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The Waterberg platinum-group element deposit, South Africa

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Examiner 2: Corrections Report:

Abstract:

Examiner: Abstract, 1st para, line 3: "…the succession comprises of basal Marginal sills,…"
Response: Changed as suggested by the examiner. "…composed of…"

Examiner: Abstract, 2nd para, 2nd last line: **"…**The Upper Zone is composed of disseminated cumulus magnetite,…"
Response: Changed as suggested by the examiner. "…is composed of…"

Chapter 1

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 1, 1st para, 2nd sentence: The Bushveld Complex has not done the developing -- change to something like new mining operations have been opened and developed in the Bushveld Complex, along the .....
Response: Changed as suggested by the examiner. "Since the discovery of PGE in the last 1920's, mines have been developed and opened along the Merensky Reef and the Upper Group 2 (UG2) of the eastern and western limbs of the Bushveld Complex and in recent years the exploration and mining activities have increased on the Platreef ore body of the northern limb."

Examiner: Page 2, 2nd para, 1st sentence: "The Earth's core is believed to have been the principle reservoir of PGE…"
Response: Changed as suggested by the examiner.

Examiner: Page 2, 2nd para, 2nd and 3rd line: "Although, some authors have suggested that the mantle is more abundant than the core,…"
Response: Changed as suggested by the examiner.

Examiner: Page 2, 2nd para, last line: "Is this the case if PGE are concentrated in a dense immiscible sulfide liquid? Not much transport is proposed here - PGE may be in the silicate melt if the degree of melting is sufficiently high for sulfide to be soluble in the silicate melt and no immiscible sulfide is present. Usually something around 15 % partial melting."
Response: Agreed with the examiner and I have referenced the authors that have suggested this mechanism for the enrichment and concentration of PGE.

Examiner: Page 2, 3rd para, line 7: "The majority of the economic PGE resources can be divided into two types of deposits associated with either Ni-Cu sulphides or chromitite (Fig. 1.1) (Misra, 2000; Mungall *et al*., 2004; Naldrett, 2004; Arndt *et al*., 2005; Maier, 2005)."
Response: Changed as suggested by the examiner. Added in "either".

Examiner: Page 2, 3rd para, line 8: "This is where problems arise if you define PGE as Platinum Group Elements (plural), as you have done above. I suggest you use PGE as Platinum Group Element and add an s where PGEs are denoted. Then you can say PGE mineralization. Otherwise you will need to re-phrase PGE mineralisation and similar."
Response: Changed as suggested by the examiner. I have changed this throughout the thesis and PGE now represent the plural and for the cases were PGE are singular the element itself has been mentioned or in the case were more than one PGE is mentioned there is 2 or 3 in front of the PGE abbreviation.

Examiner: Page 2 to 3, 3rd para, line 10 and onto the next page: "delete comma. Type II occurrences are massive ....."
Response: Changed as suggested by the examiner. "Type II PGE mineralisation occurs in massive Ni-Cu sulphides deposits, although mined primarily for Ni and Cu with recoverable amounts of PGE, particularly Pd as by products…"

Examiner: Page 3, 3rd para, line 5: "sulphur" and "sulphides" change to "sulfur" and "sulfides"
Response: I have not changed this because this is South African English and has been used throughout the thesis. Only in the cases where the chapters have been published in an American style journal has the English changed.

Examiner: Page 4, 1st para, line 10: "(iv) Furthermore, an increase in oxygen fugacity may cause the precipitation of chromite and magnetite, decreasing the FeO content of the magma, which in turn decreases the sulphur carrying capacity of the magma"
Response: Changed as suggested by the examiner.

Examiner: Page 4, 2nd para, line 2: "…sulphide liquid to silicate liquid mass ratio…"
Response: Changed as suggested by the examiner.

Examiner: Page 5, 2nd para, line 8: "jewellery" change to "jewellery"
Response: The South African English is spelt as jewellery and the US English is spelt as jewelery and this thesis South African English is used.

Examiner: Page 6, 1st para, line 7: "e.g." delete
Response: Changed as suggested by the examiner.

Examiner: Page 7, 1st bullet point: Rephrase
Response: Changed as suggested by the examiner.
"Determine the role of magmatism, contamination and hydrothermal processes in the development of the two mineralised intervals of the Waterberg Project intercepted by drilling."

