Paper 118

The Use of Density as a Stratigraphic and Correlative Tool for the Bushveld Complex, South Africa

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ABSTRACT

The Bushveld Complex of South Africa is a regionally extensive layered igneous body. The layering, caused by mineral variations, is clearly reflected in the density profiles. These profiles are used to show similarities and differences from two boreholes 300 km (~190 miles) apart. This Bushveld Complex example demonstrates that density can be used to reveal finer details of structure and mineral distributions than can be seen with the unaided eye. Though down-hole logging equipment will record density reading electronically, density also lends itself as a tool for the low technology field environment. Density should be seen as part of the first stage of exploration, along with geological and geotechnical logging or boreholes.

INTRODUCTION

The Bushveld Complex of South Africa extends over an area of approximately 65,000 km2 with a range of 7,000 to 9,000 m in thickness (Eales and Cawthorn, 1996), and is dated at 2 058.9 Ma ± 0.8 Ma (Buick et al, 2001) The majority of the Bushveld is composed of a basic, layered, suite of rocks with a younger felsic phase (Figure 1). The majority of the work has been carried out on the basic phase which has economic quantities of the platinum group metals, chrome and base metals.

The known exposure of the Bushveld Complex shows the intrusion to comprise five lobes, known as the northern/Potgietersrus limb, far western limb, western limb, eastern limb and the southern/Bethal limb. The main lobes suggest that the Bushveld Complex is composed of a series of dipping sheets that may, or may not, be linked at depth. The boreholes used in this study were drilled in the western (southwest) and eastern (northeast) limbs.

This paper looks at 1463 density readings from boreholes in the southwest and northeast of the Bushveld Complex. The boreholes, ZG74 and GC10 are approximately 300 km (186 miles) apart. The density was determined using the Archimedes Principle.

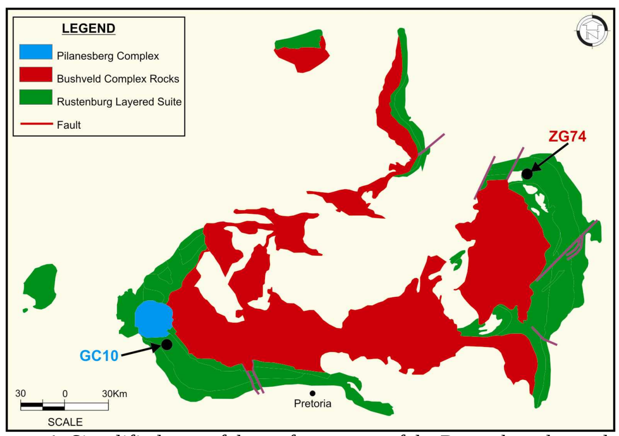

Figure 1: Simplified map of the surface extent of the Rustenburg layered suite (green) and the acid Bushveld rocks (red) which form the Bushveld Complex (map by SRK Consulting).

GEOLOGY OF THE SAMPLED BOREHOLES

The two borehole sections are within the transitional macro-unit (Seabrook et al., 2004) between the Upper Critical Zone and the Lower Main Zone as described by Kruger (1994). The boreholes intersected both the Bastard Cyclic Unit and the Merensky Cyclic Unit (including the Merensky Reef). Within the borehole sections analyzed the Merensky Reef occurs as narrow-type pyroxenite in GC10 and a thick-type pyroxenite in ZG74 (Figure 2)

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From the base of the section upwards (Figure 2) the GC10 section begins with a narrow pyroxene anorthosite (Wilson, et al., 2005) representing the very top of the UG2 Cyclic Unit. Above this is the pegmatoidal plagioclase pyroxenite of the Merensky Reef including the top and bottom chromitite stringers. Above the top chromitite stringer the plagioclase pyroxenite gradually changes into melanorite, norite and then a leuconorite. This represents the Merensky Cyclic Unit. The Bastard Cyclic Unit starts with a plagioclase pyroxenite. There is a sharp contact between the plagioclase pyroxenite and the norite and in turn a sharp contact between the norite and the poikilitic pyroxene anorthosite. The poikilitic pyroxene anorthosite continues to the top of the section.

