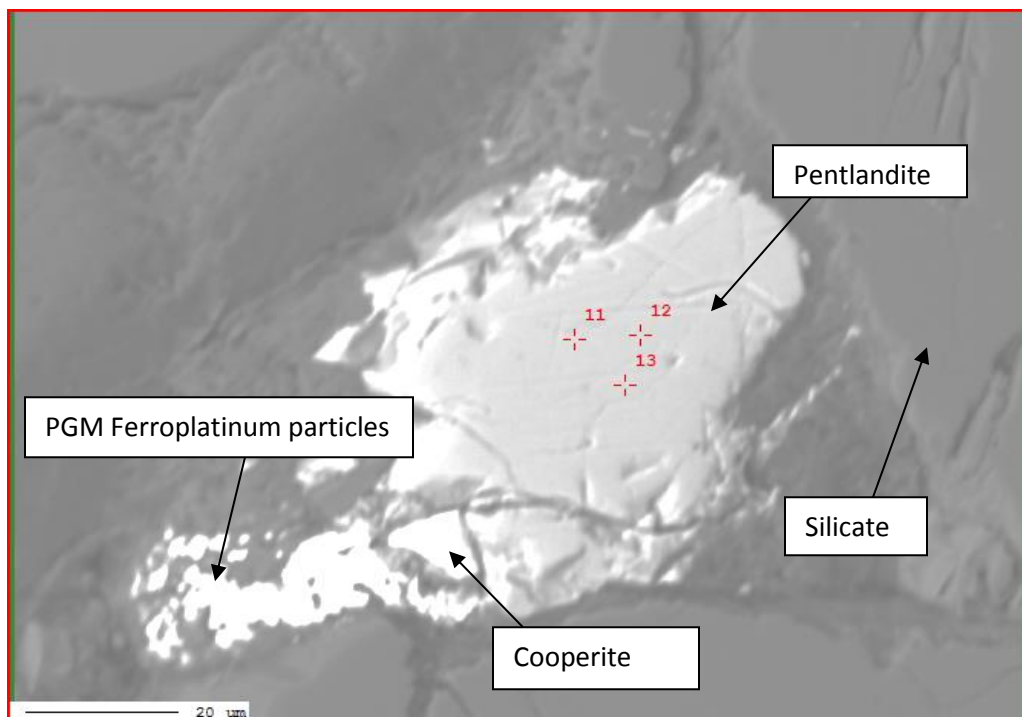


Figure 22. A backscattered electron image of the Pentlandite grain.

Table10. Showing the results of the quantitative analysis.

Point	Name	As %	S%	Fe%	Ni%	Cu%	Co%	Total%
11	Pentlandite	0.008	34.212	30.639	32.154	0.039	1.467	98.519
12	Pentlandite	0	35.066	30.713	31.765	0	1.663	99.207
13	Pentlandite	0	34.828	30.972	33.076	0.016	1.707	100.599

The sulphide in the sample has been identified as a pentlandite. The grain is located in the interstitial silicates. It occurs on the boundary of a PGM phase and other sulphide phases. The size of the sulphide particle is approximately 200 μ m. The pentlandite is clearly associated with the cooperite. There is a PGM-sulphide association in the Bushveld Complex Naldrett and von Gruenewaldt (1989).

Although it is large and well formed, it only occurs as a single phase. No alteration zones were observed in the sample suggesting that the sulphide has not been reworked and thus it is of a primary origin.

The fact that the pentlandite is large (approximately 200 μ m), is well formed and euhedral and occurs on the boundary of a PGM phase and other sulphide minerals points to an intricate magmatic texture. This intricate magmatic texture is of primary nature and is formed during the initial crystallization of the sulphides. It therefore confirms that sulphide is of primary magmatic nature and that it has not been reworked or altered by late-stage circulating fluids.

Only two points were analyzed within sample MAY C1 at points 17 and 18. The quantitative analysis results are shown in table 11.

Table 11. The quantitative analysis results.

Point	Name	As %	S%	Fe%	Ni%	Cu%	Co%	Total%
17	Chalcopyrite	0	36.794	31.145	0.023	32.69	0.036	100.688
18	Chalcopyrite	0.051	36.545	31.318	0.133	32.344	0.011	100.402

The sulphide particles appear to occur as a cluster. Although the particles occur in a cluster, only the main particle was analyzed. The size of the sulphide particle is approximately 30µm. Refer to figure 23.

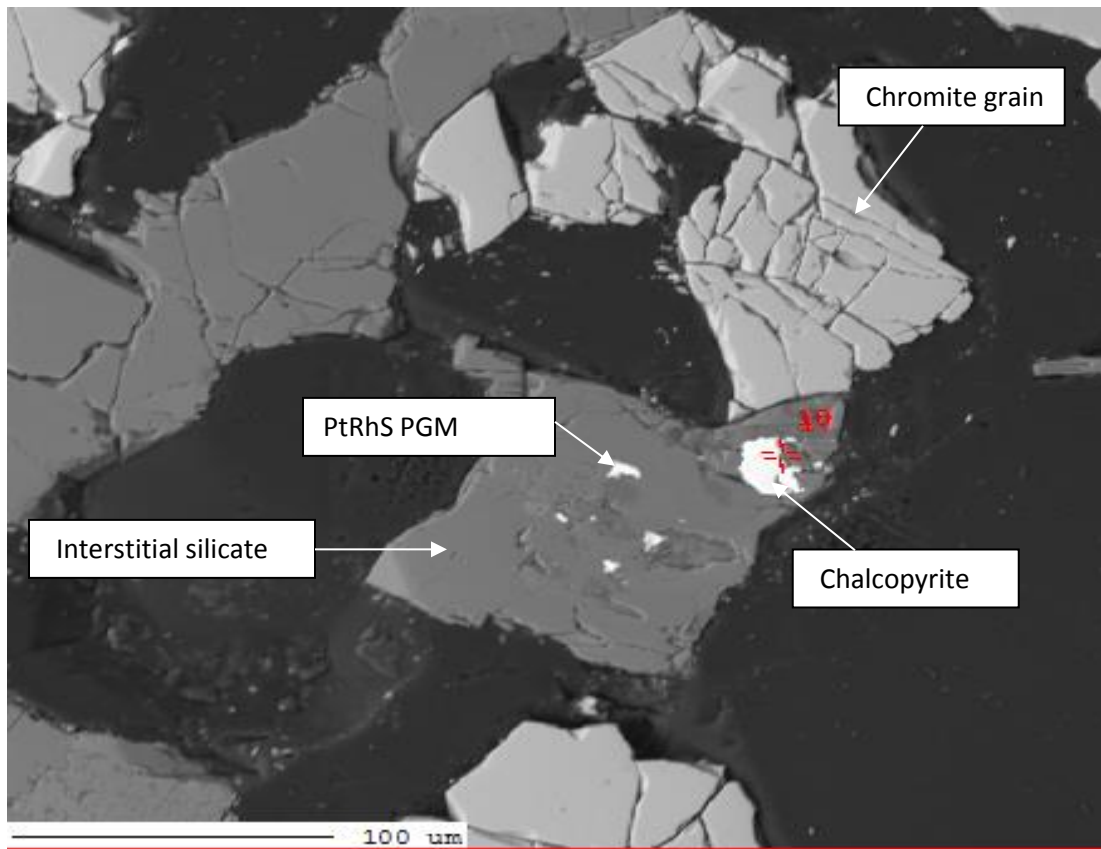


Figure 23. A backscattered electron image sulphide occurrence in sample MAY C1.

The sulphide grains are located within the interstitial silicates. The interstitial silicate is surrounded by closely packed chromite grains. The quantitative analysis has revealed that the sulphide particle is chalcopyrite. Therefore the dominant sulphide assemblage in the sample is chalcopyrite.

The chalcopyrite is well formed and euhedral. It is separate from the other sulphide grains. This intricate magmatic texture is a primary texture formed during the initial crystallization of the sulphides. It therefore confirms that the chalcopyrite has not been reworked or altered by late-stage circulating fluids.

At the May D1 sample, a quantitative analysis has been carried out at Point 4 and 6. The sulphide quantitative analysis results have been summarized in tabular format below and the imagery thereof is provided as figure 24.

Table 12. Showing the results of the sulphide quantitative analysis.

Point	Name	As %	S%	Fe%	Ni%	Cu%	Co%	Total%
4	Chalcopyrite	0.039	35.65	29.917	0	31.983	0.005	97.594
6	Chalcopyrite	0	36.325	30.525	0	32.179	0.009	99.038

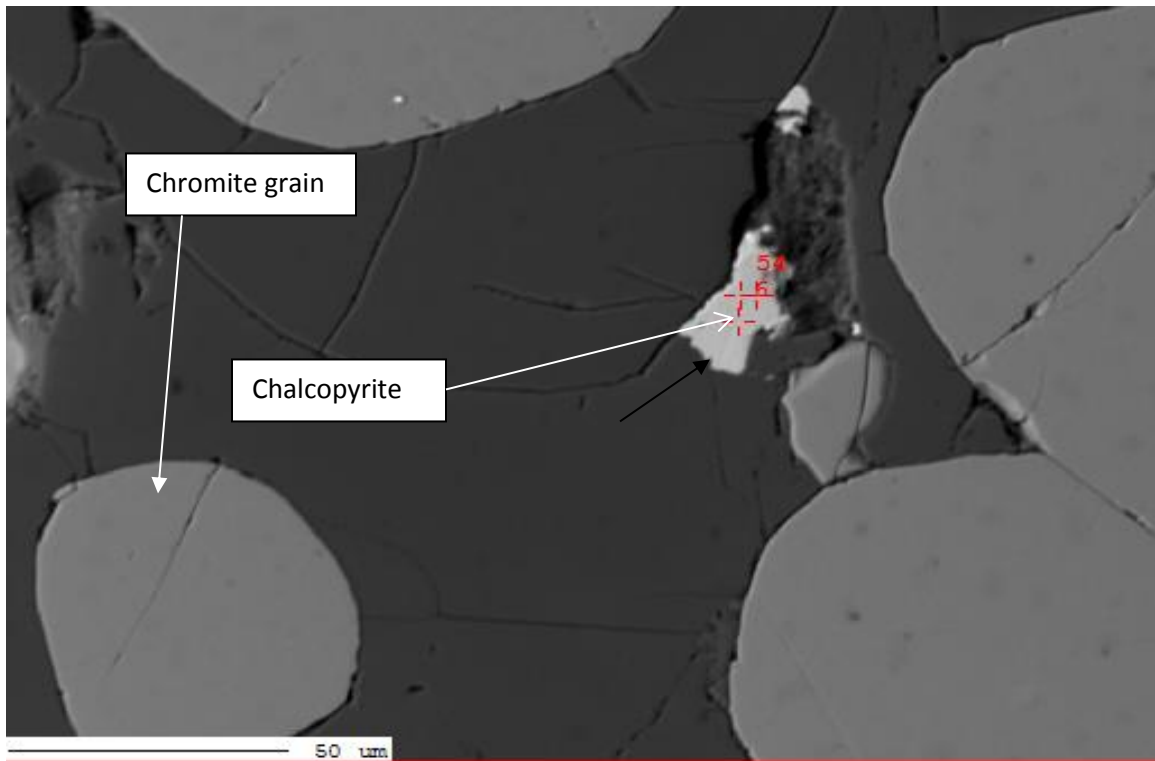


Figure 24. A backscattered electron image of sulphide occurrence in sample MAY D1.

The size of the sulphide particle is approximately 30 μ m. It is located within the interstitial silicates. The quantitative analysis has confirmed that these sulphide particles are chalcopyrite. Therefore the dominant sulphide phase in the sample is chalcopyrite and occurs as a single phase.

This large chalcopyrite well formed euhedral grain appears to be on the boundary of a silicate particle and a chromite grain. This intricate texture suggests that the chalcopyrite is of magmatic nature and may have formed in the initial sulphide crystallization. The chalcopyrite has therefore not have been reworked or altered by late fluids.

A quantitative analysis has been carried out at Point 7, 8 and 9 within sample MAY D2. The sulphide particles appear to occur as a cluster within the interstitial silicates. The results of the quantitative analysis are provided in table 18.

Table 13. Showing the results of the quantitative analysis at point 7 to 9.

Pnt	Name	As %	S%	Fe%	Ni%	Cu%	Co%	Total%
7	Chalcopyrite	0.059	36.354	30.64	0.006	32.033	0.018	99.11
8	Chalcopyrite	0.029	37.041	31.034	0	32.042	0.036	100.182
9	Chalcopyrite	0.042	35.742	30.151	0	32.193	0.03	98.158

The sulphide particles appear to occur as a cluster. The sulphide particles range in size from approximately 10µm up to 30µm, euhedral and are well formed. Refer to figure 25.

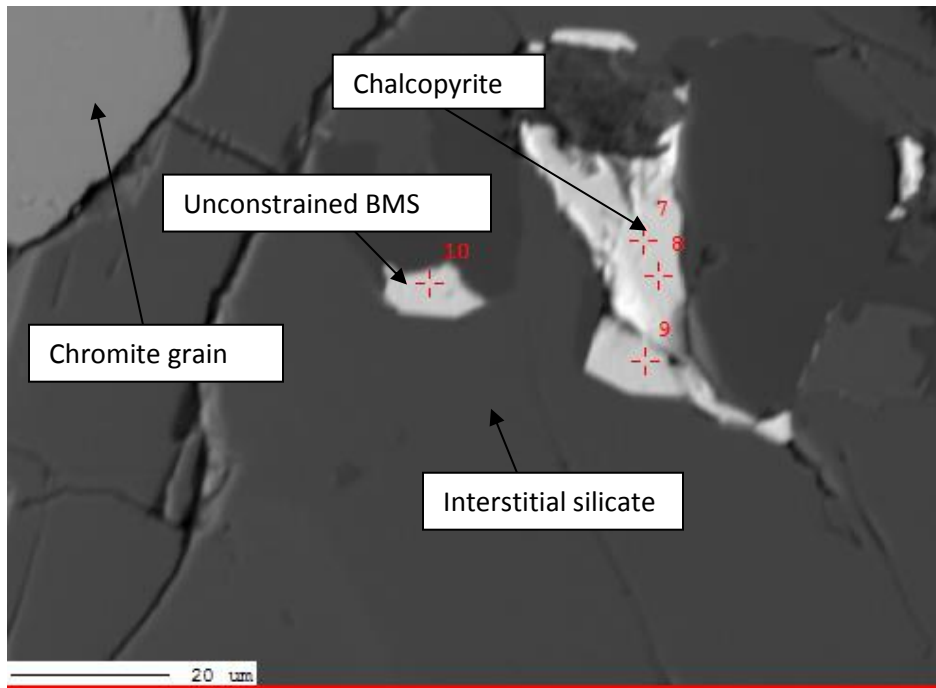


Figure 25. A backscattered electron image of sulphide occurrence in sample MAY D2.

