Earth Stewardship Science Research Institute

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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1. Introduction

Groundwater exploration has become increasingly dependent on the use of geophysical techniques to gain insight into the subsurface conditions to minimise the risk of drilling unsuccessful production boreholes. 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, heavily fractured and resulting in an increased hydraulic conductivities 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 dykes 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 twodimensional electrical resistivity tomography surveys, as well as from geological 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 which measures the *in situ* electrical conductivity of the subsurface using a pair of wound wire coils. It is an active geophysical method that uses a controlled 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 is used to calculate an apparent conductivity (with units of mS/m) for the subsurface (Fourie, 2013). During the survey the transmitter and receiver can be in a vertical or horizontal dipole mode. These dipole orientations give a significantly different response with depth and in the presence of lateral changes in the conductivity of the subsurface. The inter-coil spacing of the system determines the depth of investigation; larger spacings lead to greater depths of investigation. Three inter-coil spacings are possible with the Geonics EM34-3 system, namely: 10, 20 and 40 m.

5. Field results and interpretation

The geophysical surveys using the EM34-3 system were conducted in 15 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 5 and 7 m. Data were recorded using both the horizontal and vertical dipole 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

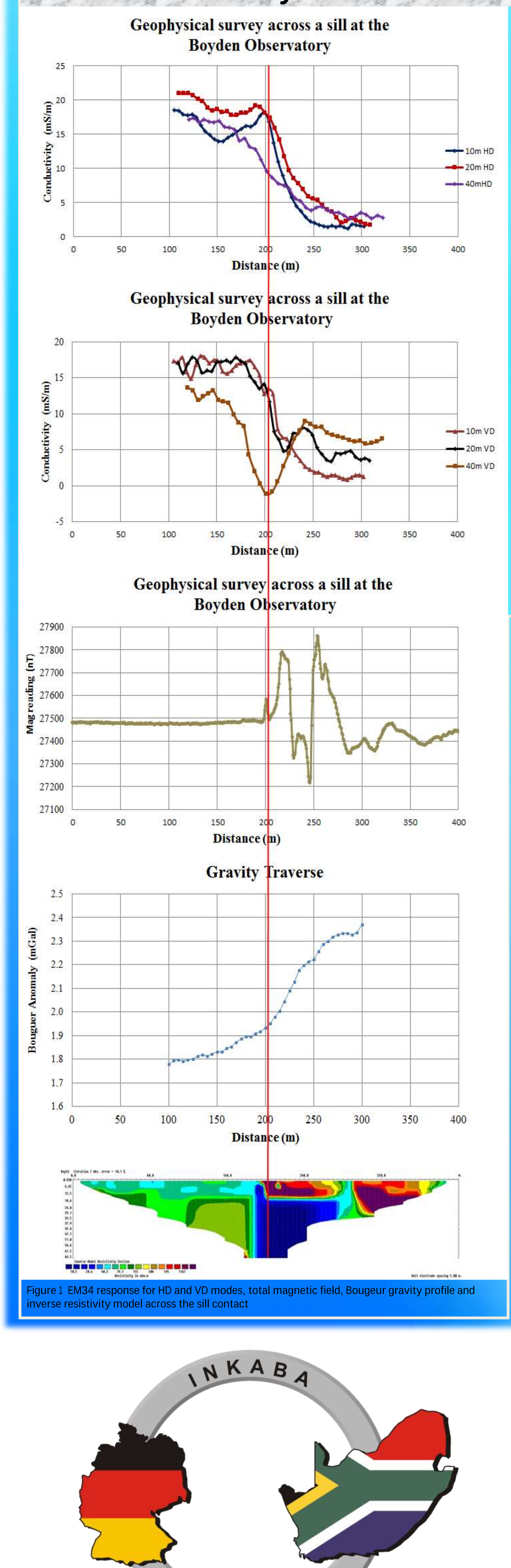

Figure 1 EM34 response for HD and VD modes, total magnetic field, Bougeur gravity profile and inverse resistivity model across the sill contact

The apparent conductivity values recorded across the contact between the Karoo sedimentary rocks and the dolerite sill show that the Karoo rocks are generally more conductive than the dolerite. Across the contact, the HD mode profiles 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 centred at contact. The ERT, 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