In ZG74 the base of the section is located within the Merensky pyroxenite which is overlain by a thick plagioclase pyroxenite, including a unit of base-metal sulfides. Above the plagioclase pyroxenite the sequence of rock types is similar to that of GC10 (Figure 2).

DENSITY

The layered nature of the Bushveld Complex lends itself to the use of density as a stratigraphic tool. Densities were calculated for 692 samples from borehole GC10 in the southwest Bushveld Complex and for 771 samples from borehole ZG74 in the northeast Bushveld Complex.

The density was determined firstly by weighing the sample dry in air, and then weighing the sample immersed in water. Density was calculated using the formula:

$$\rho d = Weight\ in\ air/(Weight\ in\ air - Weight\ in\ water)$$

This method is based on the Archimedes principle that states;

'When a body is wholly or partially immersed in a fluid it experiences an upthrust equal to the weight of the fluid displaced.'

(Abbott, 1989)

The simple density measurement equipment used consisted of an electronic scale bridged over an empty bucket for the weight-in-air reading, that was then replaced with a bucket of water for the weight-in-water reading. Measurement precision was monitored by two check samples that were regularly tested and showed no significant variation for the temperature variation experienced. The samples did not require sealing due to the compact nature of the rock.

INTERPRETATION OF RESULTS

The combined plot of the results from boreholes GC10 and ZG74 were smoothed using a none weighted three-point moving average as shown in Figure 3. The base line used is the lower chromite stringer of the Merensky reef (shown as '0' on the y axis). The bottom reef chromite stringer is located at 598.77 meters above sea level in ZG74, and 1018.73 meters above sea level in GC10. The following features described below can be seen in Figure 3.

The high values at the base of the plot (above 3.25 g/cm3) show the effects of Base Metal Sulfide mineralization. ZG74 shows a wider Base Metal Sulfide zone and pyroxenite package compared to GC10. The decrease in values at the base of ZG74 suggests that the rock grades into a norite, while the lower values at the base of GC10 correspond to pyroxene anorthosite of the UG2 hanging wall.

Both boreholes show a gradational profile of decreasing values upwards from the Merensky Reef (seen as narrow reef and wide reef facies in Figure 3) to the base of the Bastard plagioclase pyroxenite. The characteristics of the Bastard Cyclic Unit are significantly different to the Merensky Cyclic Unit. Instead of a gradational decrease in density values, step-like features mark the change from the Bastard plagioclase pyroxenite, with limited visible base metal sulfides, to the Bastard norite and the Bastard poikilitic pyroxene anorthosite (Figure 3). The differences between the Merensky Cyclic Unit and the Bastard Cyclic Unit might reflect differences in the primary magmatic processes and changing magma composition.

Broad features seen in the profiles are as follows: a slight reversal in density, with an increase of values upwards, in the Bastard poikilitic pyroxene anorthosite, in both ZG74 and GC10. The affects of pervasive alteration resulting in a decrease in values, for example at the base of the Bastard plagioclase pyroxenite, a feature most clearly seen in GC10 (identified on Figure 3 as pervasive alteration).

A common feature within the profiles is the difference between the average densities of each of the cyclic units. ZG74 shows a slightly elevated density in the Merensky Reef plagioclase pyroxenite. The gradational phase towards the footwall of the Bastard Cyclic unit shows little difference. The Bastard plagioclase pyroxenite shows slightly higher relative values for GC10. The Bastard norite is significantly denser in GC10 compared to ZG74. Within the Bastard poikilitic anorthosite, in addition to the reverse density, there is a visible gap between the elevated values of GC10 profile compared to ZG74. This may reflect a change in the iron content of the pyroxenes.

CONCLUSIONS

Density determination is a rapid and effective tool for monitoring lithological differences in the exploration industry. It can be used on site either by electronic down-hole logging equipment, or done by hand using simple equipment. Samples sent to the laboratory can also be tested for density. The resulting profiles greatly enhance information derived from visual logging. Additional information would be gained by including density measurements as part of a suite of field tools such as a hand held magnetic susceptibility meter.

In the case of the Bushveld Complex, the strong similarities between the two profiles on both a broad and detailed scale suggest that the eastern and western limbs are joined at depth. Differences between the two profiles suggest that they formed at a similar time and by similar methods but as separate cumulative units. More investigation into the significance of the features described in this paper is required.

