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Near Surface Multiple Resistivity Method and Interpretation Study for Mining Uses within the Context of the South African Eastern Bushveld Complex

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SUMMARY

The Eastern Limb of the Bushveld Complex in South Africa has very little documented near surface resistivity studies within the mining context, even though resistivity surveys are relatively cost efficient. The resistivity measurements of individual rock core samples at specific depths reveal a highly resistive gabbronorite layer between 12 m and 27 m, which could be used to track economically important layers such as the Merensky Reef. Two-dimensional apparent resistivity models are integrated into a specific processing work flow procedure to reduce root mean square errors up to 20 % in some profiles, leading to an improved subsurface resistivity models for the Eastern Limb Bushveld Complex area. Two and three-dimensional resistivity profiles provide improved mapping of dyke extent that was found by aeromagnetic methods to be around 90 m in width but was shown to be between 10 to 16 m in width by the three-dimensional and two-dimensional resistivity profiles respectively. Three-dimensional resistivity arrays are shown to provide a high resolution subsurface geological model as well as covering a larger surface area than the two-dimensional resistivity arrays. Both two and three-dimensional resistivity arrays show potential in mining hazard detection for both hydrological pathway and subsurface boulder detection.

Keywords: DC Resistivity; near surface geophysics; Bushveld; hazards; mining; three-dimensional resistivity.

INTRODUCTION

Resistivity is the factor within resistance that considers the conductive nature of the material and can be used to map the near surface geological structure efficiently and in a cost-effective manner when compared to other geophysical methods. The location of study falls within one of the greatest layered intrusion on the planet, the Bushveld Complex, as shown in figure 1. The Bushveld Complex is situated in the north-eastern part of South Africa, within the Transvaal basin (Schouwstra et al., 2000; Von Gruenewaldt et al., 1985). The Bushveld Complex is divided up into three exposed limbs, which are known as the Northern, Western and Southern limbs respectively (Schouwstra et al., 2000; Von Gruenewaldt et al., 1985). The largest concentration of platinum group elements in the world is situated within a layer known as the Upper Critical zone which resides in the Bushveld Complex (Schouwstra et al., 2000). The Bushveld Complex also contains other famous layers such as the Merensky Reef, Upper Group Chromitite No. 2 (UG-2) Reef and the Platreef (Schouwstra et al., 2000; Von Gruenewaldt et al., 1985).

The Eastern Limb Bushveld Complex has hardly any documented near surface resistivity studies within the mining context. The following studied is directed to investigate the feasibility and uses of various types of resistivity methods within the mining context. Three types of resistivity methods will be included in the study. The first method will be measuring individual rock core sample at different depths to develop an understanding of the specific conductivity properties of the underlying geological structure within the Eastern Limb Bushveld Complex. The second method will involve completing various two-dimensional resistivity arrays at different locations in order to study the possible uses and processing techniques for two-dimensional resistivity studies. Unlike a two-dimensional resistivity survey, which only produce a profile, three dimensional surveys produce a three-dimensional volume, which in theory should map out three dimensional geological features with increased accuracy when compared to the two-dimensional profiles. Hence the study will include a feasibility study of three-dimensional resistivity surveys within the Eastern Limb Bushveld Complex.

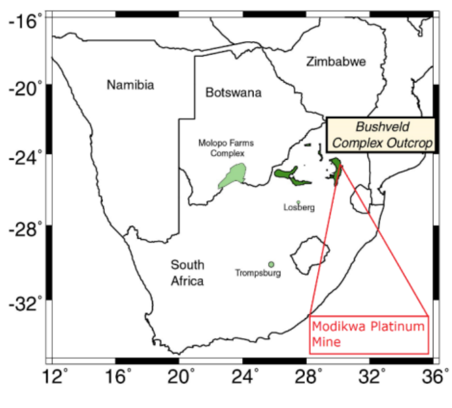

Figure 1. A map showing the Bushveld Complex outcrop in green and Modikwa platinum mine study area.

SAMPLE CORE INDUCED POLARIZATION RESISTIVITY METHOD

The individual core sample resistivity measurements involved the use of the Sample Core IP (SCIP) Tester developed and produced by GDD Instrumentation. Four borehole core samples, from a borehole with the designation OV725, were tested with the SCIP Tester. The samples were taken at depths of 12 m, 22 m, 27 m and 39 m respectively.

The SCIP tests have shown that there is a relatively resistive gabbronorite layer between 12 m and 27 m, as shown in figure 2. This gabbronorite layer could be a resistivity marker for the area of study. Anomalous resistivity layers, like the one recorder at 22 m depth can be used to track and follow economically important layers such as the Merensky Reef, which is ±100 m below this resistive layer.

