



**PROJECT TITLE**

**ESTABLISHMENT OF A MONITORING SYSTEM FOR  
SURFACE WATER AND GROUNDWATER  
IN THE CRADLE OF HUMANKIND  
WORLD HERITAGE SITE**

**REPORT TITLE**

**GEOPHYSICAL SURVEYS, STERKFRONTEIN CAVES**

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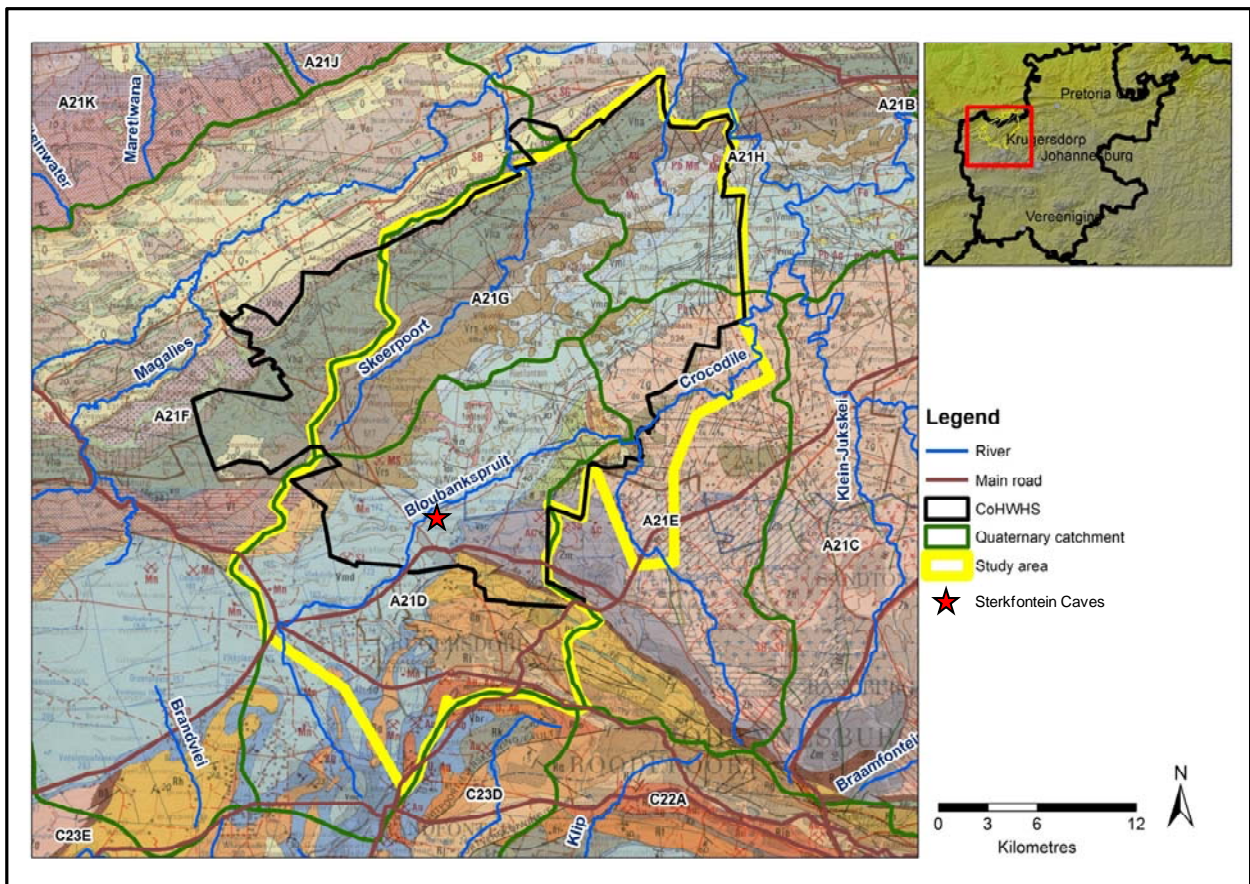
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# 1 INTRODUCTION

The geology of the Cradle of Humankind World Heritage Site (COH WHS) study area (Figure 1) is dominated by the dolomitic strata that form the karst landscape with its associated caves and fossil sites. These strata cover ~28 750 ha (or roughly 44%) of the total extent of the study area. The geophysical surveys described in this report sought to provide complementary information needed to understand the geology and structures that might exercise control over groundwater occurrence and movement in the vicinity of the Sterkfontein Caves fossil site in the COH WHS (Figure 1). A situation assessment of the surface water and groundwater resource environments of the COH WHS (Hobbs, 2011) has subdivided the karst strata into 10 compartments that also serve as groundwater resource units (GRUs). The Sterkfontein Caves are located in the Zwartkrans Compartment.



**Figure 1. Definition of the study area in regard to the geology, surface water drainages and quaternary catchments in the COH WHS area and environs.**

# 2 METHODOLOGY AND APPROACH

Of the numerous geophysical methods available for mapping the subsurface, those which measure the contrast in the conductivity (or resistivity) of subsurface strata are most suited to investigating the hydrogeologic nature of the subsurface. Such methods include the multi-electrode direct current (DC) resistivity technique also known as electrical resistivity tomography (ERT), and the frequency domain and time domain electromagnetic (FEM and TEM, respectively) techniques. These methods are typically complemented by the magnetic method for structural mapping, not least because of the comparatively rapid and cost-effective nature of magnetic surveys.