The sulphide grains are located within the interstitial silicates. They are located at the boundaries of silicate grains. The particles have been confirmed to be chalcopyrite during the quantitative analysis. The dominant sulphide phase in the sample is chalcopyrite.

The chalcopyrite at Point 9 occurs along the boundary of the main sulphide at Points 7 and 8. This texture may suggest that the chalcopyrite is of primary magmatic origin and may have formed during the initial crystallization of the sulphides. Therefore there has been no subsequent reworking or alteration of the sulphides by late-stage circulating fluids.

The sulphide is enclosed in a chromite grain in the MAY D3 sample. Refer to figure 30. A quantitative analysis has been carried out at Point 1, 2 and 3.

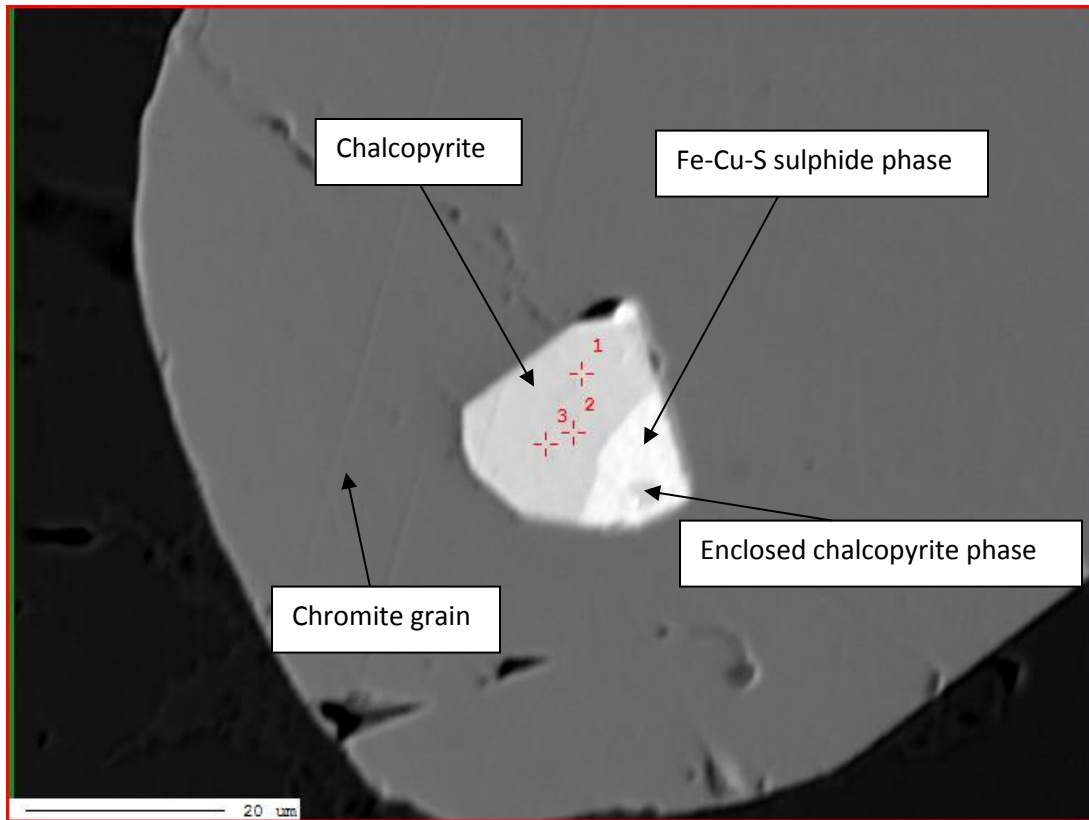


Figure 26. A backscattered electron image of sulphide occurrence in sample MAY D3

The sulphide quantitative analysis results have been summarized in tabular format below

Table 14. Showing the results of the sulphide quantitative analysis.

Point	Name	As %	S%	Fe%	Ni%	Cu%	Co%	Total%
1	Chalcopyrite	0.051	36.068	30.376	0.622	31.382	0.016	98.515
2	Chalcopyrite	0.034	35.904	31.49	0.161	32.081	0.018	99.688
3	Chalcopyrite	0	35.837	30.056	0.369	32.433	0.053	98.748

The size of the chalcopyrite grains is approximately 20μm. The sulphide appears occur as a single phase. It is enclosed within a chromite grain and occurs on the phase boundary of a Fe-Cu-S PGM particle. The sulphide is associated with the Fe-Cu-S PGM grain.

There appear to be another smaller sulphide inclusion within the PGM. The sulphide is less than 5μm. It is highly likely that this sulphide is intergrown with the Fe-Cu-S PGM particle.

The fact that the chalcopyrite occurs along the boundary of the PGM and the likelihood of a sulphide intergrowth within the PGM suggests that the chalcopyrite is of primary magmatic origin and may have formed during the initial crystallization of the sulphides. Therefore there has been no subsequent reworking or alteration of the sulphides by late-stage circulating fluids.

9.3 A brief description of the quantitative analysis of the silicates within the thin sections.

The silicates form the interstitial matrix that binds the chromite grains together. Further they host the sulphides and Platinum group metals. A quantitative analysis of the silicates was carried out in samples MAY B, MAY C and MAY D in order to determine the modal occurrences and the variation patterns of the different elements.

Four points were selected within the MAY B sample for a silicate quantitative analysis, namely points 1-4. Point 1 and 2 are in the vicinity of PGM phases, point 3 is in a mid- chromite grain junction position while point 4 is near the boundary of a chromite grain. Refer to figure 27.

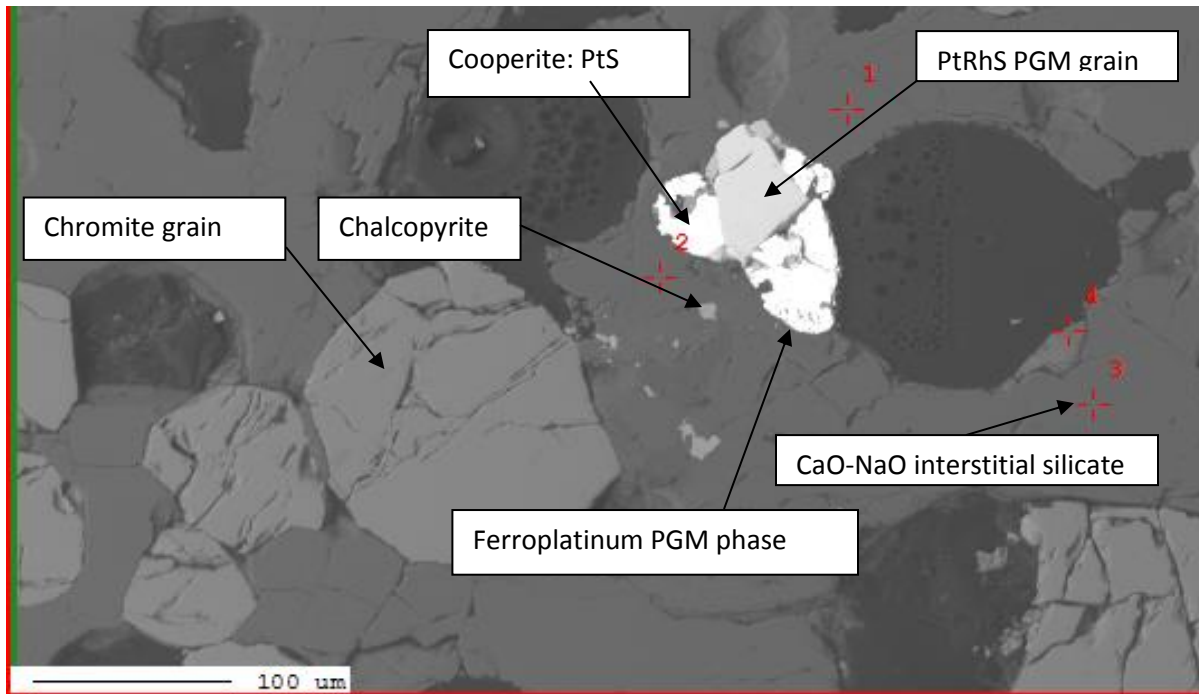


Figure 27. A backscattered electron image of the silicates and the position of the points analyzed in sample B.

The results of the silicate quantitative analysis at Points 1, 3 and 4 are provided below.

Table15. A summary of the quantitative results of plagioclase measurements.

Point	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
1	2.543	49.732	15.78	0.01	0.025	31.914	0.075	0.043	0.005	0	100.127
3	2.993	50.396	15.327	0.064	0.015	31.033	0.054	0.066	0.016	0.028	99.992
4	1.668	46.72	17.019	0.027	0.015	33.38	0	0.027	0	0.018	98.874

The quantitative silicate analysis carried out at the four points show that the silicates at these points have a similar chemical composition. The silicate has a dominant Al₂O₃-CaO- Na₂O assemblage. No MgO-Fe-MnO elements were recorded during the quantification. The Mg values are diagnostic of modal mafic phases. This suggests that the silicate consist purely of plagioclase at this location.

Four points have been selected for the silicate quantity analysis in the MAY C1 sample. Points 11 and 12 are in the vicinity of sulphides and PGMs while Points 13 and 14 are positioned in the silicates that are devoid of mineralisation. Refer to figure 28.

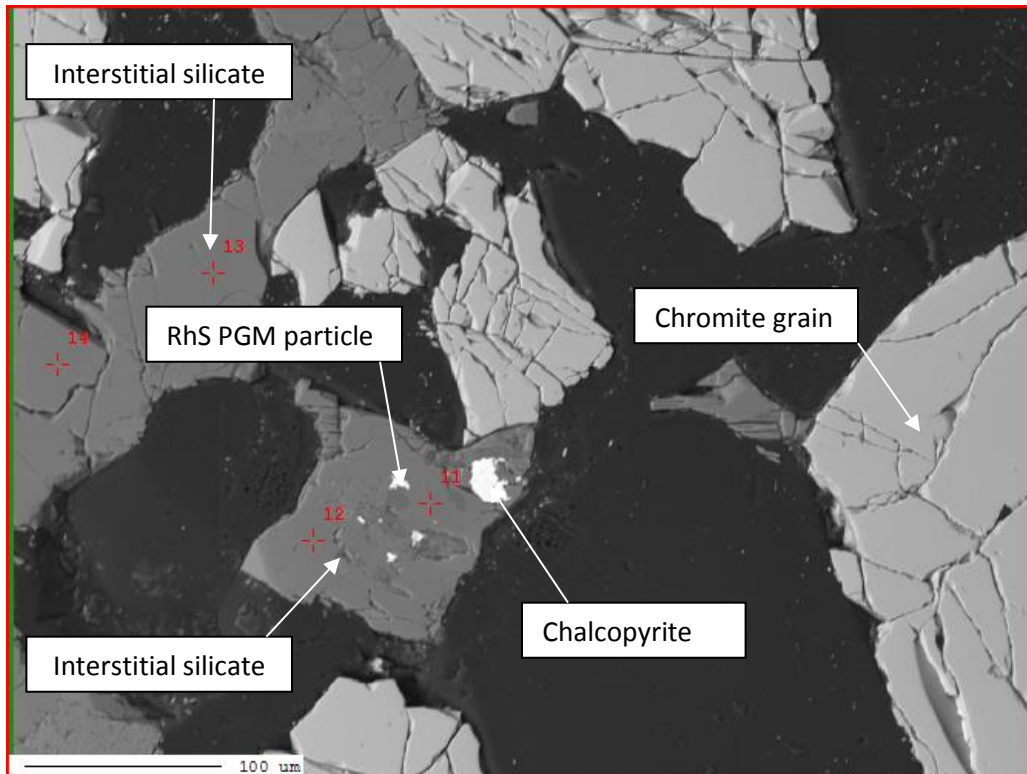


Figure 28. A backscattered electron image of the silicates and the position of the points analyzed in sample C1.

The results of the silicate quantitative analysis at Points 11, 12, 13 and 14 are provided below.

Table16. A summary of the plagioclase quantitative results.

Point	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
11	1.952	47.735	17.001	0.083	0.02	32.498	0.176	0.02	0.018	0	99.503
12	1.92	46.948	17.042	0.032	0.026	32.316	0	0.022	0	0.029	98.335
13	3.708	51.693	13.832	0.079	0.015	30.202	0.136	0.058	0	0.026	99.749
14	2.885	50.173	15.521	0.053	0.015	31.61	0.149	0.023	0.006	0.027	100.462

A quantitative silicate analysis was carried out at an area in which the silicate hosts phases of base metal sulphide. The SiO₂-Al₂O₃-CaO-NaO is the dominant assemblage within the sample. The presence of the Al₂O₃-CaO- Na₂O assemblage is sharply contrasted by the absence of MgO-FeO-MnO assemblage in the sample. These assemblages are known to strongly partition into plagioclase and orthopyroxene respectively. The occurrence of Al₂O₃-CaO- Na₂O elements suggests the modal abundance of plagioclase.

The mass percent of the CaO elements in the samples that are in the vicinity of the PGE sulphides is 2 mass % higher than of the silicate that are devoid of PGE sulphides. This could suggest a slight modal variation of plagioclase at Points 11 and 12.

Three points were selected within the MAY C2 sample for a silicate quantitative analysis, namely points 15, 16 and 17. All the three points are surrounded by numerous grains of chromite. Refer to figure 29.