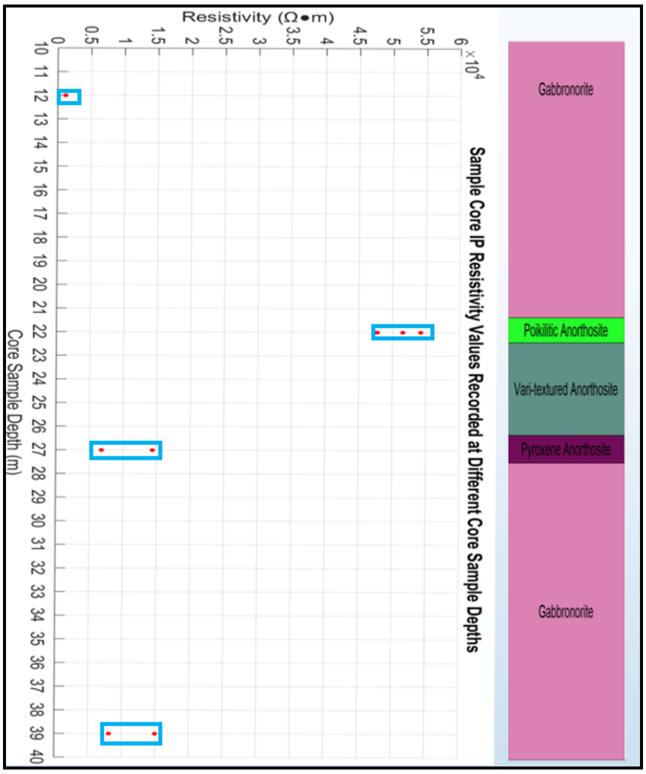

Figure 2. Calculated resistivity values taken by the SCIP Tester plotted at corresponding borehole depth.

TWO-DIMENSIONAL RESISTIVITY SURVEY METHOD

In total four two dimensional resistivity lines were constructed and placed on Modikwa Platinum Mine property. The four resistivity lines were placed near exploration boreholes in order to correlate the resistivity results with the actual underlying geology by using the borehole logs. In order to complete the two dimensional resistivity arrays the Automatic Resistivity System (ARES), which is developed by GF Instruments, as well as up to seven multi-electrode cables were used. The standard Gauss-Newton and the damped least square constraint inversion methods were conducted in order to reduce root mean square error up to 20 %. as shown in figure 3.

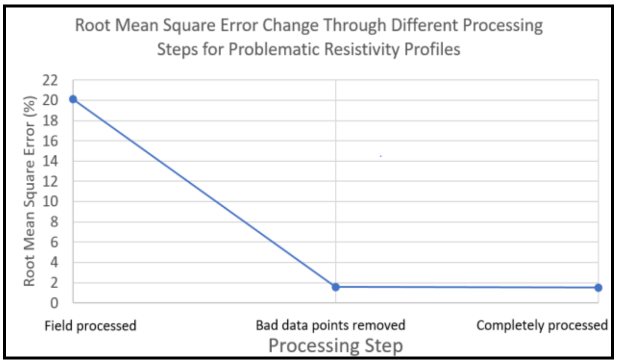

Figure 3. Root mean square (RMS) error change through different processing steps. Up to a 20 % reduction in RMS error is achieved in some of the resistivity profiles. This reduces the error in apparent resistivity contours from ± 235.57 Ω·m to ± 15.86 Ω·m. The improvement in RMS error shifts the resistivity contours and the geological model layers to the correct depths.

It is also shown that the extent of the dyke system, within the research area, is significantly overestimated by the aeromagnetic survey resolution when compared to the produced resistivity profile, as shown in figure 4. The aeromagnetic map estimated the dyke width to be around 90 m but due to the higher resolution of the resistivity profile, the produced resistivity data predicts that the width of the dykes is closer to 16 m. Hence by making use of aeromagnetic data to discover the dyke system and then making use of resistivity to further refine the mapping of the dyke extent an improved geological model of the area can be produced without the need for drilling further boreholes within the area.

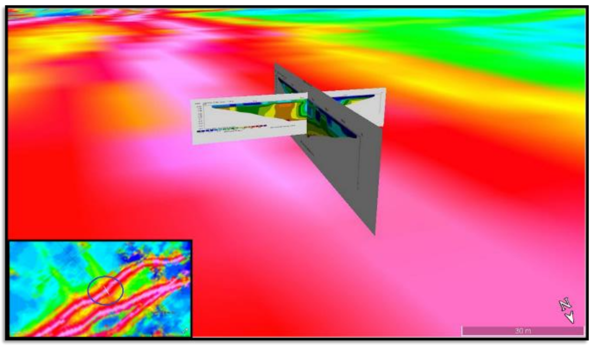

Figure 4. Two dimensional Wenner-Schlumberger lines 3 and 4 plotted on Google Earth pro, overlaying airborne

magnetic data taken within the area. Bottom left corner showing a bird's eye view of the resistivity location, marked by a blue circle, on the magnetic map.

