The Geology, Geochemistry and Geophysics of the Southeastern Flank of the Dennilton Dome, Northern Province, South Africa: Implications for Exploration

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ABSTRACT

The study area is located in the Republic of South Africa in the Northern Province between Loskop Dam and the town of Groblersdal, on the SE flank of the Dennilton Dome, and is underlain by lithologies of the Transvaal Sequence and Bushveld Complex. The rocktypes of the Rustenburg Layered Suite on the farm Rietfontein 70JS are subdivided into a Mixed Zone, Critical Zone and Main Zone, on grounds of certain geochemical and geophysical attributes. The Fe-rich constituents of these stratigraphic horizons generate a pronounced magnetic anomaly within the study area.

On the basis of, amongst other parameters, Zr/Rb and Sr/Al_2O_3 ratios the magnetite-gabbros are postulated to conform to lithotypes at the stratigraphic level of magnetite layers 8 to 14 of Upper Zone Subzone B in a normal Bushveld Complex stratigraphical subdivision. The feldspathic pyroxenites and norites that display elevated chromium values are analogues to normal Critical Zone rocktypes of the Rustenburg Layered Suite. A more precise stratigraphic correlation for the Critical Zone was, however, not possible.

Evidence produced by this study indicate that the exploration methods and techniques employed during this study can be applied with success to geological settings where lithotypes with a Bushveld Complex affinity occur, in order to elucidate potentially viable deposits. A comparison is also made between the merits of utilising regional—as opposed to detailed—grid geochemistry and geophysical methods, and the results thereof.

INTRODUCTION

The farm Rietfontein is situated 7 km north of Loskop Dam in the Northern Province on the southeast flank of the Dennilton Dome, and is located on lithologies of, inter alia the mafic and ultramafic rocks of the Bushveld Complex (BC), the Pretoria Group (BC floor-rocks) and the Rooiberg Group (BC roof-rocks). Field work consisted primarily of the establishment of a grid system, geochemical soil and hard rock sampling, geological mapping, geophysical surveys and Landsat and aerial photograph interpretations, and were conducted to ascertain the nature and economical viability of essentially the BC rocktypes adjacent to the Dennilton Dome. Five diamond drill boreholes were subsequently drilled.

The principal objectives are to provide an overview of the geology, geochemistry and geophysical signature of the mafic and ultramafic suites in the study area, and to attempt to postulate a meaningful stratigraphic correlation with the normal sequence of the Rustenburg Layered Suite (RLS) in the eastern BC. In addition, an attempt is made to compare the merits of utilising regional—as opposed to detailed—grid geochemistry and geophysical methods. Preliminary assessments (Crous, 1993) of this farm indicate that the potential for economical viable PGE, Cu, Ni and Au certainly appears feasible.

REGIONAL GEOLOGICAL SETTING AND PHYSIOGRAPHY

The mafic and ultramafic rocks underlying the area of interest on the southern limb of the Dennilton Dome is regarded as part of the Groblersdal sector of the eastern lobe of the BC, and is positioned between the Dennilton Dome and the northern limit of the Cullinan-Middelburg Basin. A diverse assemblage of lithotypes underlies the study area, and comprises predominantly of mafic rocktypes of the BC and Transvaal Sequence floor- and roof portions of the BC. The quartzites on the northern boundary of this farm give rise to a very prominent escarpment. The topography of the region is undulating in places and surface elevations range between 980 m above mean sea level (mamsl) in the central portion of this farm, to 1325 mamsl on the hilly terrain that is overlain by BC roof-rocks, in the southwestern sector of the farm. An