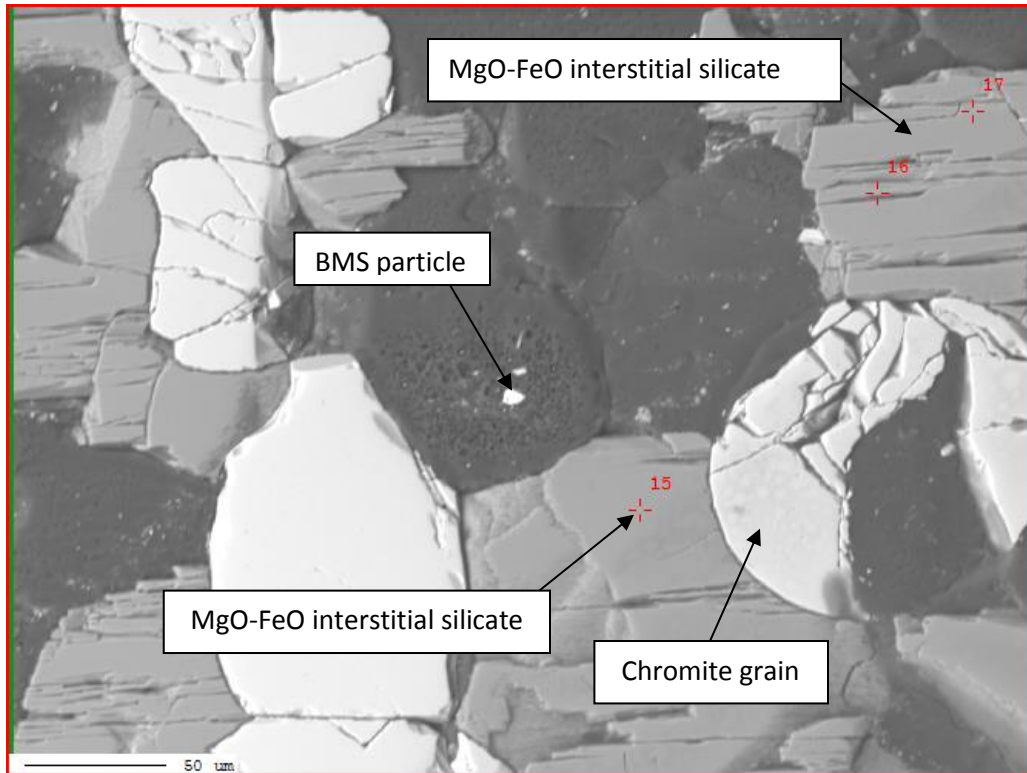


Figure 29. A backscattered electron image of the silicates and the position of the points analyzed in sample C2.

The results of the silicate quantitative analysis at Points 15, 16, and 17 are provided below.

Table 17. A summary of the orthopyroxene quantitative results

Point	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
15	0.024	57.196	0.411	0.263	34.088	0.893	6.817	0.007	0.096	0.009	99.804
16	0	57.932	0.321	0.286	34.962	1.029	7.015	0.004	0.112	0.161	101.822
17	0	57.142	0.373	0.358	33.694	1.204	6.933	0.007	0.121	0.186	100.018

All the three points show a SiO₂-MgO-FeO assemblage. The mass percentage of The Al₂O₃-CaO- Na₂O ranges is rare in this sample and thus it occurs as minor elements. The Mg values are diagnostic of mafic phases such as pyroxene while the Ca-Na contents suggest the modal occurrences plagioclase. The manifestation of MgO and FeO within the sample suggests the modal abundance of orthopyroxene.

A total of 6 points were selected within the MAY C3 sample for a silicate quantitative analysis, namely points 18-23. Points 18, 19 and 20 are in the proximal vicinity of a PGM phase while points 21, 22 and 23 are located distally. Refer to 30.

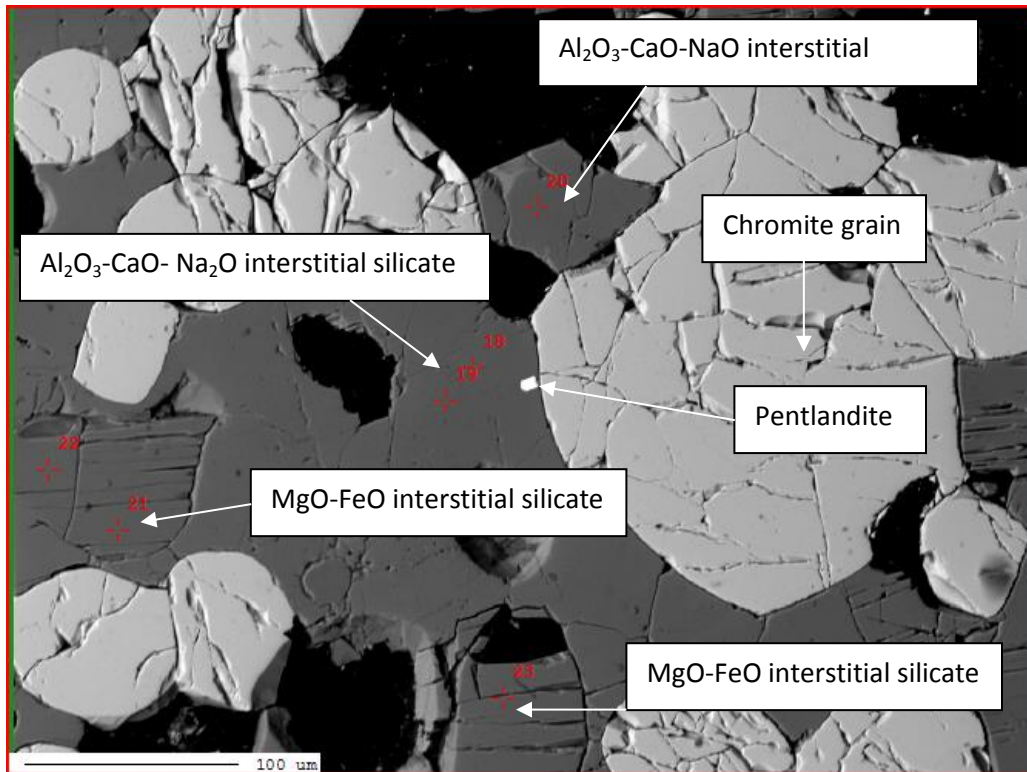


Figure 30. A backscattered electron image of the silicates and the position of the points analyzed in the sample MAY C3.

The results of the silicate quantitative analysis at Points 18, 19, 20, 21, 22 and 23 are provided below.

Table 18. A summary of the silicate quantitative results

Point	Mineral	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
18	Plag	1.606	47.602	17.531	0.082	0.008	32.801	0.136	0.028	0	0	99.794
19	Plag	2.545	49.407	15.585	0	0	31.681	0.122	0.041	0	0.017	99.398
20	Plag	3.334	51.235	14.73	0.114	0.013	30.883	0	0.059	0	0.033	100.401
21	Oxp	0.027	56.934	0.533	0.505	33.94	1.292	6.989	0.004	0.117	0.246	100.587
22	Oxp	0.008	57.072	0.655	0.325	33.985	1.218	7.121	0.01	0.123	0.184	100.701
23	Oxp	0	56.699	0.586	0.402	33.666	1.241	6.778	0	0.141	0.18	99.693

Plag=plagioclase and oxp=orthopyroxenite

The quantitative analysis at Point 18, 19 and 20 show a dominant $\text{Al}_2\text{O}_3\text{-CaO- Na}_2\text{O}$ assemblage. There is a perfect contrast between MgO-FeO-MnO and $\text{Al}_2\text{O}_3\text{-CaO-Na}_2\text{O}$. The $\text{Al}_2\text{O}_3\text{-CaO- Na}_2\text{O}$ is dominant suggesting that there is an abundance of plagioclase in this sample.

Further, the silicate at Points 21, 22 and 23 exhibit a $\text{SiO}_2\text{-MgO-FeO}$ assemblage with minor $\text{Al}_2\text{O}_3\text{-CaO- Na}_2\text{O}$ presence. The value of Mg suggests that the modal abundance of orthopyroxene in the sample.

In this instant the silicate quantitative analysis was carried out at points 32, 33 and 34 within sample MAY C4. The silicates are located between chromite grains and host a PGM particle. Refer to figure 31.

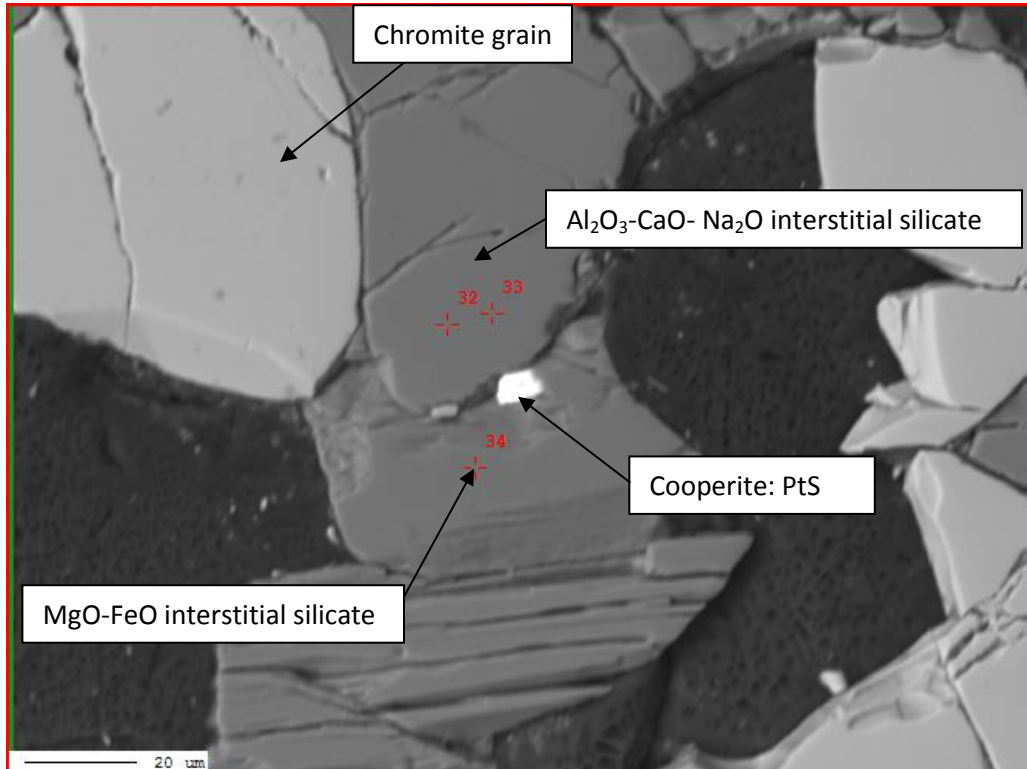


Figure 31. A backscattered electron image of the silicates and the position of the points analyzed in sample MAY C4.

Table 19. A summary of the quantitative results.

Point	mineral	Na_2O	SiO_2	CaO	Cr_2O_3	MgO	Al_2O_3	FeO	K_2O	TiO_2	MnO	TOTAL
32	Plag	2.993	49.959	15.471	0.049	0.019	31.305	0.169	0.033	0.013	0	100.011
33	Plag	2.927	49.697	15.347	0.093	0.011	31.375	0.244	0.031	0.019	0	99.744
34	Oxp	0	57.167	0.341	0.393	34.574	1.184	6.554	0.01	0.124	0.191	100.538

The silicate above the PGM is represented by Point 32 and 33 have a dominant SiO_2 - Al_2O_3 - CaO - Na_2O assemblage. There is a sharp contrast in the presence of MgO - FeO and Al_2O_3 - CaO - Na_2O .The amount of Al_2O_3 is about 31, 3 % while MgO is rare The Al_2O_3 - CaO - Na_2O is dominant, suggesting that there is an abundance of plagioclase in this sample.

The silicate below the PGM phase denoted by Point 34 exhibits a SiO_2 - MgO - FeO assemblage with minor Al_2O_3 with a mass % of 1.184. The elements MgO - FeO suggest the modal abundance of orthopyroxene.

The silicate quantitative analysis was carried out at points 35, 36, 37 and 38 in the MAY C5. Refer to figure 32.

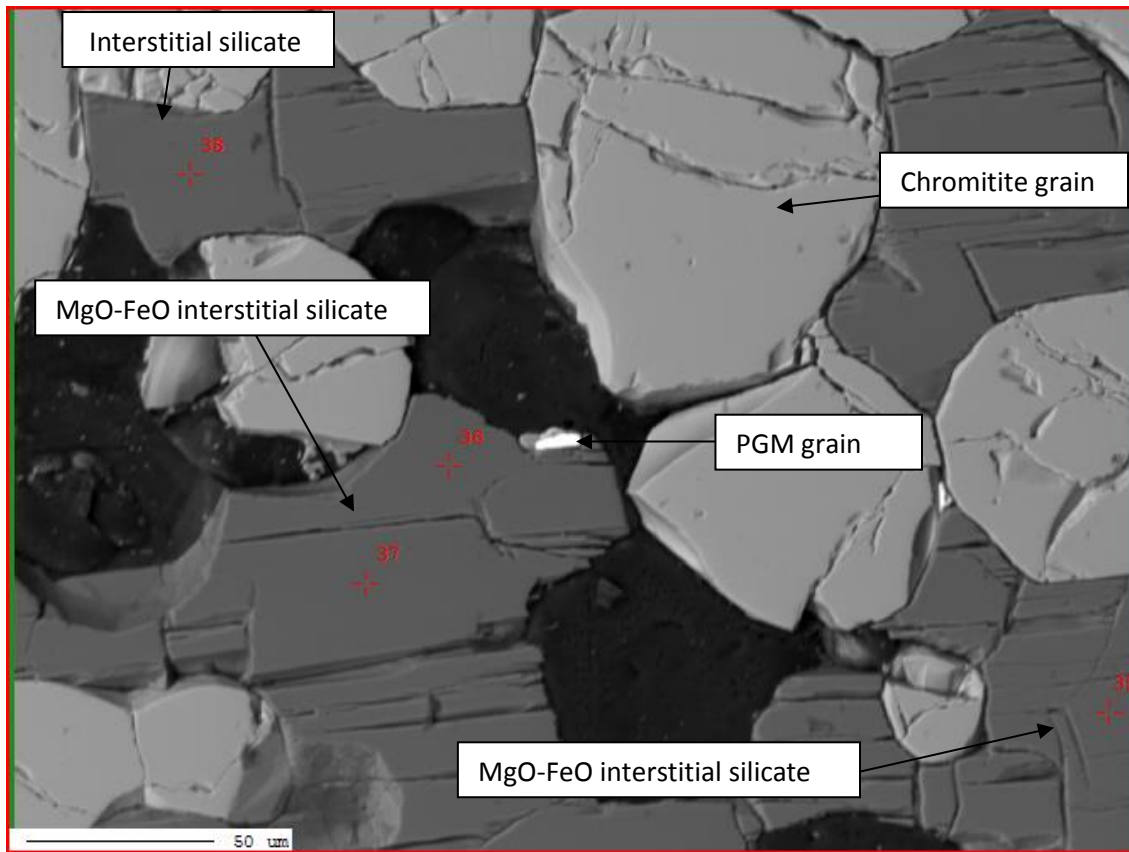


Figure 32. A backscattered electron image of the silicates and the position of the points analyzed in sample MAY C5.

The results of the silicate quantitative analysis at Points 11, 12, 13 and 14 are provided below.