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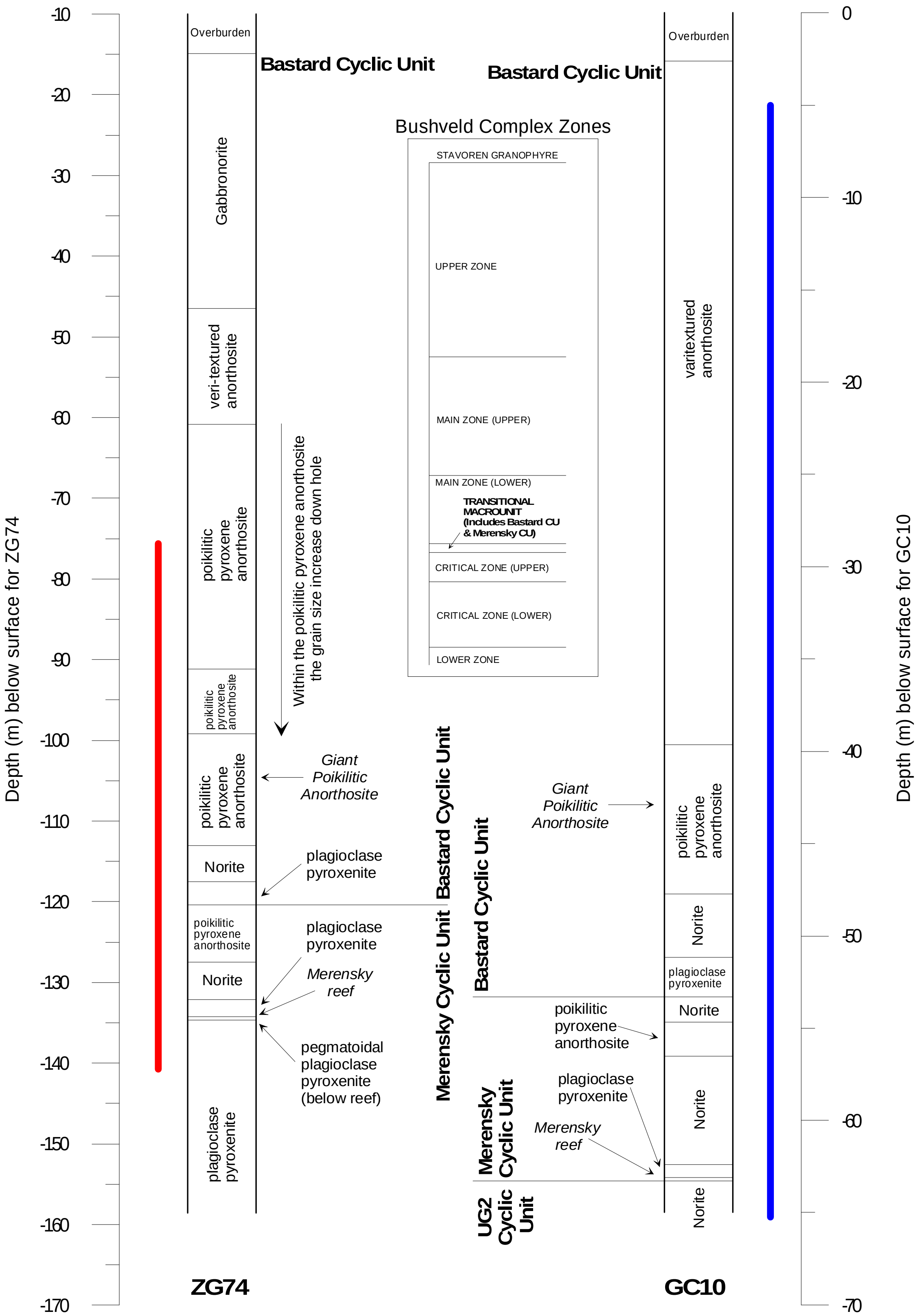

Figure 2: Simplified geological sections of the boreholes ZG74 and GC10. The red and blue bars indicate the positions of the length of core used for density measurements (from Davis, 2006).