Another use for resistivity profiling within the mining context is detecting possible boulders and large rock segments as shown in figure 5. The profiles (a) and (b), shown in figure 5, show areas of discontinues and sporadic resistivity contours. These are areas were large boulders could be seen on the surface, which have been deposited within the riverbed moving through this specific region of the resistivity profile. The same sort of behaviour can be seen deeper in profiles (c) and (d), also possibly indicating the presence of buried boulders within the region. Boulders such as these could present possible hazards for large continues mining machinery. Hence making use of resistivity arrays, the location of these buried boulders can be detected and avoided.

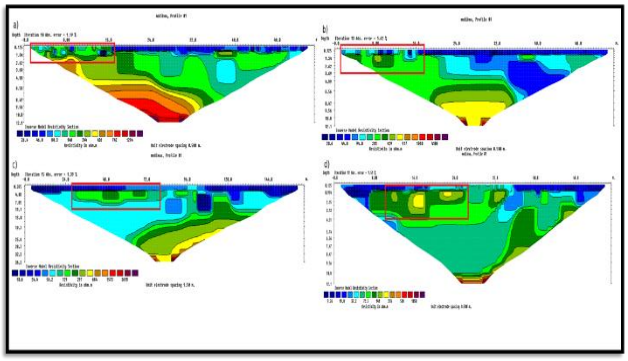

Figure 5. Boulder signatures outlined with a red box on each resistivity profile.

THREE-DIMENSIONAL RESISTIVITY SURVEY METHOD

Two three-dimensional resistivity arrays were conducted over the research period. The first three-dimensional resistivity array 1 (3DRA1) was conducted over the centre of two-dimensional resistivity profile named 2DRL1. Borehole OV725 was situated at the centre of 3DRA1.

The initial three-dimensional resistivity survey was set up as a prototype. The array itself took around an hour to set up and complete while a two-dimensional counterpart took around three to four hours to set up and complete. Figure 6 shows the resistivity model produced by the three-dimensional survey and reveals a high-resolution model which highlights a possible water flow path as seen in figure 6, possibly produced by burrowing animals. These burrows can be seen to start at the surface within the survey area. The water flow path correlates with the low resistivity contours seen in both two-dimensional resistivity surveys. The difference between the two and three dimensional surveys is that the three-dimensional model provides a high resolution three-dimensional space to display three dimensional subsurface features, hence providing both the volume and extent of features such as the possible water channels.

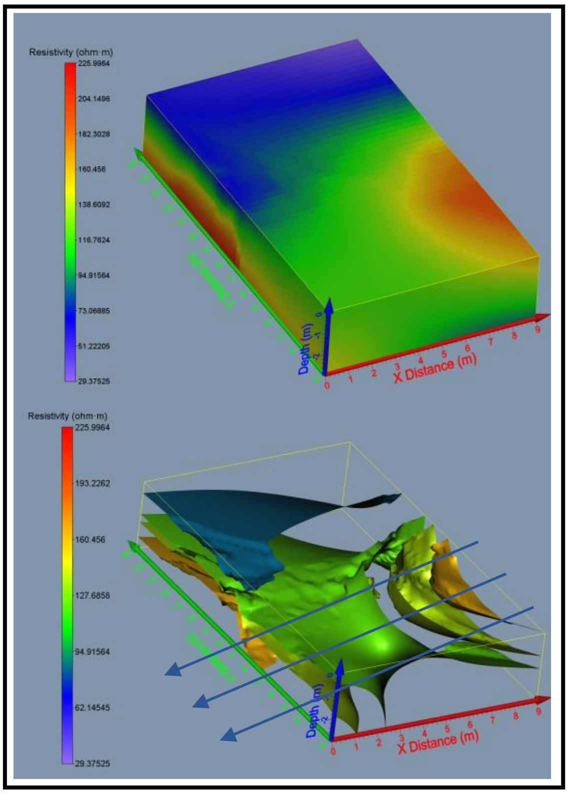

Figure 6. Surface render of 3DRA1 (top) and isosurface plot of 3DRA1 (bottom). Blue arrows indicate possible water flow path.