Table 20. A summary of the orthopyroxenite quantitative results

Point	Na_2O	SiO_2	CaO	Cr_2O_3	MgO	Al_2O_3	FeO	K_2O	TiO_2	MnO	TOTAL
35	0.016	56.984	0.43	0.397	33.868	1.218	6.859	0.005	0.115	0.213	100.105
36	0	55.928	0.301	0.401	33.913	1.139	6.709	0.002	0.116	0	98.509
37	0.019	56.655	0.406	0.366	33.852	1.061	7.115	0.014	0.093	0	99.581
38	0.001	57.072	0.241	0.542	34.508	1.039	6.649	0.005	0.155	0.002	100.214

The sample denotes a SiO₂-MgO-FeO-Al₂O₃ assemblage with a dominance of SiO₂-MgO in which FeO occurs at about 6 % and Al₂O₃ is relatively minor at about 1%. The dominance of MgO over Al₂O₃-Na₂O-CaO as well as the presence of FeO suggests the modal abundance of orthopyroxene in the sample.

The silicate quantitative analysis was carried out at silicates in the vicinity of PGE sulphides at Points 26, 27, 28 and 29 within the MAY C6. Refer to figure 27.

The results of the silicate quantitative analysis at Points 26, 27, 28 and 29 are provided below.

Table 21. A summary of the silicate quantitative results.

Point	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
26	3.982	52.171	13.375	0.055	0.03	29.724	0.102	0.059	0.018	0.004	99.52
27	3.957	51.723	13.559	0.034	0.024	29.888	0	0.067	0.016	0	99.268
28	8.206	71.648	0.102	0.029	0.018	19.622	0.163	0.035	0	0	99.823
29	9.509	71.633	0.227	0.069	0	19.838	0.081	0.026	0.002	0	101.385

The mass % of Al₂O₃-CaO- Na₂O and MgO-FeO-MnO are perfectly contrasted in all the analyzed points within the sample. The Al₂O₃-CaO- Na₂O elements strongly suggest the modal abundance of plagioclase in the sample. Further, CaO is present at Points 26 and 27 while it is absent at Point 28 and 29. Contrasting this mode of occurrence is the lower mass % of Na₂O at point 26 and 27 while a higher mass % is recorded at Points 28 and 29. The Na₂O/CaO contrast suggests a compositional variation of plagioclase.

The SiO₂ content is approximately 20% higher at Point 28 and 29 in comparison with the SiO₂ content at Point 26 and 27. Although SiO₂ partitions into both orthopyroxene and plagioclase, it does so more favourably into the former. Therefore, the SiO₂ content may be tracking the modal variation of orthopyroxene in this sample since there are indications that the plagioclase is sodic at those points.

A total of 6 points were selected within the MAY D sample for a silicate quantitative analysis. The positions of the points are shown in figure 38. The interstitial silicates form the matrix that binds the chromite grains together. A PGM phase is enclosed in one of the chromite grains. Refer figure 33.

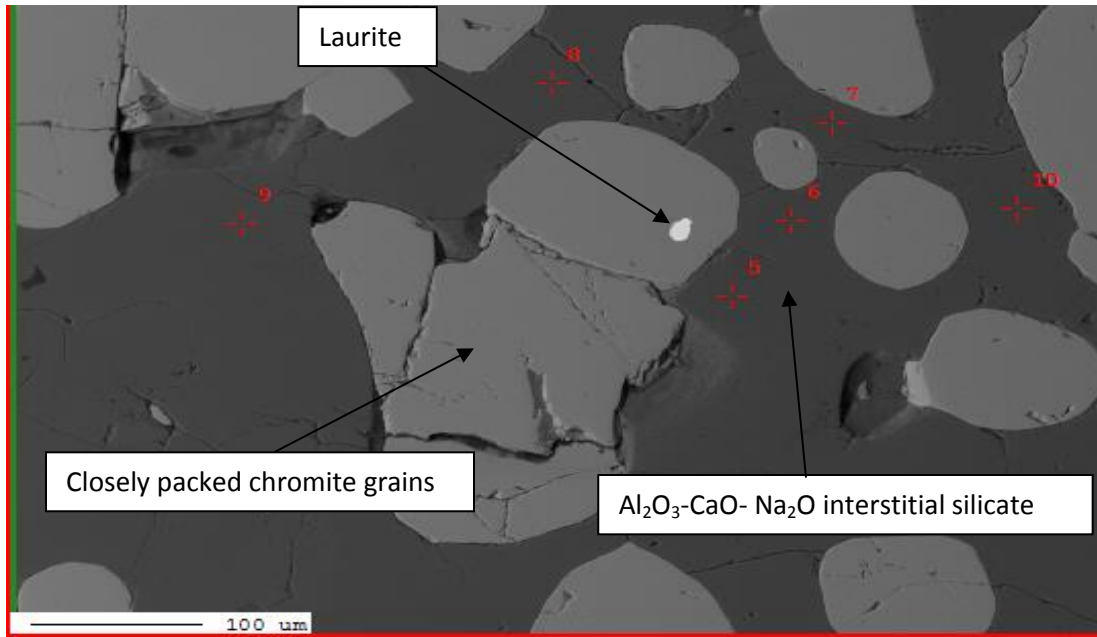


Figure 33. A backscattered electron image of the interstitial silicate, chromite grains and a PGM phase in sample MAY D.

The results of the silicate quantitative analysis are provided in a tabular format below.

Table 22. A summary of the plagioclase quantitative results.

Point	Na ₂ O	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	K ₂ O	TiO ₂	MnO	TOTAL
5	3.468	51.21	14.178	0.127	0.01	30.303	0.095	0.067	0.007	0.004	99.469
6	3.512	51.581	14.046	0.11	0.006	30.232	0.088	0.059	0.032	0	99.666
7	3.712	52.141	13.721	0.261	0.003	30.013	0.163	0.054	0.018	0.013	100.099
8	3.803	51.881	13.978	0.106	0.019	30.124	0.068	0.077	0.025	0.024	100.105
9	3.881	52.035	13.894	0.028	0.021	30.16	0.129	0.054	0.008	0	100.21
10	3.883	51.961	13.956	0.163	0.019	30.022	0.041	0.046	0.007	0.011	100.109

The silicate mass % quantities show a SiO₂- Al₂O₃-CaO- Na₂O assemblage in which SiO₂ and Al₂O₃ are dominant with 52 and 30 mass % respectively. No amounts of MgO, FeO, K₂O and MnO have been recorded during the analysis.

The presence of Al₂O₃-CaO- Na₂O is sharply contrasted by the rare existence of MgO-FeO-TiO₂-MnO elements in the sample. The Mg values are diagnostic of mafic phases while the Ca-Na contents suggest the modal occurrences of plagioclase. Therefore the dominance of Al₂O₃-CaO- Na₂O suggests the modal abundance of plagioclase within this sample.

9.4 A brief quantitative analysis of the Oxides in MAY B to MAY D samples.

This section deals with the quantification and characterization of the Oxides of the UG3 chromitite seam. Oxides are the major elements constituting chromite grains. The aim is to establish whether there are compositional differences in the various generations of the chromite grains.

Two chromite grains were analyzed at sample MAY B for their oxide quantities. The oxides quantitative analysis was carried out at three locations namely point1, 2 and point3. The chromite grain at point1 and 2 is 150um large while chromite grain 3 is 100um in size. Refer to figure 34.

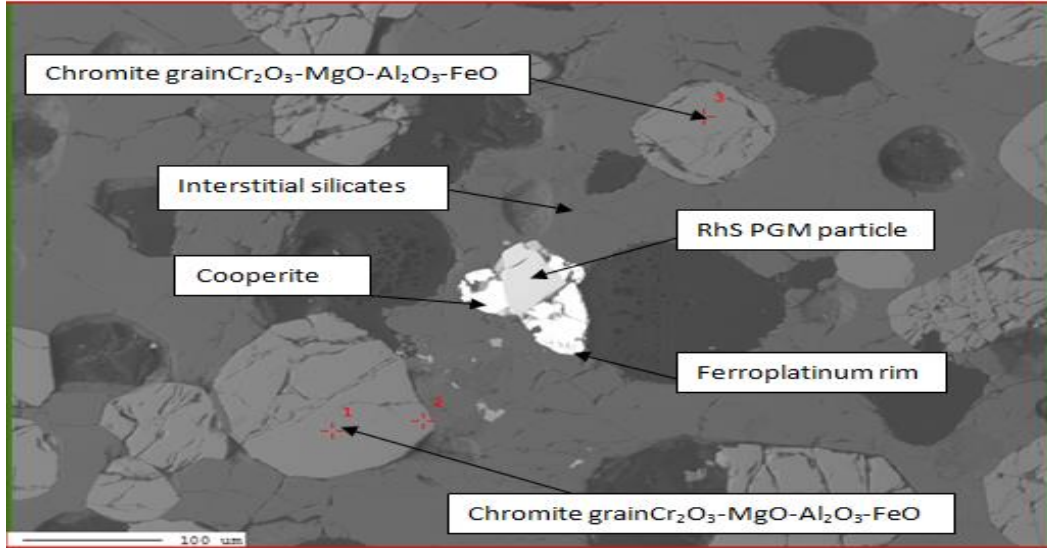


Figure 34. A backscattered electron image of chromite grains showing points at which quantitative analyses of the oxides were carried out at sample MAY B.

The oxide quantification was carried out almost in the middle of the chromite grain at point1 and point3 while at point2 it was done on the rim of the grain. The results of the quantitative analysis are provided in the table below.

Table 23. Showing the chemical mass % compositions of the chromite grains at point 1, 2 and 3.

Point	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	NiO	TiO ₂	MnO	V ₂ O ₃	TOTAL
1	0.068	0	46.915	9.162	15.398	28.174	0.11	0.765	0.3	0.456	101.348
2	0.04	0.067	45.617	8.718	15.241	27.611	0.204	0.662	0.333	0.444	98.937
3	0.037	0.006	46.177	9.217	15.165	27.747	0.307	0.832	0.33	0.453	100.271

The analysis has revealed that the two chromite grains have the same chemical composition despite their different sizes. Further, it has also observed that the core of the chromite grain at point1 and the rim of the grain have the same chemical composition as well.

The chromite grain analyzed within the MAY C1 is approximately 150um, well formed and irregular. The chromite grain appears to be part of a number of closely packed chromite grains. Refer to figure 35.

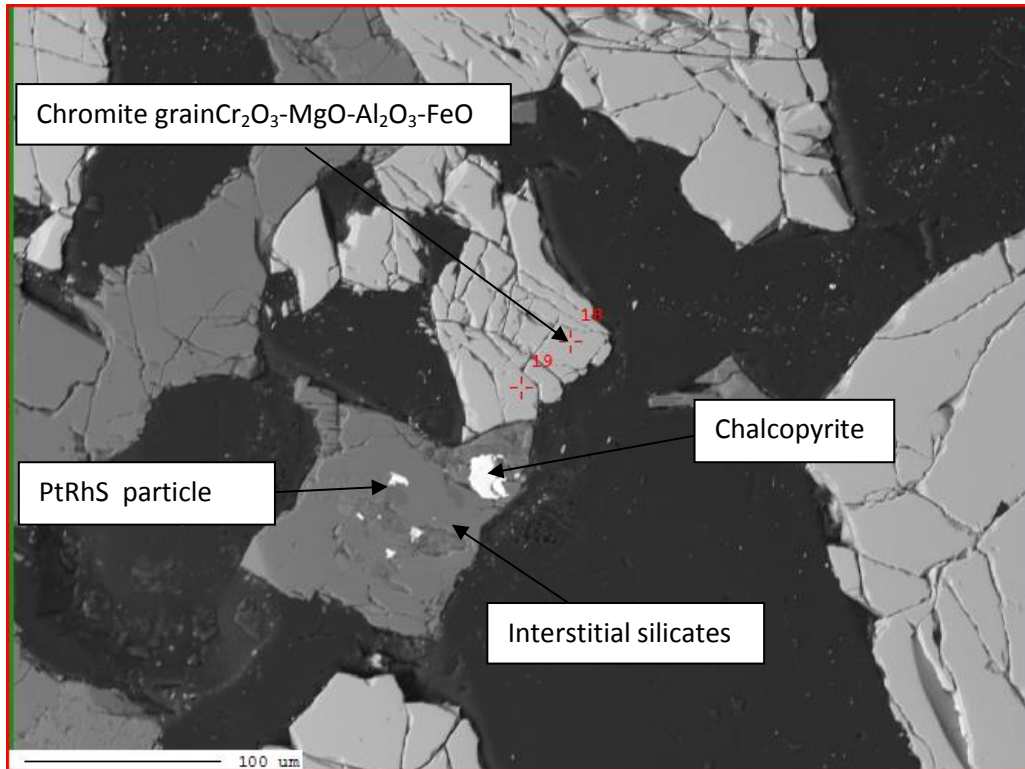


Figure 35. A backscattered electron image of an irregular chromite grain.

The results of the quantitative oxides analysis is provided below.

Table 24. Showing the chemical mass % compositions of the chromite grains at point 18 and 19.

Point	SiO2	CaO	Cr2O3	MgO	Al ₂ O ₃	FeO	NiO	TiO2	MnO	V ₂ O ₃	TOTAL
18	0.019	0.028	45.124	9.287	15.991	27.562	0.323	0.845	0.355	0.486	100.02
19	0.021	0.043	44.662	9.31	16.241	28.078	0.213	0.822	0.363	0.459	100.212

The chemical composition of the chromite grains is similar irrespective of the shape.

Two chromite grains were analyzed at sample MAY C2 for their oxide quantities. The oxides quantitative analyses were carried out within chromite grains of different shapes. The chromite grain at point 20 has an irregular shape and is approximately 60um large while the chromite grain at point 21 is sub-rounded and about 70um in size. Both chromite grains occur within the interstitial silicate. Refer to figure 36.