<u>Chapter 2:</u>

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 11, 3rd para, line 7, 8 and 9: "mantle fabrics" and "arc-like mantle fabric"
Response: These are terms used by the authors Silver et al. (2004) and the uses of these words are directly taken from this paper.

Examiner: Page 15, 3rd para, line 4: "Clarify - the composition of the noritic rocks is taken to represent the B1 parental magma?"
Response: Changed as suggested by the examiner. Rephrased
"These groups include (i) the composition of the noritic rocks with a quenched texture in contact with the Lower Zone and Lower Critical Zone were taken to represent the B1 parental magma of the Bushveld or the composition of ultramafic rocks that were within the footwall of the Lower Zone were termed B1 UM parental magma."

Examiner: Page 23, 2nd para, last sentence: Rephrased
Response: Changed as suggested by the examiner. "This would lead to progressive enrichment of elements such as PGE, Ni and Cu in residual sulphides (Kerr and Leitch, 2005; Naldrett *et al*., 2009)."

Examiner: Page 23, 3rd para, first sentence: Rephrased
Response: Changed as suggested by the examiner. “Some authors have argued against magma mixing and deem it not necessary to induce sulphide saturation.”

Examiner: Page 23, 3rd para, second sentence: Rephrased
Response: Changed as suggested by the examiner. “Cawthorn (2005) and Mavrogenes and O’Neil (1999) suggested that sulphide immiscibility as well as the formation of chromitite layers is a result of negative effect from the increase in pressure on sulphide solubility.”

Examiner: Page 24, 2nd para, line 8: Rephrased
Response: Changed as suggested by the examiner. “The Main Zone is 3100 m thick in the eastern limb (von Gruenewaldt, 1973; Molyneux, 1974). Von Gruenewaldt (1973) subdivided the Main Zone in the eastern limb into three subzones based on the appearance of primary orthopyroxene and pigeonite.”

Examiner: Page 24, 3rd para, line 7: “Be consistent - should you use "magnetite" layers or "magnetitite" layers?
Response: Changed as suggested by the examiner.

Examiner: Page 24, 3rd para, line 10: Rephrased
Response: Changed as suggested by the examiner. “The Upper Zone has been subdivided into three subzones based on the appearance of cumulus minerals (cumulus magnetite, olivine and apatite).”

Examiner: Page 27, 2nd para, line 1: Rephrased
Response: Changed as suggested by the examiner. “Hatton (1995) suggested that the emplacement of the Bushveld Complex was an intrusive event with magma volume equivalent to that of a continental flood basalt province.”

Examiner: Page 27, 2nd para, last sentence: Rephrase
Response: Changed as suggested by the examiner. “Sulphide inclusions from ~2.0 Ga diamonds recovered from the Premier and Venetia kimberlite on opposite sides of the igneous complex, show initial Os isotope ratios which are more radiogenic than those found in the ore deposits of the Bushveld Complex (Richardson and Shirey, 2008).”

Examiner: Page 27, 3rd para, first two sentence: Rephrase
Response: Changed as suggested by the examiner. “No feeder systems have been positively identified for the Bushveld Complex. However, several feeder systems have been inferred through geometric studies (Kinloch, 1982).”

Examiner: Page 27, 3rd para, third sentence: Rephrase
Response: Changed as suggested by the examiner. “It has been assumed that areas displaying positive gravity anomalies may represent pipe-like feeders (Sharpe *et al*., 1981).”

Examiner: Page 28, 3rd para, line 5: Rephrase
Response: Changed as suggested by the examiner. “The model proposes that the filling space of two adjacent pudding basins of similar size was by a feeder at the base of the lowest basin.”

Examiner: Page 28, 4th para, line 4: Rephrase
Response: Changed as suggested by the examiner. “This has been interpreted to be a result of differential flow of magma to either side of the feeder zone (Cawthorn *et al*., 2002).”

Examiner: Page 28 and 29, 4th para, last two sentences: Rephrase
Response: Changed as suggested by the examiner. "Friese (2004) suggested that the Bushveld magmas utilised the Thabazimbi-Murchison Lineament, the Palala Shear Zone and the Barberton-Magaliesburg Lineament as magma conduits. Where he suggested that at critical levels in the crust the magmatic pressure would be equivalent to the lithostatic pressure and allow for lateral spread of the sill-like intrusion of the complex."