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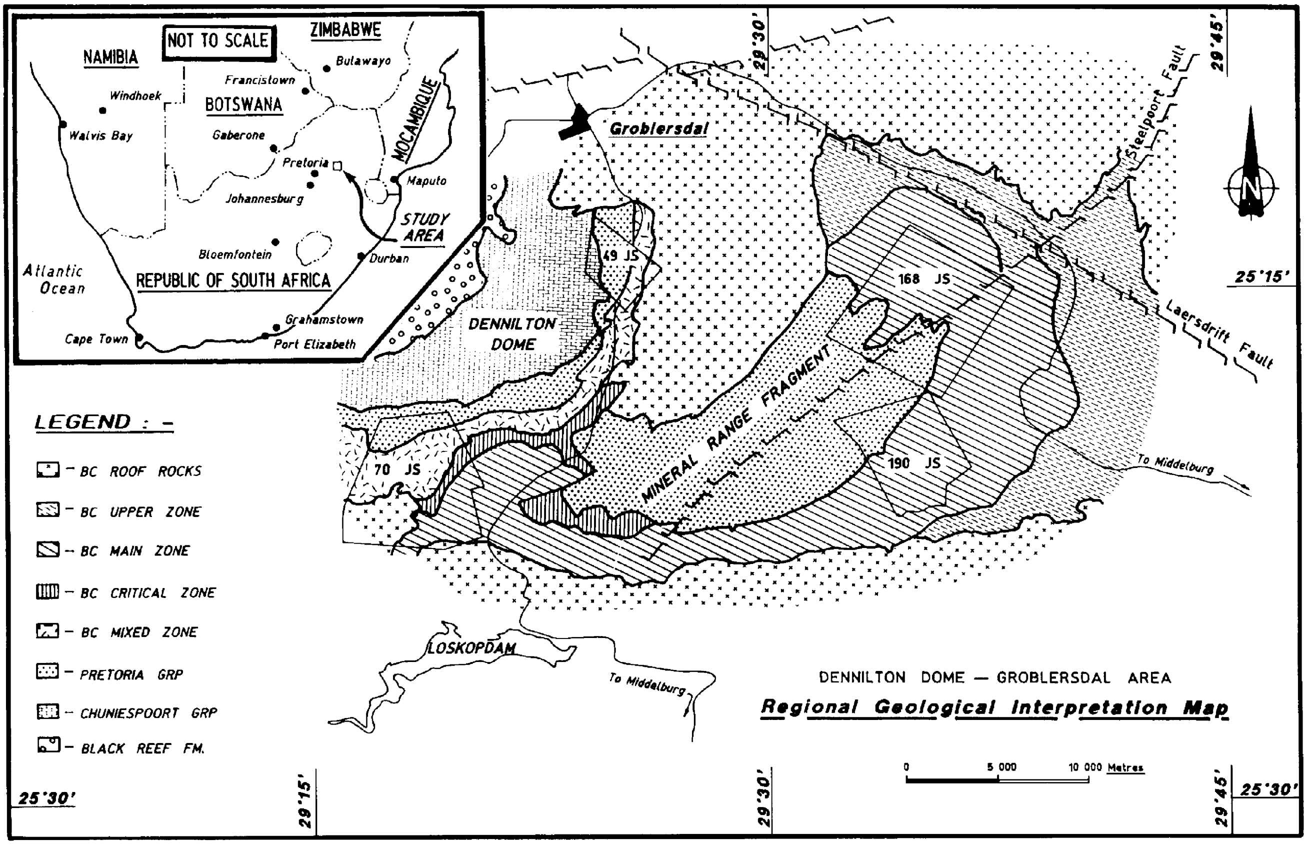

Figure 1: *Regional geological interpretation map of the Dennilton Dome – Greoblersdal area.*

ephemeral stream traverses Rietfontein in an east-west direction, and effectively dissects the two main drainage domains.

GEOLOGY AND LITHOSTRATIGRAPHY

The study area is underlain by Transvaal Sequence rocktypes, as well as various units that conform to the RLS of the BC. Due to the incomparitive nature of certain lithologies to the formal stratigraphic subdivision of the eastern BC, reference is made to a "Mixed Zone". Based on certain criteria (mineralogy, geochemistry) this Mixed Zone (MxZ) includes units that conform to the Lower Zone (LZ), Upper Zone (UZ) and possibly Critical Zone (CZ) of the normal eastern BC subdivision. For the purpose of this study, however, the CZ rocktypes are divorced from the MxZ and are thus discussed as a separate unit, but could most certainly be classified under the MxZ.

The Bushveld Complex Floor Rocks

The early-Proterozoic quartzites and shales of the Pretoria Group of the Transvaal Sequence represent the oldest rocktypes in the area. Some of the these rocktypes were subjected to metamorphism, caused by the intrusion of the BC. This metamorphic event resulted in the disturbance of the normal stratigraphic sequence of the floor-rocks in terms of thickness and continuity of certain units.