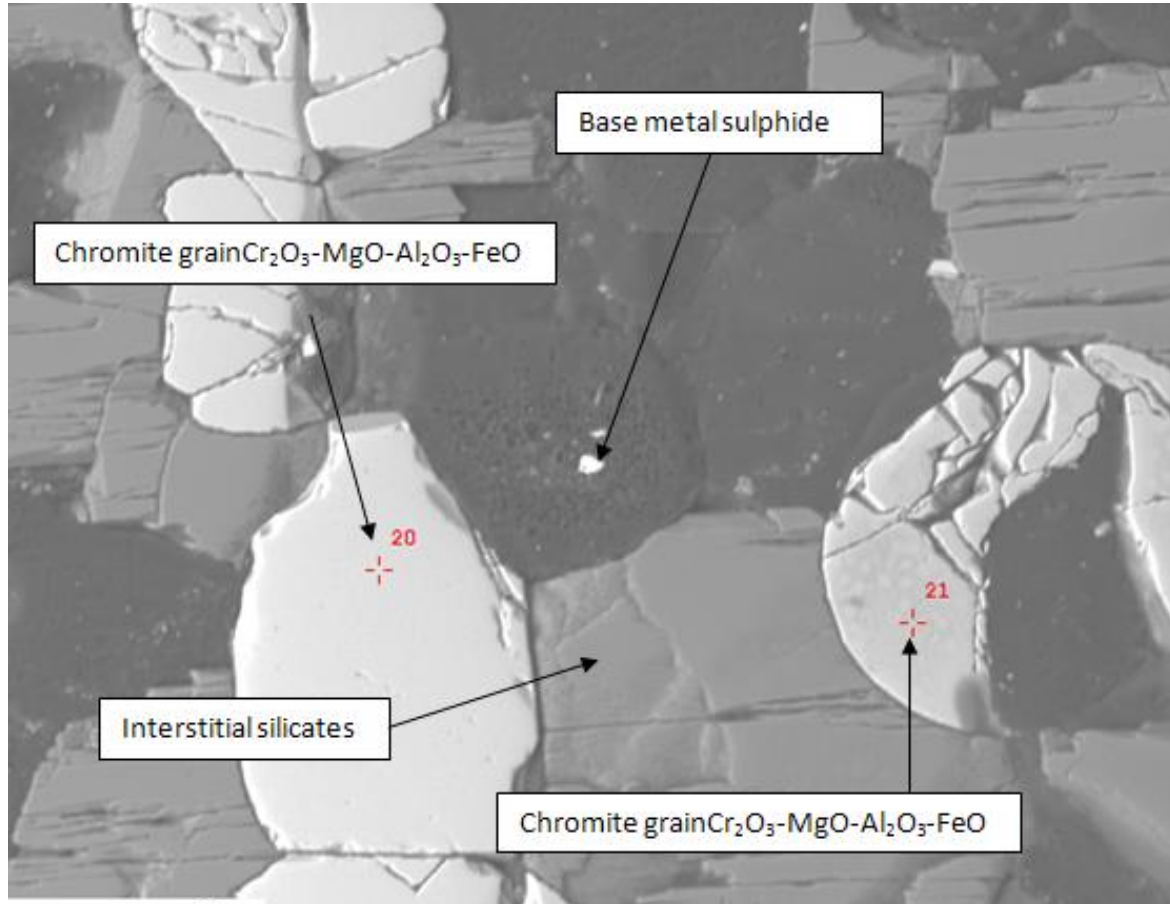


Figure 36. A backscattered electron image of the chromite grains analyzed.

The grain's chemical composition is shown in the table below.

Table 25. Showing the chemical mass % compositions of the chromite grains at points 20 and 21.

Point	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	NiO	TiO ₂	MnO	V ₂ O ₃	TOTAL
20	0.029	0.004	45.397	9.131	15.855	27.956	0.126	0.767	0.28	0.461	100.006
21	0.03	0.012	43.314	8.897	15.275	27.114	0.016	0.774	0.36	0.433	96.225

The chemical composition of the chromite grains is similar, regardless of their different shape and size.

Three chromite grains were analyzed at sample MAY C3 for their oxide quantities. The chromite grains appear to have a closed packing structure within the interstitial silicates. Refer to figure 37.

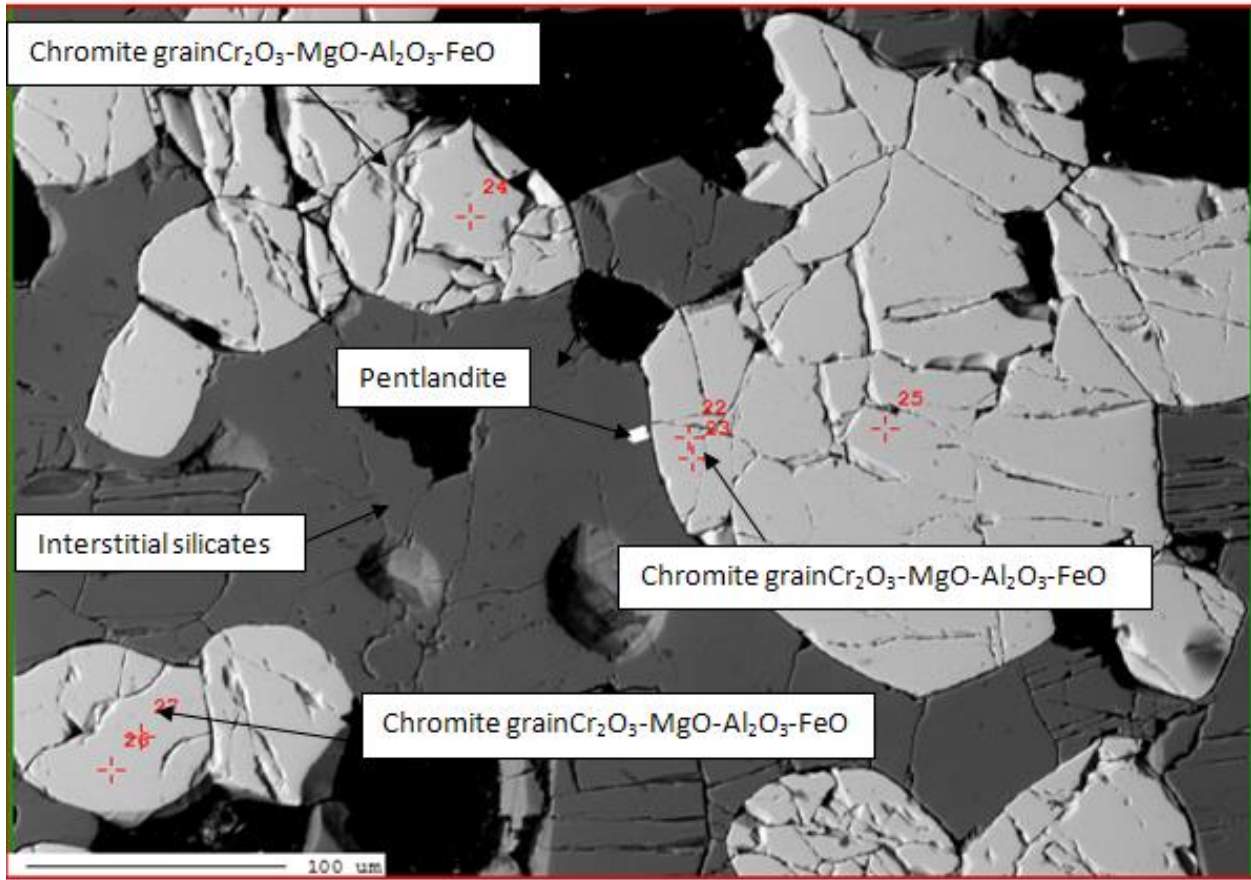


Figure 37. A backscattered electron photographic image of chromitite grains and pentlandite.

Chromite grain at points 26 and 27 is about 60µm large while the chromite grain at point 22, 23 and 25 is approximately 200µm and Chromite grain at point 24 is about 100µm large. They are all well formed and euhedral. A pentlandite phase occurs at the boundary of the chromite grain at point 22, 23 and 25. The results of the quantification analysis are provided below.

Table 26. Showing the chemical mass % compositions of the chromite grains.

Point	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	NiO	TiO ₂	MnO	V ₂ O ₃	TOTAL
22	0.036	0.09	45.469	9.185	15.359	27.884	0.181	0.783	0	0.455	99.442
23	0.026	0.07	46.143	9.066	15.672	27.993	0.181	0.78	0.343	0.484	100.758
24	0.015	0	45.591	8.969	14.894	28.694	0.299	0.758	0.303	0.469	99.992
25	0.036	0	45.924	9.076	15.309	28.107	0.103	0.806	0.404	0.447	100.212

26	0.016	0.029	45.896	9.026	15.178	26.764	0.071	0.799	0.372	0.46	98.611
27	0	0.008	45.806	8.989	15.077	27.774	0.221	0.779	0.255	0.461	99.37

Although the larger chromite grain is in the proximity of a PGM particle, it has a similar chemical composition as the other two grains. There is a perfect contrast between Ca and Mg. The presence of Mg strongly suggests that the analyzed crystal is mafic.

Three chromite grains were analyzed at sample MAY C5 for their oxide quantities. The oxides quantitative analyses were carried out at three locations as shown in figure 38.

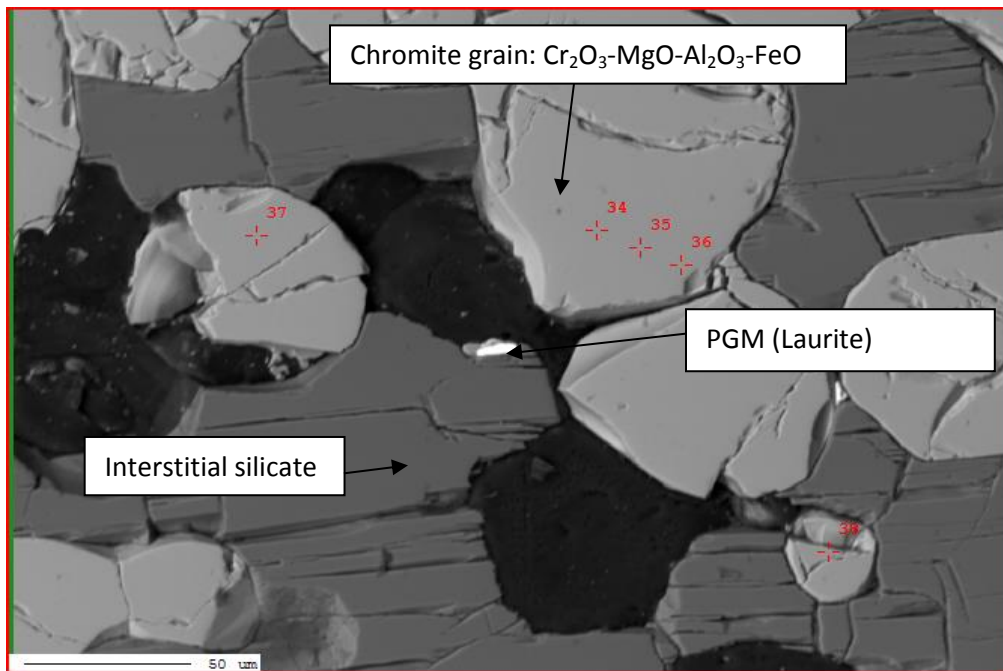


Figure 38. A backscattered electron image of chromite grains showing points at which quantitative analyses of the oxides were carried out in sample MAY C5.

A quantification analysis of oxides was carried out at point 37. The chromite grain at this location is about 60µm large and almost rounded. At points 34 to 36 the chromite grain is about 200µm in size and euhedral. The chromite grain at point 38 is approximately 50µm in size. It is relatively the smallest grain in the sample. The results of the quantification analysis are provided below.

Table 27. Showing the chemical mass % compositions of the chromite grains.

Point	SiO ₂	CaO	Cr ₂ O ₃	MgO	Al ₂ O ₃	FeO	NiO	TiO ₂	MnO	V ₂ O ₃	TOTAL
34	0.016	0	45.557	9.327	16.21	27.609	0.268	0.718	0	0.472	100.177

35	0	0	45.829	9.191	15.871	26.168	0.142	0.75	0.273	0.476	98.7
36	0.027	0.009	45.665	9.003	15.859	26.439	0.008	0.717	0	0.422	98.149
37	0	0.008	45.706	9.09	15.731	26.693	0.181	0.717	0.352	0.437	98.915
38	0.199	0.077	44.458	8.234	14.575	26.782	0.417	0.651	0.32	0.506	96.219

Chromite grain at point 38 is relatively smaller than the chromite grain at point 37 and at points 34 - 36. However, despite their differences in size, they possess a similar chemical composition. The Mg values are diagnostic of mafic phases while the Ca-Na contents suggest the modal occurrence plagioclase. The quantitative results indicate a perfect contrast between CaO and MgO. No amount of CaO has been recorded while MgO does exist. The occurrence of Mg suggests the modal mafic phases. All the chromite grains have the same chemical composition regardless of their different sizes.

The chromite grain was analyzed at sample MAY C6 for their oxide quantities. The oxides quantitative analyses were carried out at two locations.

The well formed, euhedral chromite grain is about 60µm large. The chromite grain was analyzed the core as well as at its rim. It occurs within interstitial silicate and is attached to other chromite grains. The grain is located in the vicinity of PGM and sulphide phases. Refer to figure 27.

Table 28. Showing the chemical mass % compositions of the chromite grain.

Point	SiO2	CaO	Cr2O3	MgO	Al2O3	FeO	NiO	TiO2	MnO	V2O3	TOTAL
28	0	0	45.783	8.975	15.249	27.732	0.055	0.862	0.385	0.456	99.497
29	0.495	0.055	43.938	10.376	16.931	27.954	0.126	0.526	0.272	0.418	101.091

Chromite grain and its rim have a similar mass % chemical composition. Modal mafic crystals occur at both locations. The occurrence of the Mg value is diagnostic of mafic phases.

A total of eight chromite grains were analyzed within sample MAY D for their oxide quantities. The oxides quantitative analyses were carried out at points 4 up to 16. Refer to figure 37.

Chromite grains were analyzed at location in which they are part of closely packed structure, at the core of the grain, at the rim, and where they occur within a triple junction. The analytical results thereof are provided in the table below.

Table 29. Showing the chemical mass % compositions of the chromite grains.

Point	SiO2	CaO	Cr2O3	MgO	Al2O3	FeO	NiO	TiO2	MnO	V2O3	TOTAL
4	0.021	0	45.985	9.153	15.342	26.941	0	0.817	0.33	0.444	99.033

5	0.02	0.004	45.868	9.177	15.283	26.554	0	0.78	0.337	0.404	98.427
6	0.022	0	46.027	9.106	15.439	27.966	0.031	0.682	0.359	0.438	100.07
7	0.01	0.007	46.006	9.345	15.279	27.329	0.016	0.774	0.3	0.437	99.503
8	0.013	0.058	46.24	9.168	14.827	27.093	0	0.654	0.368	0.446	98.867
9	0.143	0.247	45.457	9.339	15.27	27.743	0.031	0.655	0.317	0.419	99.621
10	0.009	0	45.347	9.194	15.895	27.525	0.22	0.809	0.325	0.406	99.73
11	0.047	0	45.17	9.392	15.907	27.746	0.016	0.849	0.285	0.461	99.873
12	0.015	0.068	46.104	9.2	15.588	27.467	0.197	0.766	0.337	0.428	100.17
13	0.013	0.024	45.892	9.164	15.589	27.291	0.15	0.812	0.356	0.439	99.73
14	0.053	0.179	44.615	9.013	15.636	27.993	0.291	0.759	0.315	0.464	99.318
15	0.039	0	45.377	9.351	15.998	27.463	0.063	0.696	0.31	0.454	99.751
16	0.006	0	44.916	9.297	16.001	27.766	0	0.836	0.278	0.432	99.532

All the chromite grains within the MAY D sample, despite their mode of occurrence, possess a similar chemical composition. There is a perfect contrast between the value of Ca and Mg elements. The Ca mass % is zero while the MgO mass% is about 9%. This suggests the modal abundance of mafic phases.