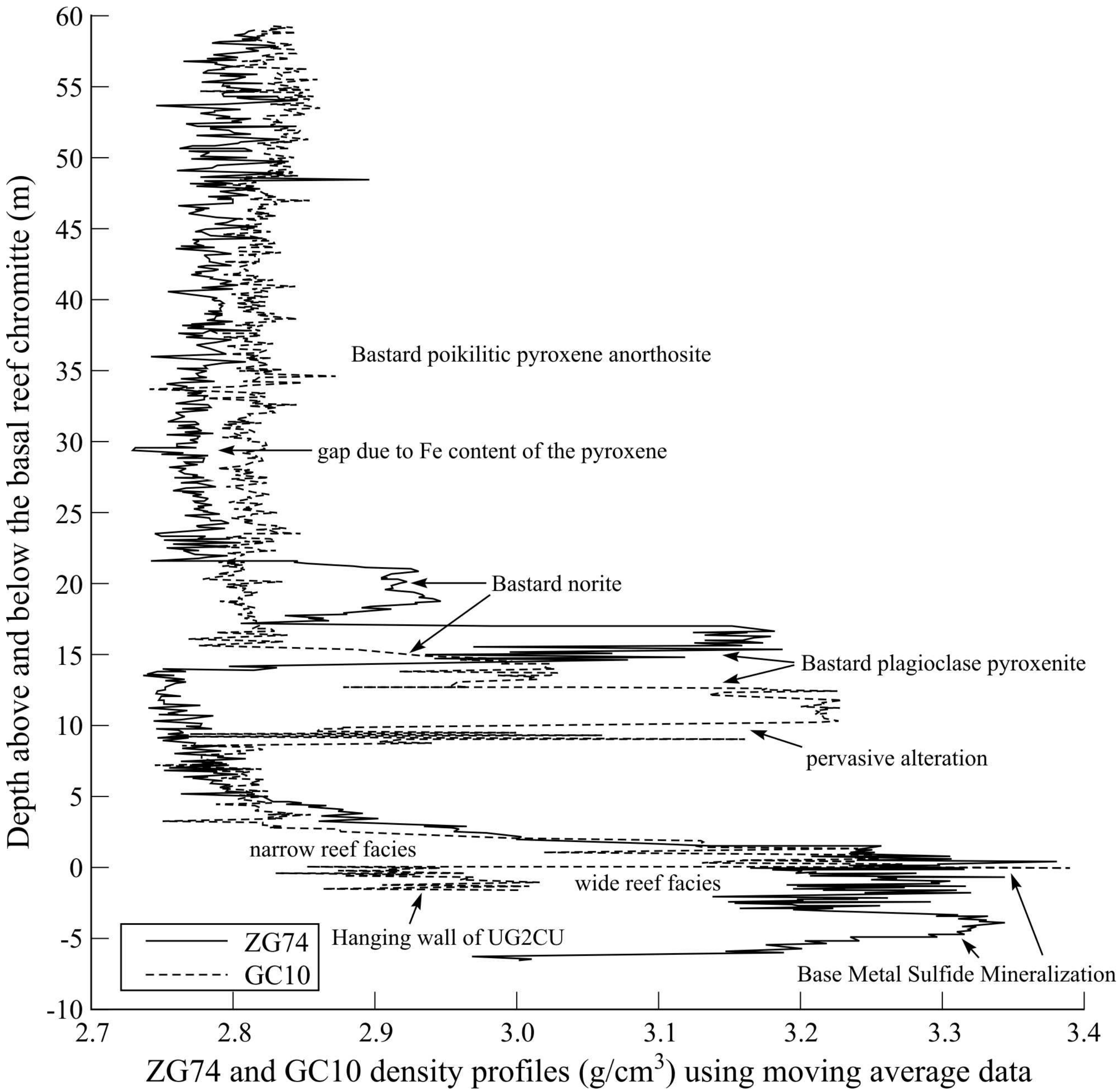

Figure 3: Density comparison between ZG74 (red) and GC10 (blue) showing the close relationships between the two profiles which come from boreholes almost 300 km apart. The base line (zero depth value) is the basal reef chromite stringer. The Merensky Reef is seen either as the narrow reef facies or the wide reef facies. Features of interest are annotated on the figure (from Davis, 2006).