Chapter 3:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 35, 2nd para, first sentences: Rephrase
Response: Changed as suggested by the examiner. "The Lower Zone cumulates are comprised of at least 1600 m of 37 cyclic units of pyroxenite, dunite, harzburgite and chromitite on the Grasvally, Volspruit and Zoetveld farms (Hulbert, 1983; Hulbert and von Gruenewaldt, 1986: Smith *et al*., 2014)."

Examiner: Page 39, 2nd para, first sentences: Rephrase
Response: Changed as suggested by the examiner. "The Platreef not only differs based on the degree of contamination and the transgressive footwall rocks but also in having a different style of mineralisation."

Examiner: Page 39, 2nd para, last three sentences: Rephrase
Response: Changed as suggested by the examiner. "Where the lowest sills are overlying granite-gneiss basement lithologies towards the north there is less contamination close to the footwall. However, a dolomite raft within the middle sill may be the source of the contamination in the northern sector (Sharman-Harris *et al*., 2005; Holwell *et al*., 2007). This reinforces the importance of the host rocks for the different sectors of the Platreef."

Examiner: Page 40, 1st para, first sentences: Rephrase
Response: Changed as suggested by the examiner. "The Platreef is considered to have formed from multiple complex sill-like intrusions of mafic and ultramafic compositions (Kinnaird *et al*., 2005; Maier *et al*., 2008)."

Examiner: Page 41, 1st para, last two sentences: Rephrase
Response: Changed as suggested by the examiner. "Naldrett *et al*. (2008) suggested that the Platreef formed from different magmas than those which formed the main Bushveld Complex. These magmas produced the UG2 and Merensky Reef."

Examiner: Page 42, 1st para, last two sentences: Rephrase
Response: Changed as suggested by the examiner. "Recently PGM have been found in the Troctolite Horizon. Sperrylite ($PtAs_2$) enclosed in cleavage planes of plagioclase, electrum and PGM-tellurides entrapped in base metal sulphides and no sulphide-dominant PGM (braggite, cooperite and vysotskite) have been found (Kennedy *et al*., 2015)."

Examiner: Page 44, 2nd para, line 4: Rephrase
Response: Changed as suggested by the examiner. "These large occurrences of sulphides are interpreted to have formed from an upgrade of the original sulphur content in the magma by assimilation of sulphide-rich footwall (Sharman-Harris *et al*., 2005)."

Chapter 4:

No correction in Chapter 4 by Examiner 2. This is a published document in "*Economic Geology*"

Chapter 5:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 92, 2nd para, line 4: Rephrase
Response: Changed as suggested by the examiner. "In the southern and northern sectors, where the footwall is unreactive quartzite and anhydrous gneiss, these floor rocks allow for limited fluid activity and the deposition of PGE was controlled by the presence of immiscible sulphide liquids (Holwell and McDonald, 2006; Maier *et al*., 2008).

Examiner: Page 118, 1st para, last line: Rephrase
Response: Changed as suggested by the examiner. "However, the differences in the stratigraphy and mineralisation are notable compared to those of the western and eastern limbs and the northern limb south of the HRSZ." This document is already published.

Examiner: Page 121, 2nd para, line 13: Rephrase
Response: Changed as suggested by the examiner. "The elevated Pt/Pd, the Pt arsenide dominance, typically lower grades and the sulphur isotope $\delta^{34}S$ values which are indicative of crustal contamination do not support a genetic link between the southern Moorddrift and far northern Waterberg mineralisation." This document is already published.

Examiner: Page 122, 1st para, line 5: Rephrase
Response: Changed as suggested by the examiner. "However, both are still within the range of mantle-derived magmatic sulphides (Naldrett *et al*., 2012)." This document is already published.

Examiner: Page 122, 1st para, line 6: Do you mean mantle? "Magmatic" is a poor term as S in magmas can have a wide range of delta values depending on source and contamination history.
Response: This document is already published.

Examiner: Page 122, 1st para, line 7: This value is definitely not mantle (at least relatively shallow mantle - i.e. MORB-like), and likely indicates crustal S addition.
Response: This document is already published.