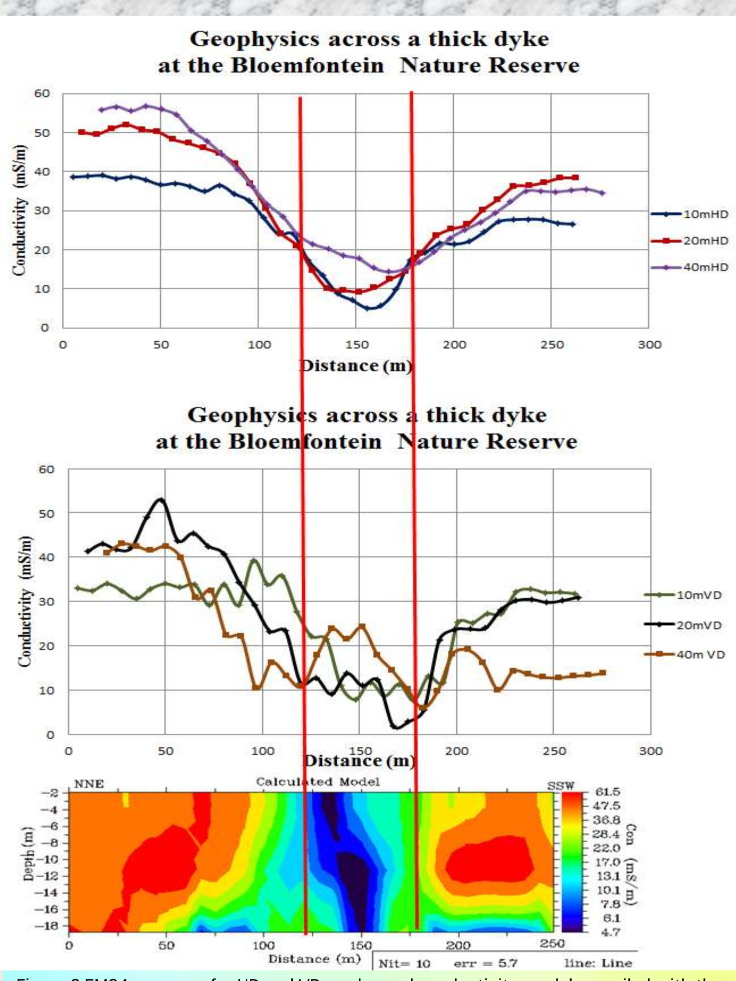

Figure 2 EM34 response for HD and VD modes and conductivity model compiled with the EM4soil software

The HD mode shows no significant change in conductivity from the starting point until at the distance of 60 m. This is followed by decrease in conductivity with all coil spacing overlapping at the dyke contact at 120 m (24 mS/m). The lowest peak occurs at the centre of the dyke. The VD mode responds similarly to the HD mode, but across the dyke the profile displays an anticline curve on the 40 m coil separation. The inverse model below the graphs shows the position of the dykes as a zone of low conductivities.