Bushveld Complex Mafic- and Ultramafic Rocks

The so-called Mixed Zone on Rietfontein conforms to some extent to certain units of the Lower CZ and LZ of the normal RLS stratigraphy. Locally, the MxZ is subdivided into the Upper-, Middle-, and Lower Units, which basically comprise of BC mafic lithotypes intruded by a number of dykes and sills of granitic composition. The entire MxZ package contains a whole range of quartzite and hornfels xenoliths. These xenoliths are not restricted to the basal portion of the MxZ. A micronorite marks the base of the MxZ, and occurs stratigraphically above a mafic hornfels. The micronoritic unit is overlain by a sulphidic norite that is made up of essentially finely disseminated chalcopyrite and pyrrhotite set in a fine- to medium grained orthopyroxene-plagioclase matrix. A medium-grained gabbro-norite occurs above the sulphidic norite, and occasionally contains minor disseminated sulphides. This gabbro-norite is in turn overlain by a magnetite-gabbro zone. In some cases, seemingly massive magnetite layers could be recognised within the magnetite-gabbro units. A relatively high chromium content is associated with the magnetite-bearing horizons of the MxZ Lower Unit on Rietfontein. Microscopically, the magnetite-gabbros primarily consist of subhedral plagioclase crystals, augite (as cumulus and intercumulus phases), and orthopyroxene. The subsidiary minerals include hornblende, chlorite and minor sericite and phlogopite. The principal opaque minerals are magnetite, ilmenite, chalcopyrite, pyrite, pyrrhotite and covellite. In the majority of cases the magnetite occurs as a cumulus phase, and is frequently partially or completely replaced by ilmenite. A