Examiner: Page 122, 1st para, line 7: Average values are not particularly useful. The range is a better indicator of magma-country rock interaction. How many values are above ~ 2 ‰? If the average is near 1 and the low values are near -0.8, I would predict that there must be several - if true your statement on similarity to mantle signals needs to be modified. This should also affect genetic models.
Response: This document is already published.

Examiner: Page 129, 1st bullet, last line: why assuming a similar mechanism of sulphide enrichment? The mineralization is either comparable or not. The mechanism of enrichment may also be similar, but this should not be a factor in comparing the styles of mineralization.
Response: This document is already published.

Chapter 6:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 135, 3rd para, line 3: Rephrased
Response: Changed as suggested by the examiner. "The Platreef is a complex PGE-, Cu- and Ni-bearing body situated between the footwall and Main Zone, which obtains a strike length of 30 km north of Mokopane (Van der Merwe, 1978; Armitage *et al*., 2002; Kinnaird *et al*., 2005; Kinnaird and McDonald, 2005)."

Examiner: Page 135, 3rd para, line 5: Rephrased
Response: Changed as suggested by the examiner. "The Platreef is not a simple tabular deposit. The orientation varies from south to north, generally dipping at 45^{o} to the west, and flattens with depth where it is then termed the Flatreef, dipping at 10^{o} to 15^{o} southwest (Grobler *et al*., 2012)."

Examiner: Page 135, 4th para, line 3: Rephrased
Response: Changed as suggested by the examiner. "The Main Zone is approximately 2000 m thick and is composed of gabbronorite and norite with minor anorthosite and pyroxenite layers (van der Merwe, 1976; Ashwal *et al*., 2005; Roelofse and Ashwal, 2012)."

Examiner: Page 137, 4th para, line 7: Rephrased
Response: Changed as suggested by the examiner. "A dolerite sill with a maximum thickness of 200 m, but typically ~80 m thick, is intercepted in most boreholes (McCreesh 2016; Kinnaird. *et al*., 2017)."

Examiner: Page 142, 2nd and 3rd para: Rephrased and edited
Response: "Samples were crushed, milled in a tungsten carbide mill, and analysed at the Earth laboratory, Bernard Price Building, University of the Witwatersrand. Whole-rock major elements were analysed by PANalytical PW2404 X-ray fluorescence (XRF) using the fused disk method. Trace elements content were also determined by the PANalytical PW2404 X-ray fluorescence (XRF) using pressed pellets and matrix-matched standards, and a detailed description of analytical procedure can be found in Wilson (2012). The Pt, Pd and Au data was provided by Platinum Group Metals Ltd RSA (PTM).

The remaining portion of the quarter-core samples were crushed, milled and sieved to an approximate size (250-100 μm). These samples were then cleaned with water and dried in an oven at 80^{o}C. Mineral grains of orthopyroxene, clinopyroxene, plagioclase and olivine were picked under the microscope and placed on double-sided tapes in rows according to the sample. A circular mold is placed over the grains and an Epofix Resin is poured into the mold to make ore blocks. The ore blocks sent for carbon-coating and the samples are ready to undergo the microprobe analysis."

Examiner: Page 143, section 6.6.2: Would this not be better as "Mineralogy" or "Mineral Assemblages"? Your petrologic interpretation would come after your chemical results have been presented.
Response: This section is called Petrology because it gives the reader a brief description of the rock types under the microscope seen in the Waterberg stratigraphy and is followed by a more detailed description of mineral chemistry.

Examiner: Page 143, section 6.6.3 Mineral chemistry: This section is very difficult to follow. I suggest one of two methods. Either describe the mineral chemical variations in each zone together, or describe the variations for one mineral at a time. Have a section for opx compositions, cpx, olivine,

chromite, etc. This needs to be better organized and easier for a reader to assimilate. I believe this is more or less what you have tried to do, but there is too much skipping from the TGA sequence to the T zone to UMS to UZ. Decide on a method and be consistent and logical.
Response: Changed as suggested by the examiner.

6.6.3. Mineral chemistry

Mineral chemistry data of orthopyroxene, clinopyroxene, olivine and plagioclase for borehole WB099 are presented in Figures 6.5, 6.6 and 6.7. The data were also shown on relevant classification diagrams in Fig. 6.4.