10. Discussion.

The mining of the UG2 open pit commenced in August 2010 and was completed in December 2012. The UG2 open pit operation yielded about 1086421 tons of UG2 ore at an average grade of 4.5g/t. An operational cash profit of R313455000 was declared.

During the mining of the UG2 chromite seam in an open pit operation, the UG3 was mined out and discarded as waste. Based on the exploration report, the UG3 have an insitu value of 2.5g/t. A UG3 chromite seam sampling exercise recently carried out at the South2 material decline yielded an in situ value of 3.15g/t. This confirms that the UG3 chromite seam have a potential good grade. The drilling, surface and underground mapping of the UG3 also confirms that the seam is laterally extensive.

The financial valuation of the UG3 chromite ore within the first Modikwa UG2 open pit indicate that the extraction and milling of the UG3 would have generated an operating cash profit of approximately R122 million. The inclusion would have resulted in a higher operating cash profit of R435889444 for the original pit and contributed to the optimization of the value of the ore reserves in the pit.

There are four UG2 pits namely Onverwacht Hill, North, Concentrator and the South3 open pit that are going to be mined in the near future. The UG3 chromite seam contribution was determined in each of the pits and it has been established that the UG3 ore would generate an estimated total profit of R330 million in the four pits combined. This is a significant amount of ore value that cannot be discarded as waste.

10.1 The financial valuation of the UG2 Open Pits at the Modikwa Platinum Mine.

The UG2 underground mining operation only commences where the vertical distance from surface to the top contact of the UG2 is approximately 40m. As a result a considerable block of ground was left between the outcrop and the underground workings. This provided a good opportunity for the mining of this block of ground in an open pit operation. The UG2 in this area is undeformed and has a constant dip of 12 degrees. A north-south trending fault has been delineated in the pit, however the fault had no reef displacement. Refer to figure39.

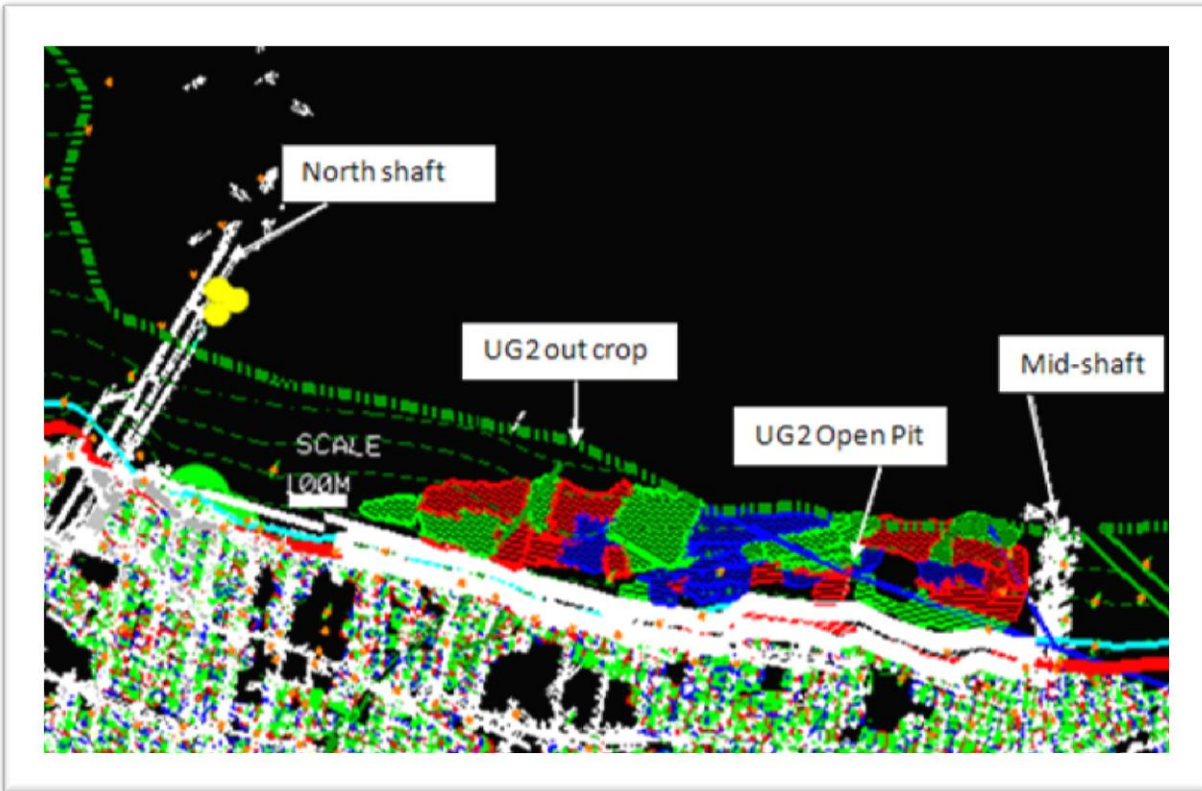


Figure 39. A plan view of the UG2 open pit at Modikwa Platinum Mine.

The mining of the UG2 open pit commenced in August 2010 and was completed in December 2012. The pit yielded about 1086421 tons of UG2 ore at a grade of about 4.5g/t. An operational cash profit of R313455000 was declared. A summary of the net cash flow is provided below.

Table 30. Showing a summary of the UG2 reef open pit cash flow.

	Year1	Year2	Year3	Total
Revenue	54188000	175408000	341910000	571506000
Operational cash cost	15132000	61760000	198069000	274961000
Operational cash profit	47500000	113648000	152307000	313455000
Tons of ore	118943	328198	639280	1086421
Capital expenditure	26304000	42264000	116441000	185009000
Net cash flow	21196000	71383000	81628000	174207000

During the extraction of the UG2 chromitite seam in this pit, the UG3 was mined and discarded as waste. It has been established from exploration borehole sampling that the average grade of the UG3 is 2.5g/t. The extraction of the UG3 would not have incurred any operational cost as it is located 10m above the UG2 reef horizon. This section will deal with the amount of UG3 ore reserves that were mined and discarded. The UG3 chromitite seam has an average thickness of 22 centimetres in the Modikwa lease area. The discarded UG3 chromite seam within the UG2 open pit covered an area of approximately

143317 square metres along dip and strike. The determination of the estimated operating cash profit that would have been generated by the mining and milling of the UG3 chromitite seam is provided below.

Tons = square metres x UG3 thickness x density

$$= 143317\text{m}^2 \times 0.22\text{m} \times 3.93\text{t/m}^3$$

$$= 123911.9\text{t}$$

Content = Tons x In situ grade

$$= 123911.9\text{t} \times 2.5\text{g/t}$$

$$= 309779.7\text{g}$$

Revenue = Content (ounce) x Price of mineral/ounce

$$= (309779.7\text{g} / 31.10348) \times (\$1639.07333 \times \text{R}7.5)$$

$$= \text{R}122434444$$

During the mining of the UG2 open pit, it was established that the operation cash cost of extracting the UG2 chromitite seam was 236 rand per ton. This figure will be used to determine the profit margin of the UG3 in an open pit operation as shown below.

Operating cash profit = revenue – operating cash cost

$$= \text{R}122434444 - (236\text{R/t} \times 123911.9\text{t})$$

$$= 122434444 - 29243232$$

$$= \text{R}93191212$$

It has been established that the extraction of the UG3 ore would have generated a significant operational cash profit of not less than R90 million. Consequently the total operating cash profit of the UG2 open pit would have been R406646212 instead of R313455000.

In Modikwa's short term plan, four more open pits will be mined namely Onverwacht Hill, North, Concentrator and the South3 open pit. The section below will deal with the financial valuation of the UG3 chromitite seam within those pits. The opportunity of extracting the UG3 during the mining of the UG2 will be quantified and documented. Certain assumptions will be factored into the determination of the operating cash profit that the pit would generate. It will be assumed that the price of the 4 PGE will be \$1396 per ounce and that the rand dollar exchange will be R10 per US dollar.

10.2 A valuation of the proposed UG2 Onverwacht Hill open pit.

The proposed Onverwacht Hill open pit is located in an area between South shaft and the Onverwacht Hill shaft. The pit covers an area of 72870 square meters. It is almost dissected by a seasonal stream. The area in the vicinity of the stream will not be mined in order to minimize the environmental impact that will be caused by the mining of the open pit. Refer to figure40.

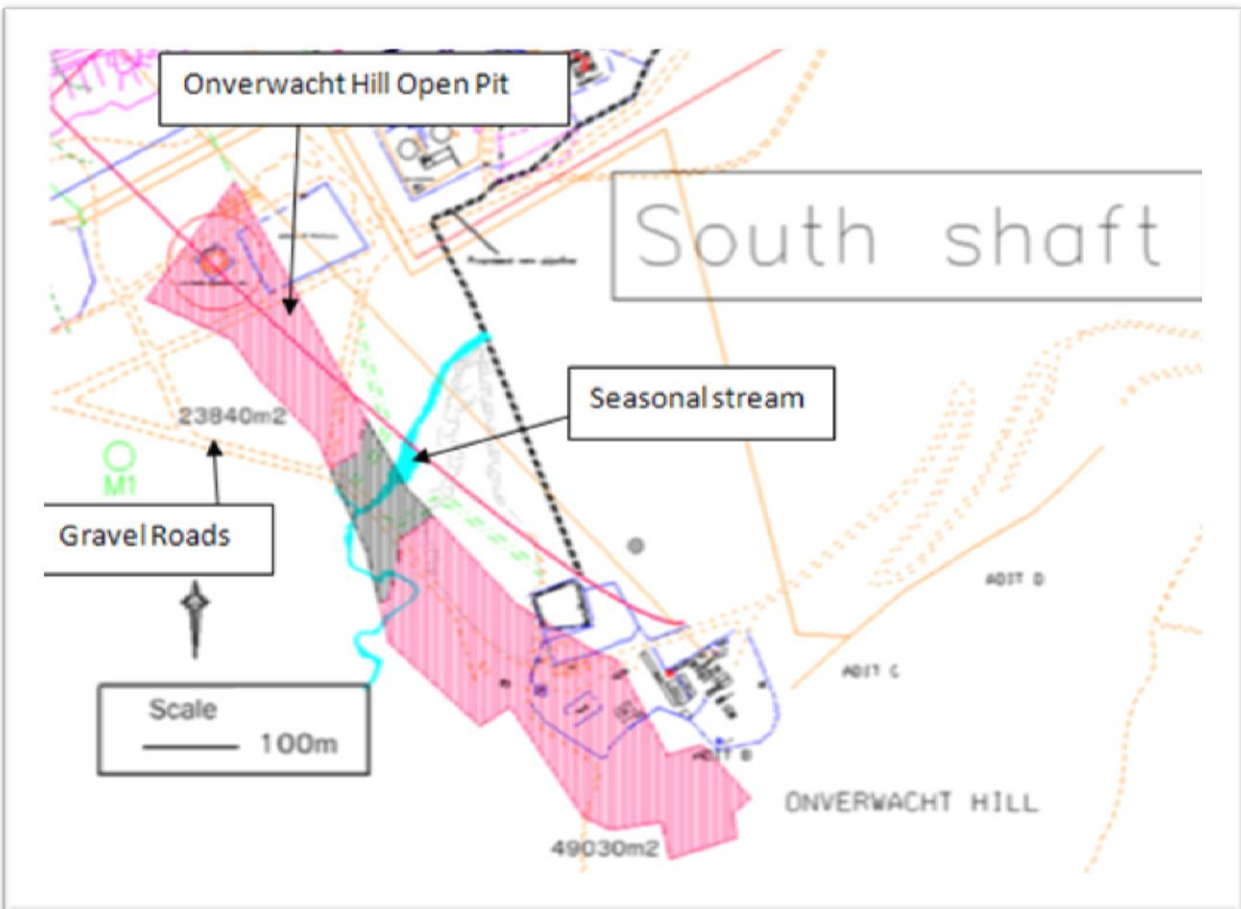


Figure 40. A plan view of the proposed Onverwacht Hill open pit.

The financial valuation of the proposed Onverwacht Hill UG2 open pit is as follows.

$$\text{Tons} = \text{m}^2 \times \text{UG2 thickness} \times \text{Density}$$

$$= 72870\text{m}^2 \times 0.6\text{m} \times 3.93 \text{ t/m}^3$$

$$= 171827.5\text{t}$$

$$\text{Content} = \text{Tons} \times \text{Grade}$$

$$= 63003.4\text{t} \times 4.5\text{g/t}$$

$$= 773223.75\text{g}$$

Revenue = Content (ounce) x Price of mineral/ounce

$$= (773223.75\text{g} / 31.10348) \times (\$1396 \times \text{R}10)$$

$$= \text{R}347041667$$

Cost = UG2 ore tons x 235.347R/t

$$= 63003.4\text{t} \times 235.34\text{R/t}$$

$$= \text{R}14827661.18$$

Profit = Revenue – cost

$$= \text{R}347041667 - \text{R}14827661.18$$

$$= \text{R}332214006$$

The proposed UG2 Onverwacht Hill open pit is expected to generate an operational cash profit of approximately R332 million.

In order to establish the impact that the extraction of the UG3 chromitite seam would have during the mining of the economic UG2 reef, a financial valuation of the UG3 would be carried out. The financial valuation of the UG3 within the proposed Onverwacht Hill open pit is as follows.

Tons = $\text{m}^2 \times \text{UG3 thickness} \times \text{Density}$

$$= 72870\text{m}^2 \times 0.22\text{m} \times 3.93 \text{ t/m}^3$$

$$= 63003.402\text{t}$$

The mineral content of the ore is as follows.

Content = Tons x Grade

$$= 63003.4\text{t} \times 2.5\text{g/t}$$

$$= 157508.5\text{g}$$

Revenue = Content (ounce) x Price of mineral/ounce

$$= (157508.5\text{g} / 31.10348) \times (\$1396 \times \text{R}10)$$

$$= \text{R}70693654.21$$

Operating cash profit = revenue – operating cash cost

$$= R70693654.21 - (236R/t \times 63003.402t)$$

$$= R70693654.21 - R 14868803$$

$$= R 55824851$$

Findings:

The inclusion of the extraction of the UG3 chromitite seam during the mining of the UG2 in the Onverwacht Hill pit could increase the cash operating profit by R70693654.21. The cash operating profit would be increased from R332 million to 402907660. This represents an increase of 21% in the cash operating profit.