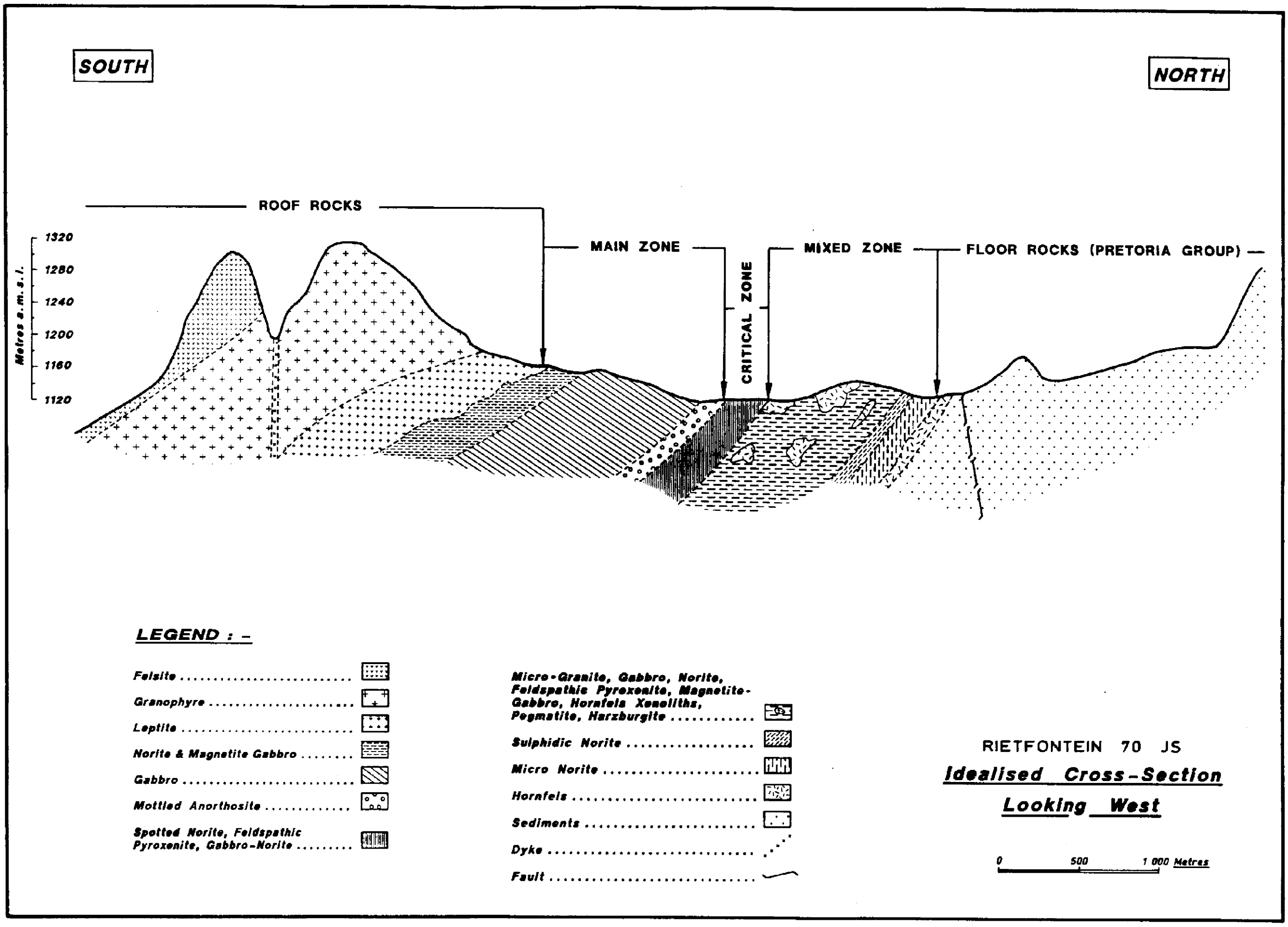

Figure 2: *Idealized cross-section looking west (Rietfontein 70 JS).*

number of relatively thin, fine-grained feldspathic pyroxenites are interlayered with the thick magnetite-gabbro pile. These pyroxenitic zones regularly include a high proportion of iron-rich pegmatites, that consist mainly of large phenocrysts of orthopyroxene, plagioclase, biotite and frequently magnetite. In many instances the pyroxenes have been altered to amphibole, which appears to be tremolite. Veins and blebs of equigranular magnetite, together with sporadic occurrences of sulphides (predominantly pyrrhotite and chalcopyrite) occur throughout the pegmatitic zone. Several, thin harzburgite layers are interwoven with the feldspathic pyroxenites. These harzburgites contain minor disseminated sulphides, and in certain instances the olivines have been severely altered. A medium- to coarse-grained micaceous, feldspathic pyroxenite caps the Lower Unit of the MxZ. This feldspathic pyroxenite frequently contains minor disseminated sulphides. Numerous veins of granitic intrusive material are present within the Lower Unit. An extremely conspicuous magnetic signature marks the Lower Unit of the Mixed zone.

The bulk of the Middle Unit of the MxZ is made up of pegmatitic pyroxenites at the base, and medium-grained norites as the topmost member of this unit. A discernible low magnetic signature demarcates the gabbronorites of the Upper Unit. The spotted norites of the Critical Zone are well exposed on surface and although it possesses a unique geochemical signature, magnetics can also be used to fingerprint this zone and separate it from the adjacent stratigraphic zones. Medium-grained feldspathic pyroxenite units are interbedded with noritic layers, and in some cases take on a pegmatitic nature with abundant disseminated sulphides. Coarser pyrrhotite and chalcopyrite can intermittently be observed within these feldspathic, pyroxenitic pegmatites. Chromite blebs are occasionally present at certain intervals throughout the feldspathic pyroxenites. Medium-grained gabbro, as well as gabbro-norite constitute the uppermost units of this zone. These gabbroic units appear to be devoid of any significant mineralization. The bulk of the Main Zone (MZ) in the study area is made up of medium- to coarse-grained, monotonous gabbro. The gabbros predominate in the MZ, together with a fine- to medium-grained norite. A very conspicuous mottled anorthosite unit marks the base of the MZ.

Bushveld Complex Roof-rocks

The leptites on Rietfontein are represented by an orange-pink, fine- to medium grained quartz-feldspar rock with a granular texture, and evidently originates from the felsites, thus a meta-felsite. Stratigraphically, the granophyres are situated between the Bushveld mafic phase and the felsic roof-rocks and occur as an orange-red coloured, medium to coarse grained rock that comprises primarily of quartz and potassium-feldspar with minor hornblende. The felsite that occupies a large portion of the mountainous area on the southwest boundary of Rietfontein is well exposed and can be recognised as a fine-grained, reddish, porphyritic, rhyolitic lava, with irregular intergrowth of quartz and feldspar. An abundance of micro-granitic and micro-granophyric veins are visible on Rietfontein.

GEOCHEMISTRY

A grid system of 200 m × 50 m (baseline = 7.5 km) was established on the southern portion of Rietfontein and was soil sampled, which resulted in 1308 soil samples being collected. All soil samples were screened by means of a –80# mesh fraction sieve and were submitted for copper (Cu), nickel (Ni), chromium (Cr), cobalt (Co), titanium (TiO_2) and vanadium (V) analysis.

In order to facilitate mapping and interpretation studies, 179 hardrock samples of different lithologies were collected and assayed for Cu, Ni, Cr, TiO_2, V and PGE+Au. Anomalous Cr, Ni and PGE+Au are associated with the norites of the CZ and the pegmatites of the MxZ Middle Unit. Half core samples from five boreholes were submitted for analysis of Cu, Ni, Cr, TiO_2, V, Co , S^{-2} and PGE +Au. It is evident that the highest *copper* values that were encountered in soils (696, 389 ppm Cu) are several orders of magnitude greater than the background value 50 ppm Cu. Bearing the moderately undulating topography and near neutral soil conditions in mind, it can be seen that the Cu anomalies correspond well with the elevated Ni and Cr values in soils, and can be attributed to the sulphide mineralization within the ultramafic lithologies and the Fe-rich gabbros of the MxZ.