The second three-dimensional resistivty survey, shown in figure 7, was conducted on a larger scale than the first three-dimensional resitivty array, revealing a possible fracture zone, caused by the dyke seen in figure 4. The zone is measured to be ± 10 m in width, which again reduces the width of the dyke from 16 m predicted by the two dimensional resistivity arrays to 10 m predicted by the three dimetional resitivty array. Again the three dimensional properties of the three dimensional surveys provide an improved subsurface geological model. An increased surface area can be modeled over the same period of time as a two dimensional resistivity survey. The reduced total length extent required by the three dimensional array, when compared to two dimensional array, can provided an alternative survey type for regions with obstacles and harsh terrain, since the three dimensional arrays do not have to reach the same length extent as the two dimensional resistivity arrays in order to operate properly.

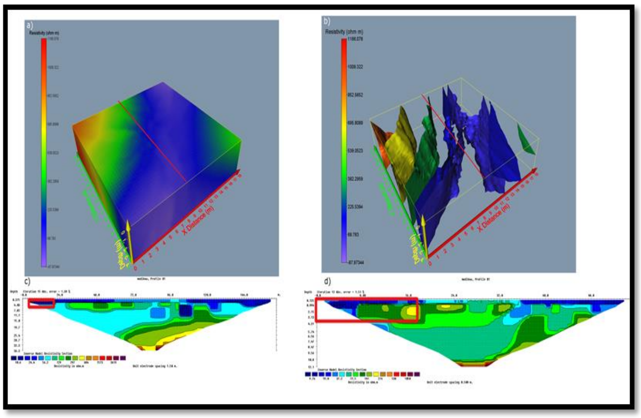

Figure 7. (a) Surface render of the processed three dimensional resistivity array 2. (b) Isosurface plot of the processed three dimensional resistivity array 2. Red square indicating the position of the three dimensional array over the two dimensional dipole-dipole resistivity line 3 (c) and Wenner-Stumberger resistivity line 3 (e).

Another possible use of high resolution three dimensional near surface resistivity arrays, is to search for near surface boulders over a larger surface area than the two-dimensional resistivity surveys. Two dimensional surveys have the disadvantage of entirely missing a boulder more often than three dimensional surveys. A synthetic resistivity model was designed with a boulder of 4 m by 3 m and 2.5 m in depth contained within the model. An 11 by 12 electrode survey was designed to search for the boulder with an electrode spacing of 5 m. As seen in figure 8, the survey could detect the boulder, seen in red, even though a large electrode spacing was used which decreases the resolution of the survey. Hence, if need be, a smaller electrode spacing can be used to find smaller boulder like structures within the mining environment. The larger spacing does however span a larger area, hence a larger section of the subsurface will be explored at a greater depth, reducing the overall time required to completely explore a survey site with two dimensional surveys.

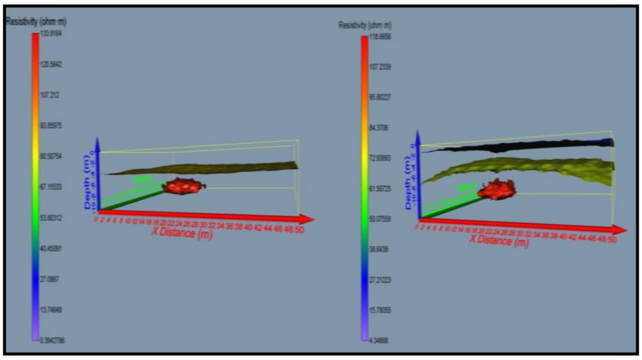

Figure 8. Wenner-Schlumberger (left) and dipole-dipole (right) Synthetic boulder three dimensional resistivity model. The red shape is the detected boulder within the model.

The three-dimensional properties of the three-dimensional surveys provide an improved subsurface geological model. An increased surface area can be modelled over the same period of time as a two-dimensional resistivity survey. The reduced total length extent required by the three-dimensional array when compared to two dimensional can provided an alternative survey type for regions with obstacles and harsh terrain, since the three-dimensional arrays do not have to reach the same length extent as the two-dimensional resistivity arrays to operate properly.

CONCLUSIONS

The SCIP tests showed that the individual resistivity borehole core test can assist in identifying prominent resistivity layers which could be used as markers for tracking associated economic geological layers and assist in improving produced geological models. It was also shown that the appropriate processing procedure is required when processing resistivity data since the root mean square error of the inversion results can be reduced by up to 20 %.

Three dimensional resistivity arrays provide a detailed model of the near surface geology which can be used in the mining context to track hazards such as boulders or track the flow of water within a mining prospecting area. Another advantage of three dimensional resistivity surveys is that the survey models a three dimensional geological environment and takes into account all conductivity changes in each direction, while two dimensional resistivity surveys only account for two directional conductivity changes. Hence a better represented geological model can be produced with a three dimensional resistivity survey.

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