Orthopyroxene

The orthopyroxene are mainly enstatites and show a range of Mg# between 61 and 87 through the Waterberg Bushveld stratigraphy with the CaO being <2 wt. % (Fig. 6.4 and 6.5). The low-Ca pyroxenes in the UmS are Mg-rich (Mg# 76 to 87; average Mg# 82). These values are similar to both the feldspathic pyroxenite and feldspathic harzburgite lithologies found in the Platreef down dip on Akanani (Yudovskaya *et al*., 2011). The Cr concentration in low-Ca pyroxene within the UmS ranges from 700 to 4300 ppm (average ~2400 ppm), which mirrors the Mg# (Fig. 6.5). MnO (0.16 to 0.40 wt. %) shows an opposite trend to the Mg# and Cr values within the UmS. The Mg# of low-Ca pyroxene in the TGA sequence decreases gradually upwards, with the highest Mg# associated with the troctolite unit at the base of the sequence (Fig. 6.5).
The basal TGA sequence (1270.16 m to 952.00 m) has a high Cr concentration ranging from 700 to 5000 ppm (average ~3100 ppm) hosted by troctolite and olivine-gabbronorite. Above the olivine-bearing intervals at the base of the TGA sequence the Cr content decreases upwards to the base of the T2 (Fig. 6.5). The Mg# of low-Ca pyroxene in the T zone is fairly constant between 67 and 72, with a slight increase in the T1 associated with olivine-rich lithologies. The Cr concentration is fairly low in the T zone between 120 and 900 ppm (average ~500 ppm) which is significantly lower than UmS. The Mn content ranges from 2500 to 3800 ppm and shows an opposite trend to the Mg# (Fig. 6.5). The low-Ca pyroxene in the magnetite gabbronorite samples of the UZ are more Fe-rich and have an Mg# ranging from 63 to 77 (Fig. 6.5).

Clinopyroxene

The clinopyroxenes are mainly augite and diopside, with Mg# between 71 and 93 and the CaO is >20 wt. % (Fig. 6.4 and 6.6). The UmS contains minor amounts of clinopyroxene as this stratigraphic unit is dominated by orthopyroxene. The clinopyroxene values obtained from the UmS sequence have an Mg# between 82 and 89 which are slight higher than the low-Ca pyroxene values (Fig. 6.6). The Cr concentrations are high in the clinopyroxene within the UmS ranging from 2400 to 9000 ppm (average ~6000 ppm). The MnO shows an opposite trend to the Mg# (Fig. 6.6). The Mg# of the clinopyroxene in the TGA sequence range from 77 to 93, with the highest values associated with olivine-bearing gabbronorite, and a slight decrease to the base of the T2.
The clinopyroxene Mg# in the T zone is lower than the two previous sequences, ranging from 73 to 81 (average 78). The Cr concentrations are very low compared with the UmS, the Cr ranges from 300 to 1500 ppm (average ~1000 ppm) (Fig. 6.6). The clinopyroxene grains are slightly more Fe-rich towards the top contact with the UZ lithologies. The Mn values are 1.2 x higher in the T zone compared with the UmS (Fig. 6.6). The Mg# associated with the magnetite gabbronorite of the UZ range from 75 to 83. Overall the clinopyroxene Mg# values are higher through the Waterberg Bushveld stratigraphy compared with the Mg# values obtained from the orthopyroxene samples (Fig. 6.5 and 6.6). Similar features are seen in the northern limb stratigraphy (Bellevue drillcore) and in the Aurora project stratigraphy (Ashwal *et al*. 2005; Roelofse and Ashwal 2012; Tanner *et al*. 2014; McDonald *et al*. 2017).

Plagioclase

The plagioclase is mainly labradorite and bytownite, which display a variation in composition (An_{54-82}) through the Waterberg stratigraphy (Fig. 6.4). The plagioclase associated with the feldspathic pyroxenite and feldspathic harzburgite within the UmS are generally interstitial and their composition has a large range (An_{54-85}) (Fig. 6.7). Within the TGA sequence the plagioclase crystals are mainly cumulus and the composition has a more restricted range (An_{65-80}, average of An_{72}) (Fig. 6.7). The plagioclase in the T zone has compositions of An_{69-82}, although there are three samples within the mineralised package with more sodic compositions (An_{61-63}) associated with pegmatoidal units. The UZ rocks show the most restricted plagioclase compositions (An_{68-74}) (Fig. 6.7).