The very high nickel assay values that were encountered for the magnetite-gabbro units in borehole RF5 can be attributed to nickel contained in sulphides. The relatively high inherent Ni content of the ultramafic lithologies due to the silicate Ni in the lattice, must also be brought into account when interpreting the dispersion pattern of Ni. The more primitive magmas in the lower parts of intrusions such as the BC possesses a higher forsterite (Fo) content than the evolved magmas at higher levels in the succession. The position of the low-Ni, olivine-rich rocktypes can thus be determined. The high Fo-olivines are more susceptible to weathering, with the subsequent formation of magnesite ($MgCO_3$) and the possible contemporaneous release of Ni. The highest Ni values in the soils are in the order of 305 ppm, with minor highly anomalous values (1155 ppm Ni) over some of the apparently mineralized areas, where the Ni anomalies occur in close association with Cu and Cr.

In a number of cases visible chromite was observed in the core of certain boreholes, and corresponded with elevated chromium assay values. Although it is possible that in the absence of chromite, chromium can substitute in magnetite, it appears that a closer association with the pyroxenes is evident. The anomalous Cr levels can consistently be related to the pyroxenitic and harzburgitic units of essentially the MxZ and CZ, where the actual Cr values are in the order of 3000 to 9300 ppm Cr. There are, however, isolated cases where magnetite-bearing units are responsible for anomalous Cr values. Background values of 147 ppm Cr in soils were calculated, with the highest values encountered being 1324 and 2748 ppm. Bearing in mind the mobility of Cr in the secondary environment, it can be seen that the anomalous Cr values seem to effectively outline the pyroxenitic units of the MxZ, as well as the CZ lithologies. These anomalies over the CZ correspond well with the anomalous signature displayed by Ni in soils, whereas the Cu in soils did not show any significant response.

The elements titanium and vanadium can be used to establish fractionation trends for chemically more evolved rocktypes at higher stratigraphical levels in this layered intrusion. Rocktypes such as the titanomagnetite layers and magnetite-gabbro units that reside under the BC UZ can thus be differentiated on grounds of, amongst other parameters, the TiO_2 and V trends and signatures. In a normal BC situation, the TiO_2-content of the magnetite-bearing units gradually increases upwards in the UZ succession, with an associated decrease in V_2O_5. Klemm *et al.* (1985) provide compositional variations for the UZ units, and distinguishes between massive magnetite layers and units containing disseminated magnetite. The massive magnetite layers clearly show distinct lower V_2O_5 values to that of the units with the disseminated magnetite. The magnetite-bearing rocktypes on Rietfontein display assay values of up to 9.44% TiO_2 and 8789 ppm V, but the average TiO_2 and V values for the magnetite-rich units are in the region of 6.63% and 2724 ppm respectively. Calculated background values for TiO_2 and V in soils are 1.17% and 116 ppm respectively, with the highest values in the order of 770 ppm V and 5.04% TiO_2. The and TiO_2 contour maps effectively outline the magnetite-rich units of the MxZ. Only the soils and boreholes RF4 and RF5 core samples were assayed for cobalt. An isolated high value of 558 ppm Co was encountered in the soils and can possibly be explained by the limited Co substitution of certain sulphides (Ni-bearing ?) and Fe-Mg silicates in the MxZ lithotypes.

Selected borehole core and hard rock samples were analysed for PGE's and Au and the most encouraging values are associated with the CZ norites and the pegmatitic rocktypes of the MxZ Middle Unit. Only three platinum group elements were assayed for viz. platinum (Pt), palladium (Pd) and rhodium (Rh), together with Au. The highest PGE value encountered was 2430 ppb total PGE (1270 ppb Pt, 800 ppb Pd, 340 ppb Au) over a 630 mm intersection of a pegmatitic, magnetite-gabbro in the MxZ.

A number of hard-rock samples were collected from the various stratigraphic units in an attempt to separate certain units on grounds of geochemical element ratios. Results of these studies showed that the ratios $Cr/Ni*TiO_2$ and V/TiO_2 produced distinct, separate populations for the various rocktypes. These element groupings were utilised to aid in the interpretation and separation of the different stratigraphic entities of essentially the MxZ. Ratios such as V/TiO_2, Cr/Ni and Cr/TiO_2 were empirically derived to assist in the characterisation of mainly the finer grained rocktypes in borehole core of RF1 to RF5.