10.3 A valuation exercise of the proposed UG2 North Pit.

The proposed North Pit is located on the northern side of the main North Modikwa shaft. The pit covers an area of approximately 192301 square metres. Refer to figure 41.

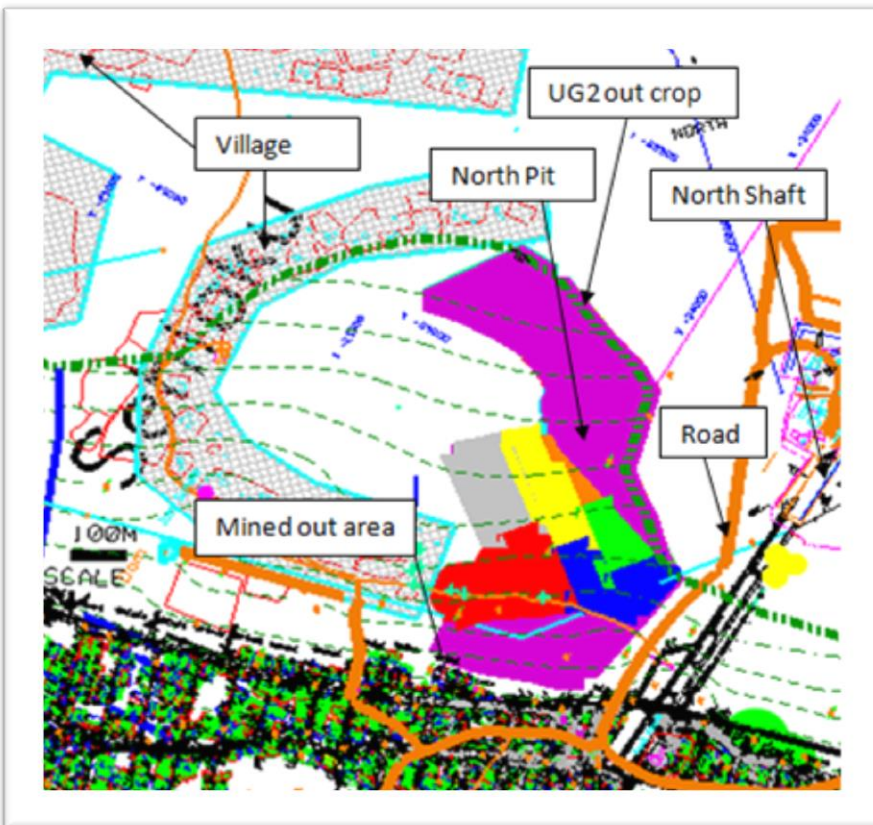


Figure 41. A plan view of the North Pit located on the northern side of North Modikwa Shaft.

The financial valuation of the proposed UG2 North Pit is provided below.

Tons= $m^2 \times \text{UG2 thickness} \times \text{Density}$

$$= 192301m^2 \times 0.6m \times 3.93 \text{ t/m}^3$$

$$= 453445.758t$$

Content = Tons x Grade

$$= 453445.758 \text{ t} \times 4.5g/t$$

$$= 2040505.911g$$

Revenue = Content (ounce) x Price of mineral/ounce.

$$= (2040505.911/31.10348) \times (\$1396 \times R10)$$

$$= R915828792.1$$

Cost = UG2 ore tons x 235.347R/t

$$= 453445.758 \text{ t} \times 235.34R/t$$

$$= R106717098.8$$

Profit = Revenue – cost

$$= R915828792.1 - R106717098.8$$

$$= R809111693$$

In order to establish the impact that the extraction of the UG3 chromitite seam would have during the mining of the economic UG2 reef, a financial valuation of the UG3 would be carried out. The financial valuation of the UG3 within the proposed Onverwacht Hill open pit is as follows.

The financial valuation of the North Pit is as follows.

Tons= $m^2 \times \text{Reef width} \times \text{Density}$

$$= 192301m^2 \times 0.22m \times 3.93 \text{ t/m}^3$$

$$= 166263.4t$$

Content = Tons x Grade

$$= 166263.4t \times 2.5 \text{ g/t}$$

$$= 415658.5g$$

Revenue = Content (ounce) x Price of mineral/ounce

$$= (415658.5g / 31.10348) \times (\$1396 \times R10)$$

$$= R186557666.9$$

Operating cash profit = revenue – operating cash cost

$$= R186557666.9 - (236R/t \times 166263.4t)$$

$$= R186557666.9 - R14868803$$

$$= R39238162$$

Findings:

The extraction of the UG3 chromitite seam during the mining of the UG2 at the North Pit will increase the cash operating profit by approximately R39238162. Thus the total cash operating profit of the pit will appreciate from R809111693 to R 848349855.4.

10.4 The valuation of the Concentrator UG2 open pit.

The Concentrator UG2 open pit is located in the vicinity of the Modikwa Concentrator plant. The UG2 chromitite seam extends to about 82470 square metres along dip and strike. A dyke and some minor faults cut across the proposed pit area. It is anticipated that the dyke will be mined together with the reef as it will result in negligible dilution. The pit is relatively small in comparison to the other UG2 open pits due to the presence of the Concentrator Plant infrastructure. Refer to figure 42.

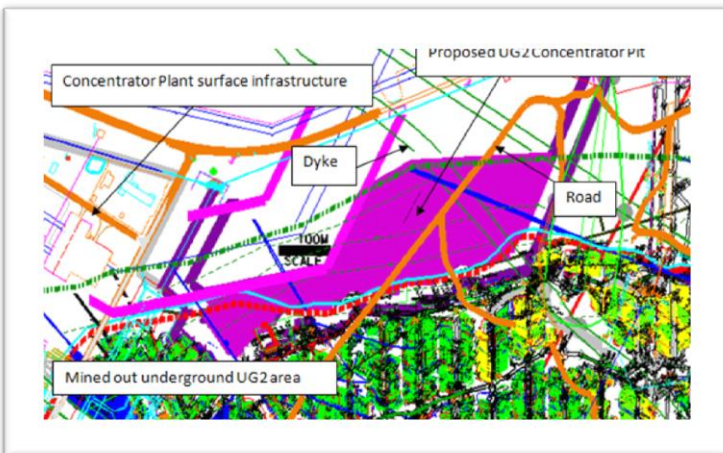


Figure 42. A plan view of the proposed Concentrator UG2 open pit located in the vicinity of the Modikwa Concentrator Plant.

The valuation of the pit is provided below.

Tons = Square metres x Reef thickness x Density.

$$= 82470\text{m}^2 \times 0.6\text{m} \times 3.93\text{t}/\text{m}^3$$

$$= 194464.26\text{t}.$$

Content = Tons x Grade.

$$= 194464.26\text{t} \times 4.5\text{g}/\text{t}.$$

$$= 875089.17\text{g}.$$

Revenue = Content (ounce) x Price of mineral/ounce.

$$= (875089.17\text{g} / 31.10348) \times (\$1396 \times \text{R}10).$$

$$= \text{R}392761350.60$$

Cost = UG2 ore tons x 235.347R/t.

$$= 194464.26\text{t} \times 235.34\text{R}/\text{t}$$

$$= \text{R}45765218.95$$

Profit = Revenue – Cost.

$$= \text{R}392761350.60$$

The valuation of the UG3 chromitite seam within the Concentrator Pit is provided below.

Tons = Square metres x Reef thickness x Density.

$$= 82470\text{m}^2 \times 0.22\text{m} \times 3.93\text{t}/\text{m}^3$$

$$= 71303.56\text{t}.$$

Content = Tons x Grade.

$$= 71303.56\text{t} \times 2.5 \text{ g}/\text{t}$$

$$= 178258.9\text{g}.$$

Revenue = Content (ounce) x Price of mineral/ounce.

$$= (875089 \text{ t}.17\text{g} / 31.10348) \times (\$1396 \times \text{R}10).$$

$$= R80006941.8$$

Operating cash profit = revenue – operating cash cost

$$= R80006941.8 - (236R/t \times 71303.56t)$$

$$= R80006941.8 - R16827640.16$$

$$= R63179301.64$$

It is estimated that a cash operating profit of R63179301.64 would be generated if the UG3 chromitite seam is extracted during the mining of the UG2 chromitite seam in this open pit operation.

10.5 The financial valuation of the South3 UG2 open pit.

The South3 UG2 open pit is located on the southern boundary of the Modikwa lease area. The pit covers an estimated area of 225000 square metres. Refer to figure 43.

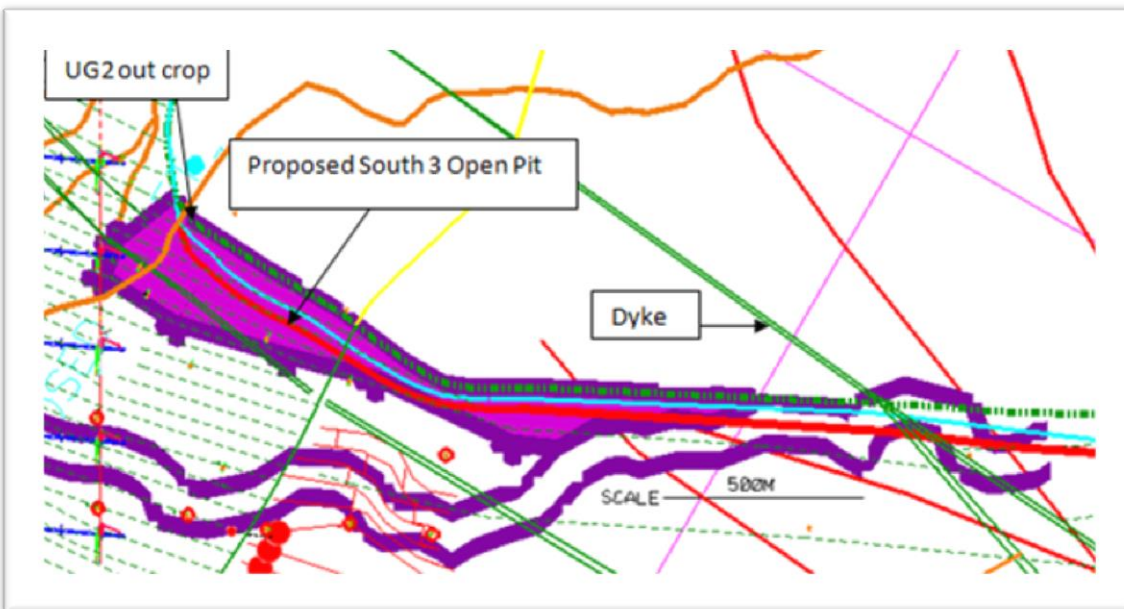


Figure 43. A plan view of the proposed UG2 South3 open pit.

The financial valuation of the pit is as follows.

Tons = Square metres x Reef thickness x Density

$$= 225000m^2 \times 0.6m \times 3.93t/m^3$$

$$= 530550t$$

Content = Tons x Grade

$$= 530550 \times 4.5\text{g/t}$$

$$= 2387475\text{g}$$

$$\text{Revenue} = (\text{Content/ounce}) \times (\text{Price in US dollars} \times \text{Rand value})$$

$$= (2387475\text{g} / 31.10348) \times (\$1396 \times \text{R}10).$$

$$= \text{R}1071556977$$

$$\text{Cost} = \text{UG2 ore tons} \times 235.347\text{R/t}$$

$$= 530550\text{t} \times 235.34\text{R/t}$$

$$= \text{R}124859637$$

$$\text{Operating cash profit} = \text{Revenue} - \text{cost}$$

$$= \text{R}1071556977 - \text{R}124859637$$

$$= \text{R}946697340$$

In order to establish the impact of including the mining the UG3 together with the UG2 the financial valuation will be carried out and it is as follows.

$$\text{Tons} = \text{Square metres} \times \text{Reef thickness} \times \text{Density}$$

$$= 225000\text{m}^2 \times 0.22\text{m} \times 3.93\text{t/m}^3$$

$$= 194535\text{t}$$

$$\text{Content} = \text{Tons} \times \text{Grade}$$

$$= 194535 \times 2.5\text{g}$$

$$= 486337.5\text{g}$$

$$\text{Revenue} = (\text{Content/ounce}) \times (\text{Price in US dollars} \times \text{Rand value})$$

$$= (486337.5\text{g} / 31.10348) \times (\$1396 \times \text{R}10).$$

$$= \text{R}218280125$$

$$\text{Operating cash profit} = \text{revenue} - \text{operating cash cost}$$

$$= \text{R}218280125 - (236\text{R/t} \times 194535\text{t})$$

$$= \text{R}218280125 - \text{R}45910260$$

$$= \text{R}172369865$$

It is estimated that a cash operating profit of R172369865 would be generated if the UG3 chromitite seam is extracted and milled during the mining of the UG2 chromitite seam in this open pit operation.

10.6 A summary of the operating cash profit of all the proposed UG3 pits.

A total sum of the estimated operating cash profit of the all the proposed pits was determined. The summary is provided below.

Table 31. Showing the total operating profit that the proposed UG3 reef will generate.

Pit	Estimated ore tons	Estimated cash profit
Onverwacht Hill Pit	63003.402	55824851
North Pit	166263.4	39238162
Concentrator Pit	71303.56	63179301.64
South3 Pit	194535	172369865
Total	495105.4	330612180

The inclusion of the mining of the UG3 chromitite seams in the all the pits constitutes a total operating cash profit of approximately R300 million. This is a very significant amount of ore value that could optimize the UG2 pit operations.

Since the extraction of the UG3 chromitite seam incurs no cost and does not require capital investment, it thus represents the Net profit value of the reef before tax.

10.7 The mineralization of the UG3 chromitite seam.

An in-depth study of the UG3 chromitite seam was carried out to characterise the ore. The study included the textural properties of the UG3 and the PGE mineralization.

The UG3 chromitite seam comprises a framework of cumulus chromite within the interstitial silicate in terms of texture. The packing structure ranges from open which is the common type, to closed structure which is rare. That is, in an open packing structure the chromite grains are matrix supported while in the close packing structure the chromites are grain supported.

The UG3 seam is not a single solid layer but rather comprise of two units separated by a thin lense of anorthosite.

A contrast of substantially larger and very small grains has been noted. This is likely a function of two generations of chromite grains. The large grains could have been formed in areas of greater pore space where they were allowed to crystallize in an open environment. During compaction these grains were then forced together and coalesced to form substantially chromite nodules. The grains displayed the same chemical composition regardless of shape or generation.