Olivine

The olivine composition is dominated by forsterite which range from Fo_{61-89} within the olivine bearing units of the Waterberg Bushveld succession (Fig. 6.4). The olivine compositions are extremely high (Fo_{74-89}, average Fo_{82}) within the olivine-bearing UmS (Fig. 6.7). The overlying troctolite unit at the base of the TGA sequence from 1270.16 m to 1208.00 m, has a restricted composition for olivine (Fo_{76-80}, average Fo_{77}, NiO wt. % 0.23 to 0.27) (Fig. 6.7). Olivine concentrations decrease upwards into an olivine-gabbronorite with a larger compositional range (Fo_{69-75}, average Fo_{72}, NiO wt. % 0.16 to 0.27). The T1 contains olivine with a restricted compositional range (Fo_{64-66}, NiO wt. % 0.18 to 0.21) associated with olivine-feldspathic pyroxenite and troctolite (Fig. 6.7).

Examiner: Page 151, 1st para, line 1: Rephrased.
Response: Changed as suggested by the examiner. “Pure plagioclase has a ratio of 0.6 and orthopyroxene contains minimal amounts of either element, therefore amounts values above or below 0.6 suggest the presence of clinopyroxene or possible reactions with dolomite (Kinnaird, 2005).”

Examiner: Page 151, 2nd para, line 5: Rephrased.
Response: Changed as suggested by the examiner. “At the base of the T2 there is an increase in the $Sr:Al_2O_3$ ratio that decreases gradually towards the top of the T1, with $Sr:Al_2O_3$ dropping from 18 to 10. The UZ samples show a range from 2 to 8 associated with the $Sr:Al_2O_3$ ratio. According to Kinnaird (2005) the Al_2O_3:FeO+MgO ratio varies with changing pyroxene to plagioclase proportions and sudden changes may indicate whether more than one magma was involved in forming the Bushveld succession. There is only one significant change in the Al_2O_3:FeO+MgO ratio at the contact between the UmS and TGA sequence in the Waterberg stratigraphy.”

Examiner: Page 151, 3rd para, line 3: Rephrased. Rewrite - makes no sense as written
Response: Changed as suggested by the examiner. “The TiO_2 contents in the UmS varies depending on the lithologies, the feldspathic orthopyroxenite samples have higher TiO_2 values (0.14 and 0.23 wt. %) and the TiO_2 contents ranges between 0.06 to 0.08 wt. % for the harzburgite and mela-troctolite samples.”

Examiner: Page 154, 2nd para, line 2: Why in this sentence are you talking about Pd dominance, thickness and Pt-Pd-Au grade? Organization needs to be improved - make it easy for the reader to follow a logical pattern.
Response: This section is labelled mineralisation and figure 6.10 accompanies this paragraph. Here we are describing the mineralised packages of the Waterberg stratigraphy. This sentence is giving the reader a brief understanding of the thickness and grades associated with the ore-bearing minerals. “Variations in PGE+Au grades, base metals, S and Cr content in the WB017 F zone are shown in Fig. 6.10 based on the assay results obtained from Platinum Group Metals (PTM). The mineralised interval is approximately 50 m thick (1004.00 m to 1054.00 m) in WB017 with grades of Pt+Pd+Au ranging from <2 g/t to >10 g/t (Fig. 6.10).”

Examiner: Page 154, 2nd para, last line: Rephrased
Response: Changed as suggested by the examiner. "There is generally a good correlation with visible chalcopyrite and pentlandite in core with high PGE+Au grades."

Examiner: Page 154, 3rd para, last line: Rephrased
Response: Changed as suggested by the examiner. "The Cu/Pd values is a good indicator of sulphide melt enrichment due to a contrast in Cu and Pd partitioning coefficient into sulphide melt during the exchange with silicate melts (Barnes and Maier 2002; Naldrett *et al*. 2009). The Cu/Pd values are between 250 and 600 associated with grades greater than 2 g/t of 2PGE+Au. The F mineralised zone hosts disseminated, blebby and semi-massive sulphides with accessory chromite, the PGE comprise 65% Pd, 30% Pt, and 5% Au with 0.07% Ni and 0.17% Cu (Table 6.1) (PTM 2016). The dominant PGM that occur in the F zone are sperrylite (up to 82%) and Pt-Pd bismuthotellurides (up to 32%) and there is a lack of PGE sulphides (McCreesh *et al*., 2018)."