To investigate overall fractionation patterns within the layered sequence on the SE flank of the Dennilton Dome, 39 selected half core samples were subjected to major- and trace-element whole-rock analysis. The TiO_2 and associated V values that are reported for the magnetite-bearing rocktypes are significant in that it may provide answers as to the possible stratigraphic correlation of the latter units with a normal BC UZ scenario. The trace elements Sr, Rb, Y, Sc and Zr aided greatly to achieve this objective. If the trends of the indicator elements in the BC UZ are considered, it can be seen that the values of the selected elements collected from the study area fall within the prescribed range. In general, the Zr/Rb ratios of the magnetite-gabbros of the MxZ have values in the region of 2.55 which fall within the Zr/Rb range mentioned by Cawthorn and McCarthy (1985) for the magnetite-rich units of the upper 500 m of the RLS. The magnetite-gabbros of the MXz on Rietfontein that are located closer to the floor contact does, however, display extraordinary low Zr/Rb ratios such as 0.23 and 0.35, as a result of anomalously low Rb values. Cawthorn and McCarthy postulate that rocks rich in magnetite will have anomalously high (~10) Zr/Rb ratios, as the Zr is incorporated into the cumulus phase of the magnetite. In the upper 500 m of the BC sequence the incompatible elements Rb, Zr, Y and Nb show distinct trends where the content of the latter elements increases notably with stratigraphic height (Cawthorn and McCarthy, 1985). The magnetite-rich lithologies on Rietfontein fit well into the middle of this 500 m zone for all four elements. The calculated Sr/Al_2O_3 ratio values for the magnetite-gabbros from the study area are overall in the order of 5 units higher than the Sr/Al_2O_3 ratios quoted by Hoyle (1994) for the western BC UZ Subzone A (UZA), but seem to match comfortably with the normal UZ Subzone B (UZB). Hoyle (1992) furthermore used the oxides TiO_2 and P_2O_5 as parameters to distinguish between different stratigraphic units in the vicinity of the Pyroxenite Marker moreover within the UZ. If only the TiO_2 levels of whole rock analysis data taken from magnetite-rich rocks from Rietfontein are used, these lithotypes can be matched with either the typical C- or B- subzones of the UZ. The P_2O_5 content of the latter rocks, though clearly indicate an association with the UZB. Similarly, units that fall within the MZ on Rietfontein display Sr/Al_2O_3 ratios of 14.5 to 14.8 for the MZ gabbros, and 15.7 to 16.3 for the MZ anorthosites, which is also in agreement with the range for normal MZ stratigraphy of the RLS. Based on data supplied by Harmer and Sharpe (1985), the peridotitic lithotypes of the lower portions of the MxZ on Rietfontein can undoubtedly be correlated with the olivine-rich marginal rocks of the eastern BC, where an MgO content of 26–35 wt%, SiO_2 of 41–49 wt% and Rb/Sr ratios of >0.1 is required to fit this stratigraphic category.

In conclusion, the magnetite-rich units that occur on Rietfontein thus conform to the stratigraphy in the vicinity of magnetite layers 8 to 14 of Subzone B in a normal BC UZ scenario. Although the MZ gabbros fit a typical RLS MZ on grounds of whole rock geochemistry, it is not possible to make any further detailed stratigraphic correlation.

GEOPHYSICAL COMPONENTS

In conjunction with the geochemical sampling programmes on Rietfontein, a groundmagnetic and regional infill gravity survey was initiated. Groundmagnetic readings were recorded on an existing grid system with 200 m line spacings and 10 m station intervals and covered all the lithologies on the southern portion of the farm. Interpretation results of the groundmagnetics indicate a number of very prominent magnetic highs and lows. These anomalies effectively demarcate the different stratigraphic units on a broad scale, and also coincide with the different zones delineated by geochemistry. The groundmagnetic highs reach values in excess of 31 000 nT in certain areas (Fe-rich pegmatites, magnetite-gabbro units), whereas the felsites are well defined by a magnetic signature of greater than 29 400 nT. The MZ gabbro depicts a pronounced low (<29 200 nT) background value. The Pretoria Group sediments and the basal hornfels unit can also quite easily be outlined by means of groundmagnetics.