5.3 Geophysical survey across a dyke at Morgenzon Farm

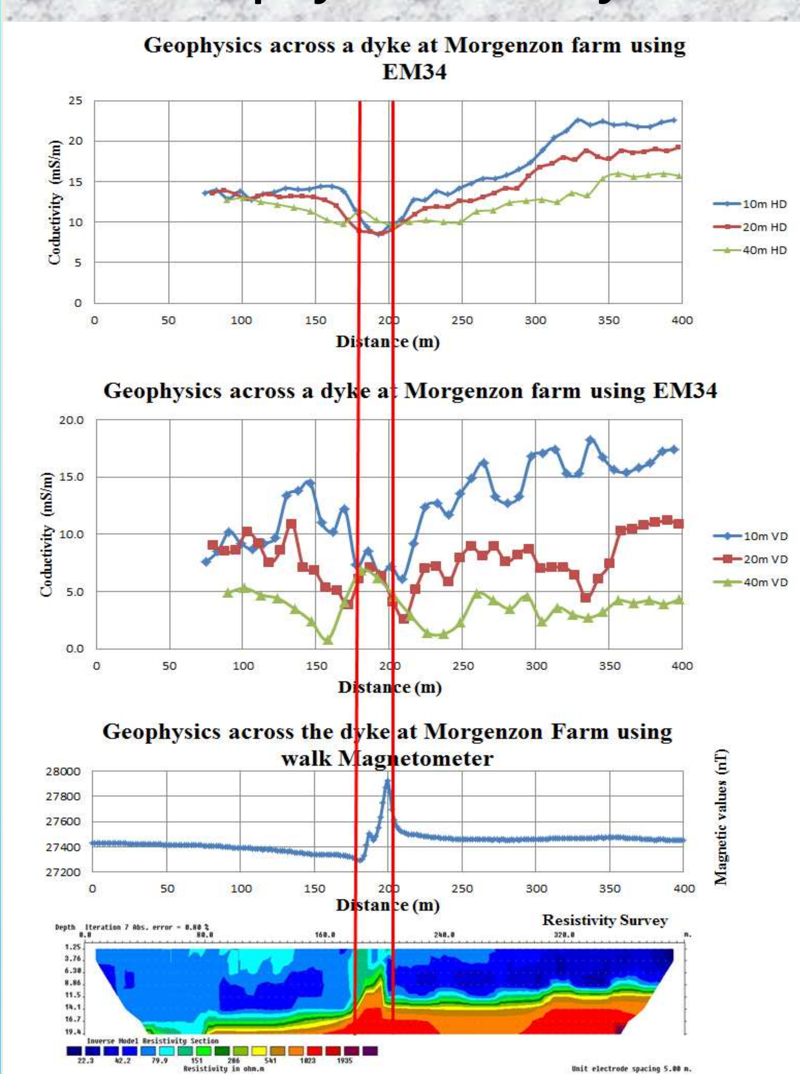

Figure 3 The EM34 response for the HD and VD modes, total magnetic field and inverse resistivity model across the dyke

No significant anomalies were recorded with either the HD and VD modes between 70 and 130 m; however, variations in the electromagnetic signatures were recorded between 170 and 210 m for both the HD and VD modes.

The decreases in conductivity on the HD measurements between 180 and 203 m are caused by the dyke. A significant magnetic anomaly occurs between 185 and 207 m with an amplitude of more than 500 nT. Overlapping of the different profiles in the HD mode occurs at the second dyke contact at a distance of 203 m. The elevated conductivity after the dyke is possibly caused by highly fractured baked sandstone which was observable on surface between stations 200 and 260 m.

5.4 Geophysical survey across a dyke at Burchardt Farm

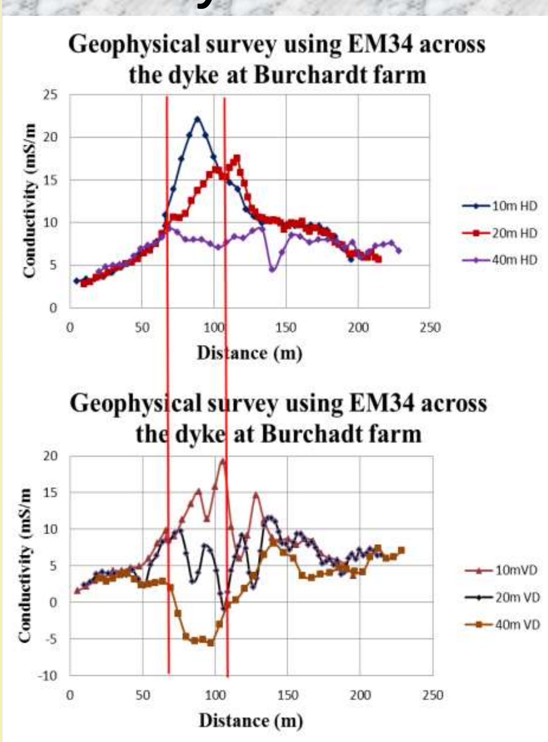

Figure 4 EM34 response for HD mode, and VD mode

The dyke occurs between stations 69 and 109 m and 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 recorded across conductors (Meulenbeld, 2007).

6. Conclusion

The shapes and magnitudes of the apparent conductivity anomalies recorded with the Geonics EM34-3 system across intrusive dolerite structures in Karoo rocks contain information on the positions of these structures. In this study, EM surveys were conducted across numerous known dykes and sills in an attempt to systematically investigate the shapes of the anomalies in relation to the positions of the known intrusives. Preliminary results suggest that the HD mode generally yields less noisy data that is easier to interpret and to relate to the positions of the intrusive structures. However, in some instances the positions of the intrusives are better shown by the VD measurements.

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

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