Examiner: Page 155, 1st para, line 6: Rephrased
Response: Changed as suggested by the examiner. "The Cr content is extremely low (<300 ppm) and there is an anti-correlation with Cr and PGE+Au enrichment which is similar to the F zone (Fig. 6.11)."

Examiner: Page 160, 1st para, line 3: Rephrased
Response: Changed as suggested by the examiner. "However, these two ultramafic sequences show significant differences in terms of mineralogy, geochemistry and mineralisation when compared to the ultramafic F zone."

Examiner: Page 160, 2nd para, line 14: Rephrased
Response: Changed as suggested by the examiner. "The MnO (wt. %) and Cr_2O_3 (wt. %) of low-Ca pyroxenes are also comparable to that of the low-Ca pyroxene in the Platreef (Fig. 6.12)."

Examiner: Page 160, 2nd para, line 14: How does olivine form mineralized rock types? Be more meticulous in what you are saying.
Response: Changed as suggested by the examiner. "In certain areas of the Platreef and Merensky Reef (western limb) olivine (Fo_{81-85} and Fo_{79-80}, respectively) forms feldspathic harzburgite (Van der Merwe, 1976; Vermaak and Hendriks, 1976; Kruger and Marsh, 1982; Maier and Eales, 1997; Yudovskaya *et al*., 2011)."

Examiner: Page 161, 1st para, line 3: Very unclear what you are concluding. Is the F zone Platreef? Or do you mean it formed from a similar Critical Zone type melt.
Response: Changed as suggested by the examiner. "However, the F zone has some unique features, rather than indicating that this mineralised zone is directly related to the Platreef, we suggest that the F zone formed from a Critical Zone type melt (i.e. Platreef)."

Examiner: Page 167, 1st para, last sentence: fractionated
Do you mean the initial fractionation was reversed by addition of new magma? And then the process of crystal fractionation started again?
Response: Changed as suggested by the examiner. "Subsequently, fractionation of gabbroic magmas may have been disturbed by addition of more gabbroic liquid, leading to a fractionated TGA sequence upwards."

Examiner: Page 167, 2nd para, line 6: Rephrased
Response: Changed as suggested by the examiner. "Furthermore, interstitial disseminated magnetite is present in the upper T2, indicating a possible conversion of SO_4^{-2} in the magma to S^{-2} that contributed to sulphur saturation being attained (Keays and Tegner, 2015)."

Chapter 7:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Abstract

Examiner: Page 170, Abstract, line 5: not a good indicator - the range and mode are better
Response: The average is given here to indicate that most of the sulphur isotope values fall within the magma or mantle range. The range and mode may indicate that there is quite a bit of crustal contamination which is not the case in the Waterberg sulphur isotope values.

Examiner: Page 170, Abstract, line 5: Rephrased
Response: Changed as suggested by the examiner. "The ultramafic mineralised zone at the base of the Waterberg succession has sulphur isotopic signatures which are within mantle range (average $\delta^{34}S$ = 1.18 ‰), although close to the footwall, there are a few samples with higher S isotope ratios thought to be related to remobilisation of sulphides during later hydrothermal processes (highest $\delta^{34}S$ = 3.17 ‰)."

Examiner: Page 170, Abstract, last two sentences: Rephrased
Response: Changed as suggested by the examiner. "Sulphur isotope ratios are consistent with the involvement of mantle S only in the mineralised zones. There is no evidence for contamination involving S-bearing sedimentary rocks; this is a unique characteristic compared with the rest of the northern limb. The data suggest that sulphide saturation in the magmas was not caused by external S addition, and that PGE enrichment was due to fractional crystallisation processes or influxes of PGE enriched magmas."

Examiner: Page 170, 2nd para, 2nd sentence: Rephrased
Response: Changed as suggested by the examiner. "Many authors have considered the presence of sulphur-bearing country rocks as one of the favourable factors in producing sulphide mineralisation, as an addition of external sulphur during transportation or emplacement is thought to be a key processes for the formation of many magmatic Cu-Ni-PGE deposit (Naldrett, 2004; Ripley and Li, 2013; Lesher *et al*., 2017)."

