A systematic approach to the interpretation of conductivity anomalies recorded with the Geonics EM34-3 electromagnetic instrument across intrusive dolerite dykes and sills in the Karoo Supergroup

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Introduction

Groundwater exploration has become increasingly dependent on the use of geophysical techniques to gain insight into the subsurface conditions to minimize the risk of drilling unsuccessful production bores. Dolerite dykes and sills are often targeted during groundwater exploration programmes in Karoo rocks. Due to the high pressures and temperatures that reigned during the emplacement of these structures, the sedimentary host rocks along the margins of the intrusive structures are typically strongly altered, highly fractured, and resulting in an increased hydraulic conductivity as compared to the unaltered host rock. The altered zones often act as preferential pathways for groundwater migration, making them preferred targets during groundwater exploration.

In conjunction with magnetic methods, electromagnetic (EM) methods are the techniques most often used for groundwater exploration in Karoo rocks. In South Africa, the ground EM system most commonly used is the Geonics EM34-3 frequency-domain system. This system has already been in use for a few decades, yet a great deal of uncertainty still remains regarding the interpretation of anomalies recorded over geological structures associated with lateral changes in electrical conductivity. This uncertainty results from the fact that the Geonics EM34-3 system employs measurements of the out-of-phase components of the secondary magnetic field relative to the primary magnetic field to calculate an apparent conductivity for the subsurface. The apparent conductivity profiles across lateral changes in conductivity often do not make intuitive sense. This project focuses on the development of guidelines for the interpretation of anomalies recorded with the EM34-3 system across intrusive structures of geohydrological significance in Karoo rocks.

**2. Objectives**

- To carry out EM surveys across known dolerite dykes and sills using the Geonics EM34-3 system with different loop orientations and separations to evaluate the relationships between the recorded anomalies and the positions and orientations of the dyke and sills.
- To develop guidelines for the interpretation of anomalies recorded with the EM34-3 system across intrusive structures of geohydrological significance in Karoo rocks.

**3. Methodology**

- Geophysical surveys were conducted across known dykes and sills in an attempt to systematically investigate the responses recorded across these structures.
- Data from magnetic and longitudinal electromagnetic resistivity tomography surveys, as well as from geophysical borehole logs in some cases, were used as controls to assist in the interpretation.

**4. The Geonics EM34-3 system**

The Geonics EM34-3 system is a frequency-domain electromagnetic instrument that measures the in-situ conductivity of the subsurface using a pair of wound wire coils. It is an active geophysical method that uses concentrated source to send electromagnetic waves into the ground. The flux of magnetic waves through conductive earth materials gives rise to induced electrical currents in the subsurface. These electrical currents cause secondary electromagnetic waves. The ratio of the quadrature component of the secondary magnetic field to the primary magnetic field gives an apparent conductivity (in units of mS/m) for the subsurface (Fourie, 2007). During the survey the transmitter and receiver can be in a vertical or horizontal orientation. This gives rise to the HD and VD modes of operation. The HD mode is used to detect negative anomalies that are caused by a distance between a transmitter and receiver. The VD mode is used to detect positive anomalies that are caused by a distance between a transmitter and receiver. The apparent conductivity profiles across intrusive structures often do not make intuitive sense. This project focuses on the development of guidelines for the interpretation of anomalies recorded with the EM34-3 system across intrusive structures of geohydrological significance in Karoo rocks.

**5. Field results and interpretation**

The geophysical surveys using the EM34-3 system were conducted in 3 locations with known dolerite occurrences. Traverses were conducted perpendicular to the strikes of the known intrusive bodies. Apparent conductivity data were recorded on station spacings that varied between 3 and 7 m. Data were recorded using both the horizontal and vertical dipoles orientations, while all three possible inter-coil separations (10, 20, and 40 m) were used to investigate the subsurface to different depths.

**5.1 Geophysical survey across a sill at the Boyden Observatory**

The apparent conductivity values recorded across the contact between the Karoo sediments and the dolerite sill show that the Karoo rocks are generally more conductive than the dolerite. Across the contact, the HD profile for both the 10 and 20 m coil separations exhibit local increases in the apparent conductivity. This behaviour is, however, not observed in the HD profile of the 40 m coil separation which displays a monotonic decrease. The apparent conductivity values recorded with the 40 m VD mode shows a pronounced negative anomaly centered at the contact. The GPR, gravity, and magnetic surveys show good correlation with regard to the position of the contact.

**5.2 Geophysical survey across a thick dyke at the Bloemfontein Nature Reserve**

The dyke occurs at stations 10 and 15 m and is situated 12 m below surface. At the dyke contact, all the coil separations of the HD mode display the same conductivity values. The VD mode shows a negative response on the 40 m coil spacing and erratic response on the 10 and 20 m coil spacings. Negative conductivity anomalies in the VD mode may be correlated across conductors (Maunder, 2007).

**5.3 Geophysical survey across a dyke at Morgenkloof Farm**

No significant anomalies were recorded with either the HD or VD modes between 10 and 150 m; however, variations in the electromagnetic signatures were recorded between 10 and 200 m for both the HD and VD modes. The decreases in conductivity on the HD measurements between 10 and 20 m are caused by the dyke. A significant magnetic anomaly occurs between 150 and 200 m with an amplitude of more than 500 nT. Overlaying of the different profiles in the HD mode occurs at the dyke contact at a distance of 203 m. The elevated conductivity associated with the dyke is caused by highly fractured banded sandstone which was observable on surface between stations 200 and 265 m.

**5.4 Geophysical survey across a dyke at Burchardt Farm**

The dyke occurs at stations 80 and 130 m and is situated 12 m below surface. At the dyke contact, all the coil separations of the HD mode display the same conductivity values. The HD mode shows a significant increase in conductivity at a distance of 10 m. This is followed by decrease in the HD mode with an increase in coil spacing overlapping at the dyke contact at 120 m (345 m²). The lowest peak occurs at the same contact as the HD mode, but across the dyke the profile displays an anticline curve on the 40 m coil separation. The inverse model below the graph shows the position of the dyke as a zone of high conductivities.

**6. Conclusion**

This project is still ongoing and aims at providing a set of guidelines for the interpretation of EM anomalies across intrusive structures.

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**8. References**