The total field government aeromagnetic data not only shows the existence of an extremely prominent magnetic high on Rietfontein, but

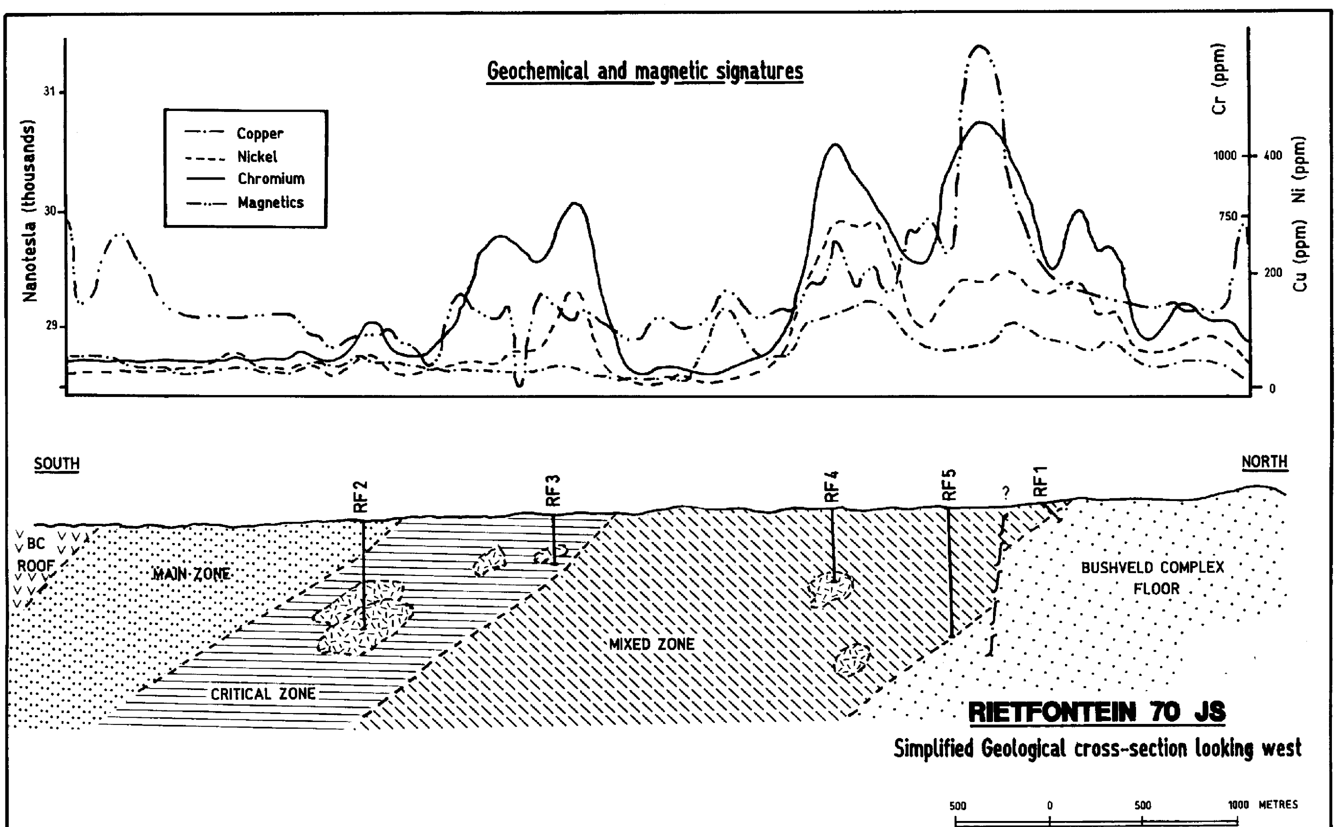

Figure 3: *Geochemical and magnetic signatures on the simplified geological cross-section section (looking west). Rietfontein 70 JS area.*

also supports the theory that mafic lithologies of the BC does occur as one continuous body all the way from Rietfontein on the southern rim of the Dennilton Dome up to the mafics to the east of Groblersdal. The magnetic field vertical derivative image shows that the structural framework seems to have had very limited influence on the proposed PGE-bearing ore deposit models. Regionally, the government Bouguer gravity data was supplemented with infill gravity obtained in the area, in order to produce a composite Bouguer gravity contour map of the entire southern and eastern flank of the Dennilton Dome. This contoured gravity image enhances the argument posed for the existence of mafics below the granites around the eastern perimeter of the Dennilton Dome. Two very pronounced gravity anomalies (> -100 mgal) are situated directly to the south of Groblersdal, and can possibly be ascribed to BC mafics in contact with inter alia, carbonate-rich lithotypes of the Malmani Subgroup beneath the granites/granophyres, on or near a conspicuous southeast-northwest trending lineament (parallel to the Laersdrift direction). These anomalies may represent a skarn-type ore body, Fe/TiO_2 plug or even Platreef-type mineralization of significant magnitude.