The sulphides mineralisation is concentrated in the UG3 chromitite seam. The general sulphide assemblage comprises pentlandite and chalcopyrite. Texturally the sulphides range in size from less than 1µm to large composite particles of 200µm in size. Pentlandite occurs as a 200µm large particle in sample MAY A. The sulphides in the UG3 chromitite seam are mainly concentrated in the interstitial matrix between the cumulus chromite and silicate particles. They are located on the boundaries of PGM, occur as discrete grains within the interstitial silicate and some sulphide grains are also found to be fully enclosed within chromite grains.

The intricate texture exhibited by the sulphides suggests that they were formed during the primary magmatic phase. This serves as direct evidence that there has been no subsequent reworking of the sulphides by late-stage circulating fluids.

The platinum-group minerals (PGM) occur within the interstitial silicate and occasionally within the chromite grains. The matrix that hosts the platinum-group minerals are dominantly cumulus plagioclase, orthopyroxene occurs as a minor mineral. The platinum-group minerals are fine grained in general with a few larger particles present in the samples. The largest PGM observed is a cooperite which is approximately 70µm in size. Refer to figure 15. The PGM occur as discrete grains as well as grains comprising two or more phases.

The PGM show a strong preference to contact boundaries of the silicate grains, the chromite grains and the sulphide phases. In some instances, the PGM are enclosed within the chromite grains in association with sulphides. This observation is consistent with the work of Scoon and Teigler who observed that PGM also occurred as inclusions within chromite grains and form a diverse suite of minerals within interstitial matrix. Refer to figure 28. These intricate textures show a strong PGM-sulphide association as there is an intimate link to their location. The enclosure PGM within chromite grains and their preference to the boundaries also points to the intimate link between chromite and PGM phases.

The detail descriptions of the samples have revealed that PGM are closely associated with sulphides phases, are relatively large, euhedral in general, well developed and they have a proclivity to contact boundaries. The above mentioned attributes suggest that the PGE-sulphides formed the original PGM assemblage. Their primary magmatic nature points to the fact that the PGM have not been affected by secondary fluids in any manner and thus they have not been altered.

The PGE-sulphides form the predominant PGM assemblage in the UG3 chromitite seam at the Modikwa Platinum Mine. Rixom (2005) has shown that the UG2 orebody throughout the Eastern Bushveld is unaltered and has a PGM assemblage dominated by PGE-sulphides. The UG2 chromite seam is 10m below the UG3 chromite seam.

The main constituent of the interstitial matrix are silicates. The silicates comprise of cumulus plagioclase with minor intercumulus pyroxene. The silicates host sulphides and PGE mineralization.

Two prominent assemblages were identified, namely the SiO₂- Al₂O₃-CaO- Na₂O and the SiO₂-Al₂O₃-MgO-FeO. The CaO-Na₂O and MgO occurrences are perfectly contrasted in the two assemblages. The

two elements tend not to co-exist, in samples in which MgO-FeO is present, CaO-Na₂O is absent or occurs as a minor amounts and the direct opposite is true.

According to Cawthorn and McKenna, (2006), the Mg values are diagnostic of mafic phases while the Ca-Na contents suggest the modal occurrence plagioclase. These elements namely, CaO-NaO and MgO-FeO have an affinity for plagioclase and orthopyroxene respectively. Pyroxene is Mg-rich while plagioclase is Na-Ca-rich. Following this logic, the interstitial silicates that form the matrix of the UG3 chromite grains consist of plagioclase with minor occurrences of orthopyroxenite in the samples.

Further, the CaO and Na₂O occurrences denote a variation of plagioclase. It was also established that more than one phase or variation of plagioclase occurs in the interstitial silicates of the UG3 chromitite seam. The variation is not wide spread. The grains range in size from about 10µm to about 350µm.

A comparison between large chromite grains and small chromite grains revealed that their chemical composition is similar. Further, irregularly shaped grains have the same chemical compositions as grains that are sub-round to almost perfectly rounded grains. The irregular chromite grain in sample MAY C1 has the same chemical composition as a sub-rounded chromite in sample MAY D.

The chromite grain at point 4 in the MAY D sample encloses a PGM phase. However the grain has a similar chemical composition as any of the grains in that sample.

Lastly chromite grains that are located in the vicinity of PGMs or Sulphides have the same chemical compositions as those that are within the interstitial silicates.

It has been established that chromite grains of different generations have the same chemical compositions in the UG3 chromitite seam. As expected, all the chromite grains have a Cr₂O₃-MgO-Al₂O₃-FeO element assemblage and are mafic. The Mg values are diagnostic of mafic phases.

10.8 A brief description of the Modikwa Concentrator plant and its suitability to process the UG3 chromitite seam ore.

This section aims to highlight the capabilities of the Modikwa concentrator plant and to speculate its suitability to mill the UG3 ore.

The UG3 reef is described as a black fine grained chromitite seam. The chromite grains range in size between 10um and about 350um. The chromite seam is platiniferous. The PGM range in size from less than 10um to 70um. The platinum-group minerals occur in the interstitial silicates.

The results of the borehole sampling have indicated that the average grade of the UG3 chromitite seam is 2.5g/t. It is expected that the UG3 ore would be milling at the Modikwa concentrator plant should the mining of the UG2 in the proposed open pits include the extraction and milling of the UG3 ore.

The Modikwa plant is presently processing the economic UG2 chromitite seam. The UG2 is platiniferous and has an in situ average grade of 6g/t. The platinum-group minerals are fine grained and occur in the

interstitial silicate. Some platinum-group minerals also are enclosed in chromite grains. The UG2 chromitite seam has about 43% chromite. As a result the milling and concentrating process is required to liberate the PGE mineralization from both the silicates and the chromite. The concentrator plant is equipped to deal with these requirements. Refer to figure 44.

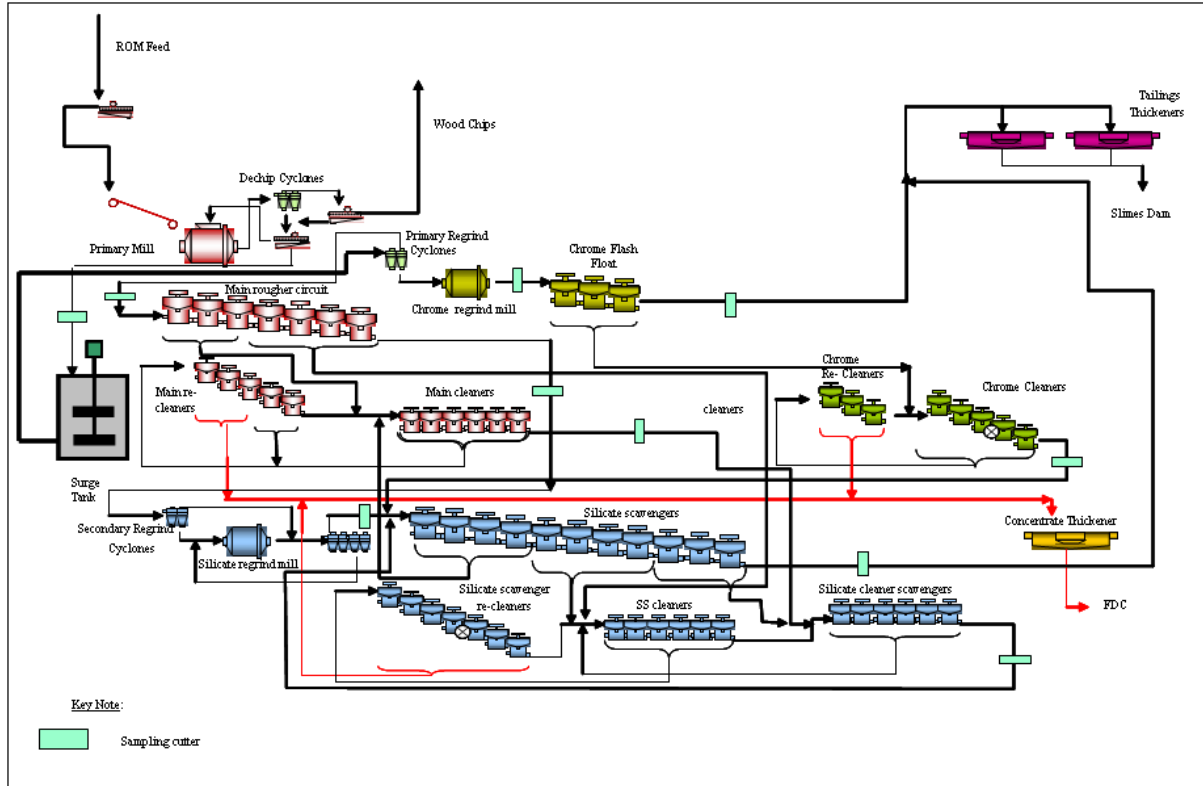


Figure 44. A schematic diagram of the Concentrator plant layout.

The ore is fed through the ROM feed to the primary mill. Once the ore has been milled it is routed to the Main rougher circuit. The ore is then sent to the silicate circuit where upon the PME are liberated. The residue is routed to the Chrome Flash Float and some more PGE are liberated. At the end of the process the ore has an estimated grade of approximately 100g/t. The plant predominantly concentrates chalcopyrite (CuFe sulphide), pentlandite (NiFe sulphide) and pyrrhotite (iron sulphide) along with the PGMs and some gangue.

The concentrate is then transported to the smelter house in Polokwane for further processing. The main function here is to remove non-valuable components (silicate) and the molten furnace matte is sent to the converter, where silica is added. Blowing with air oxidizes and removes iron into the slag and removes sulphur as SO₂. The end product is a Fe and 5 deficient converter matte system with the approximate composition. The matte is poured into large ingot moulds and slow cooled for five days in a 28 ton ingot. The main purpose here is to separate PGE into an alloy phase. The cooled matte is crushed and the alloy phase is magnetically separated. The magnetic alloy phase (now only 10-15 % of the original material) contains the PGE and goes to the Precious Metal Refinery for extraction of PGE and Au.

It is envisaged that the Concentrator has the capabilities to process the UG3 chromite seam as it has the chromite and the silicate circuit. Secondly the UG3 chromitite seam has similar metallurgical characteristics as the UG2 chromitite seam.

11. Conclusions.

UG3 is a planar 22cm thick chromitite seam. It has an in situ PGE content of 2.5g/t. The UG3 reef is uneconomic to mine in an underground operation, however it can be extracted profitably in an open pit operation during the mining of the UG2 chromitite seam. It has been illustrated that the four proposed UG2 pits namely Onverwacht Hill, North, Concentrator and the South3 open pits will generate a combined operating cash profit of approximately R555 million in the four pits combined, if they extract the UG3 chromitite.

This is a significant mineral resource that contributes positively to the overall pit optimization exercise. The revenue generated by the extraction of the UG3 chromite seam becomes pure profit since it takes place in conjunction with the mining of the UG2 economical reef and incurs no operating cash costs.

It has also been demonstrated that the chromitite seam occurs in abundance along a strike length of 24km and more than 1.2km on dip. The UG3 chromite seam is platiniferous. The seam bears platinum-group minerals. The size of the platinum-group minerals range from less than 10um to about 70um and are associated with sulphides. The PGE mineralization is concentrated in the chromitite seam. These metallurgical characteristics of the UG3 chromite seam will enable the milling and liberation of the platinum-group minerals from the UG3 ore at the Modikwa concentrator plant.

It is therefore recommended that future UG2 open pit mining should include the extraction and milling of the UG3 chromitite seam. Further, it is also recommended that the near surface portion of the UG3 chromitite seam should be classified as an ore reserve.

Further work

- Bulk sampling of the UG3 chromitite seams should be carried out in order to determine the recovery rates of this reef.
- Whenever possible, any exposure of the UG3 chromitite seam will be sampled to increase levels of confidence in the UG3 resource.
- A detailed study of the UG3A and UG3B should be carried out as well.

References

- Arndt, N., Jenner, G., Ohnenstetter, M., Deloule, E., Wilson, A.H. (2005). *Trace elements in the Merensky Reef and adjacent norites Bushveld Complex South Africa*. Mineral. Dep., 40, pp. 550-575.
- Burger, A. J., & Coertze, F.J. (1975). *Age determinations*. April 1972 – March 1974. South Africa Geol. Survey Annals, 10. pp. 135 – 141.
- Cawthorn, R.G. & Walraven, F. (1998). *Emplacement and crystallization time for the Bushveld complex*. J. Petrol., 39, pp.1669-1687.
- Twist, D. (1985). *Geochemical evolution of the Rooiberg silicic lavas in the Loskop Dam area, southeastern Bushveld*. Economic Geology, v. 80, pp. 1 53-1165.
- Eales, H.V., & Cawthorn, R.G. (1996). *The Bushveld Complex*. In: Cawthorn, R.G (ed.). Layered Intrusions. Elsevier Science. p.531.
- Gain, S.B. (1985). *The Geological Setting of the Platiniferous UG2 Chromitite layer of the Farm Maandagshoek, Bushveld Complex*. Economic Geology, v. 80, pp. 925-943.
- Kinnaird, J.A. (2004). *The Bushveld Large Igneous Province*. Geoscience Africa, University of the Witwatersrand.
- Maier, W. D. (2005). *Platinum-group element (PGE) deposits and occurrences. Mineralization styles, genetic concepts, and exploration criteria*. Journal of African Earth Sciences 41, pp.165-191.
- Mathez, E.A., & Mey, J.L. (2005). *Character of the UG2 chromitite and petrogenesis of its footwall rocks, eastern Bushveld Complex*. Econ. Geol. V.100. pp.1617-1630.
- Naldrett, A.J., & von Gruenewaldt, G., (1989), *Association of platinum group elements with chromitite in layered intrusions and ophiolite complexes*. ECONOMIC GEOLOGY, v. 84, pp. 180–187.
- Raith, M. M., Raase, P. and Reinhardt J.(2005). *GUIDE TO THIN SECTION MICROSCOPY*. University of KwaZulu-Natal.
- Rixom, (2005). *Geometallurgical Characterisation of the UG-2 Reef in the North-Eastern Bushveld*. Anglo Research Mineralogy Report No. M/05/110.
- Scoon, N. & Teigler B. (1994). *Platinum-Group Element Mineralization in the Critical Zone of the Western Bushveld Complex*. Sulfide Poor-Chromitites below the UG-2. Economic Geology. 89, pp.1094-1121.
- Twist D., (1985). *Geochemical evolution of the Rooiberg silicic lavas in the Loskop Dam area, southeastern Bushveld*. Economic Geology, v. 80, pp. 1153-1165.

Walraven, F. (1986). *A note on the stratigraphic terminology of the Bushveld Complex*, In. Anhaueser, C.R.,and Maske, S (eds) *Mineral Deposits of Southern Africa, 2*, Johannesburg. Geology. Soc. S. Afr., pp.1039-1040.