Examiner: Page 170, 2nd para, 3rd sentence: Rephrased
Response: Changed as suggested by the examiner. "The reef-style PGE mineralisation in the Bushveld Complex such as the Merensky Reef, UG2 and the newly discovered reef-style mineralisation in the upper Platreef on Turfspruit and Sandsloot generally have sulphur isotopic signatures that are consistent with mantle derivation (Liebenberg 1968; Holwell *et al*., 2007; Penniston-Dorland *et al*., 2012; Yudovskaya *et al*., 2017)."

Examiner: Page 171, 1st para, last sentence: Rephrased "not clear - on the style of Waterberg mineralization as compared to other mineralized areas in the Bushveld Complex????"
Response: Changed as suggested by the examiner. "Our findings also shed a light on a style mineralisation in the Waterberg area when comparing with the rest of the mineralised zones associated with the Bushveld Complex."

Examiner: Page 172, 1st para, first sentence: Rephrased
Response: Changed as suggested by the examiner. "The platinum-group element (PGE) resources of the Bushveld Complex are hosted by three of the largest PGE deposits; the UG2, the Merensky Reef and the Platreef (Eales and Cawthorn, 1996)."

Examiner: Page 177, 1st para, third sentence: Rephrased
Response: Changed as suggested by the examiner. "The overlying Ultramafic Sequence (UmS), intruded as chonolith-shaped bodies (i.e. elongated, irregular or tube-like bodies propagating as finger-like injections) (Huthmann *et al*., 2018).

Examiner: Page 177, 3rd para, line 5: Rephrased, mantle? But somewhere you will need to mention that you are referring to MORB-like mantle, or some similar reference. Depending on your preference for the origin of kimberlites, their mantle source appears to be characterized by a wide-range of S isotope values. Could be SCLM or mantle affected by subduction, but in either case S isotope values are variable, and outside of the +/- 2 ‰ range seen in more shallow mantle.
Response: Changed as suggested by the examiner. "magmatic" changed to "mantle-like"

Examiner: Page 177, 4th para, third sentence: Rephrased
Response: Changed as suggested by the examiner. "Hulbert (1983) concluded that most of the sulphides formed from S of mantle origin, whereas the elevated values were attributed to contamination with volatiles from sedimentary material."

Examiner: Page 178, 3rd para, last sentence: I suspect that you mean "mantle". But shallow mantle values are not 3.3 ‰. Delta values this high indicate a contribution of crustal S. The external S may have had lower values than those of the shales, for example, but still a crustal contaminant is indicated.
Response: I agree which the examiner and have change the term "magmatic" to "mantle-like". The interpretation however, is the work of Sharman-Harris et al., (2005). Here the authors is not arguing with work done by others and is simply proving a review of the current data on the northern limb.

Examiner: Page 179, 4th para, second sentence: Rephrased
Response: Changed as suggested by the examiner. "Holwell *et al*. (2007) sampled pyrite, chalcopyrite and millerite from granite-gneiss on the La Pucella farm and obtained $\delta^{34}S$ values ranging from -1.5 to 0.8 ‰."

Examiner: Page 185, 1st para: Rephrased
Response: Changed as suggested by the examiner. "*T zone:* eight sulphide separates from medium- to coarse-grained gabbronorite and gabbro showed a narrow range of -0.48 to 0.29 ‰, which are the "purest" mantle-like signature within the Waterberg dataset (Fig. 7.3)."

Examiner: Page 185, 4th para, second sentence: Rephrased
Response: Changed as suggested by the examiner. "Westerlund *et al*. (2004) analysed sulphide inclusions in diamonds hosted by eclogites from the Klipspringer kimberlite 25 km east of Mokopane, which yielded $\delta^{34}S$ values between -1.8 and +2.4 ‰ with a mean of +1.0 ‰ determined from 44 samples (Fig. 7.2)."

Chapter 8:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Chapter 9:

Response: All small comments have been corrected as seen in the PDF as suggest by the Examiner (i.e. grammar, punctuation and addition or removal of certain words).

Examiner: Page 248, 3rd para, first sentence: Rephrased
Response: Changed as suggested by the examiner. “The mineralisation of the Rum intrusion in Scotland is very different from that in the F zone (Table 9.3).”