Density and magnetic susceptibility measurements were conducted in a number of boreholes that were drilled on Rietfontein. Although rather subtle, concentrations of magnetite and the zones of chloritization and serpentinization could unquestionably be differentiated from the surrounding units on grounds of magnetic susceptibilities.

DISCUSSION AND CONCLUSIONS

The objectives of this study to provide an overview of the geological, geochemical and geophysical signatures of the study area were met. Certain analogies and relationships such as correlating the magnetite-gabbros on Rietfontein with Subzone B of the standard BC UZ stratigraphy could be drawn on grounds of incompatible trace element geochemistry. The hybrid nature and geological/geochemical complexity of the rocktypes in the study area does not render itself to a more comprehensive stratigraphic correlation, an issue which is further complicated by the intrusion of pre- and syn-RLS gabbroic sills in the vicinity of the BC marginal rocks. The relatively unaltered MZ gabbros on Rietfontein does, however, conform on a broad basis to normal MZ lithologies on grounds of geochemistry and petrography.

Three possible explanations are posed to elucidate the enigma of the occurrence of CZ lithologies stratigraphically above the magnetite-bearing rocktypes of the UZ. It is assumed that the CZ was already in place and solidified at the time of UZ intrusion. Firstly, the UZ magma possibly intruded into weak zones below the CZ conceivably caused by the updoming of the Dennilton Dome, thus following the path of least resistance. Secondly, an alternative scenario is premised whereby large fragments of crystallised CZ were broken off and transported by the intruding UZ magma, together with various foreign fragments. These large CZ and BC floor "xenoliths" were exposed to re-melting and re-crystallization processes, resulting in a myriad of diverse rocktypes of complicated hybrid compositions. The latter ideology may also explain the erratic distribution of the anomalous Cu, Ni, Cr and PGE values in close proximity to these xenoliths. In accordance with theories posed by Scoon and Mitchell (1994), the magnetite-rich gabbros and pegmatites may have formed by magmatic replacement of existing cumulates in response to infiltration of Fe-rich melts. In a normal BC set-up these Fe-rich replacement units become progressively enriched in Fe and Ti oxides with stratigraphic height, where preferential replacement of anorthositic cumulates takes place (Scoon and Mitchell, 1994) to result in the formation of essentially Fe-Ti-rich pegmatites.

Considering the fact that magnetite was identified as a cumulus phase in magnetite-gabbros on Rietfontein together with the layered effect displayed by these Fe-gabbros, and the discordant nature of certain Fe-Ti-rich pyroxenitic pegmatites, a combination of the latter three theories could provide a solution for the genesis of the Fe-rich lithologies in the study area. The mere existence of a CZ-type environment with cumulus chromite and plagioclase with elevated Ni, Cr and PGE values should provide an incentive for further exploration in the area.

The possibility exists that the original mineralization may have been destroyed or dispersed by the apparent transgressive character of the UZ lithotypes. The geophysical signature, and in particular the magnetics, of the rocktypes on the eastern flank of the Dennilton Dome indicates that the more evolved, Fe/Ti-rich rocks either thins or becomes absent as one progresses further northwards from Rietfontein.

It is therefore postulated that the potential for viable PGE's, Au, Cu and Ni within a Merensky Reef-type scenario, and/or contact-type situation under a thin veneer of BC roof-rocks, appears feasible. It is thus imperative that proven guidelines and parameters be employed to demarcate these favourable units viz. the CZ norites and feldspathic pyroxenites, as well as the contact between the ultramafics and Pretoria Group sediments on the eastern flank of the Dennilton Dome, where economically significant units may be developed at shallow depths.

In view of the geochemical results that were encountered on Rietfontein, it is clear that the elements Cu, Ni, TiO_2 and Cr ostensibly represent the most suitable pathfinder elements for locating potentially viable BC-type mineralization. Similarly, the element ratios such as Cu/Ni*Cr and Cr/Ni*TiO_2 proved to be invaluable in discriminating between different lithological units and also in providing answers as to the nature of the mineralization, when present. The –80# fraction sieve adequately enhanced relatively anomalous areas in soils.

It is argued that if the results of the regional aeromagnetic survey is compared to a detailed ground magnetic survey, it can be derived that exactly the same deductions could be made from both surveys, once the prospective horizon has been identified. The latter comments are obviously only applicable to a geological setting and proposed deposit models of this nature.

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