## **2.1 Magnetic Method**

Magnetic data were acquired with two Geometrics G856 magnetometers. These instruments measure variations in the magnetic field of the earth which are attributable to changes of structure or the magnetic susceptibility of near-surface strata. The basic assumption of the method is that the measured parameter, the magnetic field strength, includes a component of the total magnetic intensity (TMI) due to geological structures. The earth's geomagnetic field at any fixed location is not constant at any one point in time, but changes due to magnetic storms and diurnal variations. In order to determine the variance associated with spontaneous ionosphere magnetic values, a second magnetometer is positioned within the survey area to serve as a stationary (fixed) base station measuring and recording these values. The base station values, recorded at 1-minute intervals, are used to adjust (correct) the field traverse- or grid-based TMI values in order to reflect the variation associated with far-field signal inputs during the survey.

Data were collected in a N-S orientation, i.e. roughly perpendicular to the principal regional geologic strike direction. After acquisition, the field data were transferred to a computer and corrected for diurnal variations using the Magmap 2000 software by Geometrics. The corrected data were exported to Geosoft format for gridding, and presented as a contour map of the residual total magnetic field.

## **2.2 Electromagnetic Method**

Electromagnetic (EM) data were acquired with a Geonics EM34 instrument. This instrument generates an electromagnetic field in the frequency domain which induces current in the earth and, in turn, causes the subsurface to create a magnetic field. The instrument also measures the magnitude and phase of induced electromagnetic currents, from which information about subsurface features and their properties can be deduced. The EM currents are related to the electrical conductivity of strata in the subsurface, which again are a function of the soil and rock matrix, percentage of saturation and the conductivity of the pore fluids. The results are similarly used to deduce the presence of water-bearing structures at shallow depths (typically <60 m), depending on the receiver-to-transmitter coil separation distance and orientation.

An EM survey can cover a large area quickly and therefore economically. However, despite rapid data collection and high lateral resolution, the method suffers from limited vertical resolution and is susceptible to interference from induced noise from power lines and cultural features such as buried metal pipes, fences, vehicles and electricity utilities. The commonly used coil configuration is the horizontal dipole mode. In this configuration the measurement is relatively insensitive to coil misalignment because the secondary magnetic field is in maximum coupling with the receiver coil (McNeill, 1985). The theoretical depth of investigation depends on the transmitting (Tx) to receiving (Rx) coil separation distance, with a separation of 20 m expected to investigate ~15 m deep in horizontal mode.

Processing of the acquired data entailed transfer to a computer using the DUMP34W software, followed by its conversion to an XYZ format and filtering to remove 'noisy' values before plotting in Oasis Montaj to produce terrain conductivity maps.

## **2.3 Resistivity Method**

The DC multi-electrode resistivity method is used to deduce the subsurface resistivity distribution by carrying out measurements on surface. The resistivity measurements are normally made by introducing current into the ground through two current electrodes, and measuring the resulting voltage difference at

two potential electrodes. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. The ERT results can be used to infer the thickness and depth of geological strata on the basis of their differing resistive (or conductive) properties, as well as to define geological structures such as dykes, sills, faults and contact zones. All of these features may have relevance to the occurrence and movement of groundwater.

Data were acquired with a Syscal Pro Switch 72 multi-electrode instrument using the dipole-dipole array at 10 m spacing to ensure fast and maximum depth coverage at high lateral resolution. Input voltages varied between 500 and 800 V to ensure maximum current penetration in the strata of the study area. After the field survey, the resistance measurements were reduced to apparent resistivity values using the Prosys 11 software. A 2-D model for the subsurface consisting of a large number of rectangular blocks was used for interpretation. The computer program RES2DINV (developed by Geotomo Software of Malaysia) was used to generate the model blocks and to determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey. The RES2DINV software automatically subdivides the subsurface into a number of blocks, and then uses a least-squares inversion scheme to determine the appropriate resistivity value for each block (Loke, 1996). The program has a set of default parameters which guide the inversion process. In most cases the default parameters give reasonable results. The problem of non-uniqueness is well known in the inversion of resistivity sounding and other geophysical data. For the same measured data set, there is a wide range of models giving rise to the same calculated apparent resistivity values. To restrict the range of possible models, normally some assumptions are made concerning the nature of the subsurface that can be incorporated into the inversion subroutine. The constraints are based on known geological information, proximity to streams and wetlands and occurrence of known mine shafts in areas of known shallow undermining.

The resulting resistivity models were then exported to Surfer (Golden Software) for gridding and adding interpretation annotations. Anomalies of interest were projected to the land surface in Google Earth.

### **3 RESULTS**

#### **3.1 Magnetic Survey**

The residual total magnetic field contour map generated for the survey area is presented in Figure 2. The positions of anomalies inferred from the electromagnetic (section 3.2) and electrical resistivity (section 3.3) surveys are superimposed on this map in Figure 3. The composite data reveal the presence of E-W trending magnetic ('hot' colours) and non-magnetic ('cool' colours) bodies. Cutting across the centre of the survey area is a consistent E-W striking and linear non-magnetic (compared to the background field strength) anomaly that is interpreted as a shear zone. The significance of this inferred structure for groundwater occurrence and flow is indeterminable with the available information.

The location of the caves at the northern end of resistivity traverse R1 (Figure 3) appears to coincide with a non-magnetic anomaly which probably reflects the non-magnetic character of dolomitic strata. However, an E-W trending magnetic anomaly is prominent immediately to the south of the caves. It would appear that east of the caves, this anomaly is displaced toward the north along a N-S fault. The rather narrow and linear geometry of this anomaly suggests that it might be associated with a positively magnetized dyke structure. An extensive magnetic body to the south of the inferred shear zone might

represent the presence of a subhorizontal intrusive sill structure. Such features in the area are known from previous mapping efforts (Wilkinson, 1973).

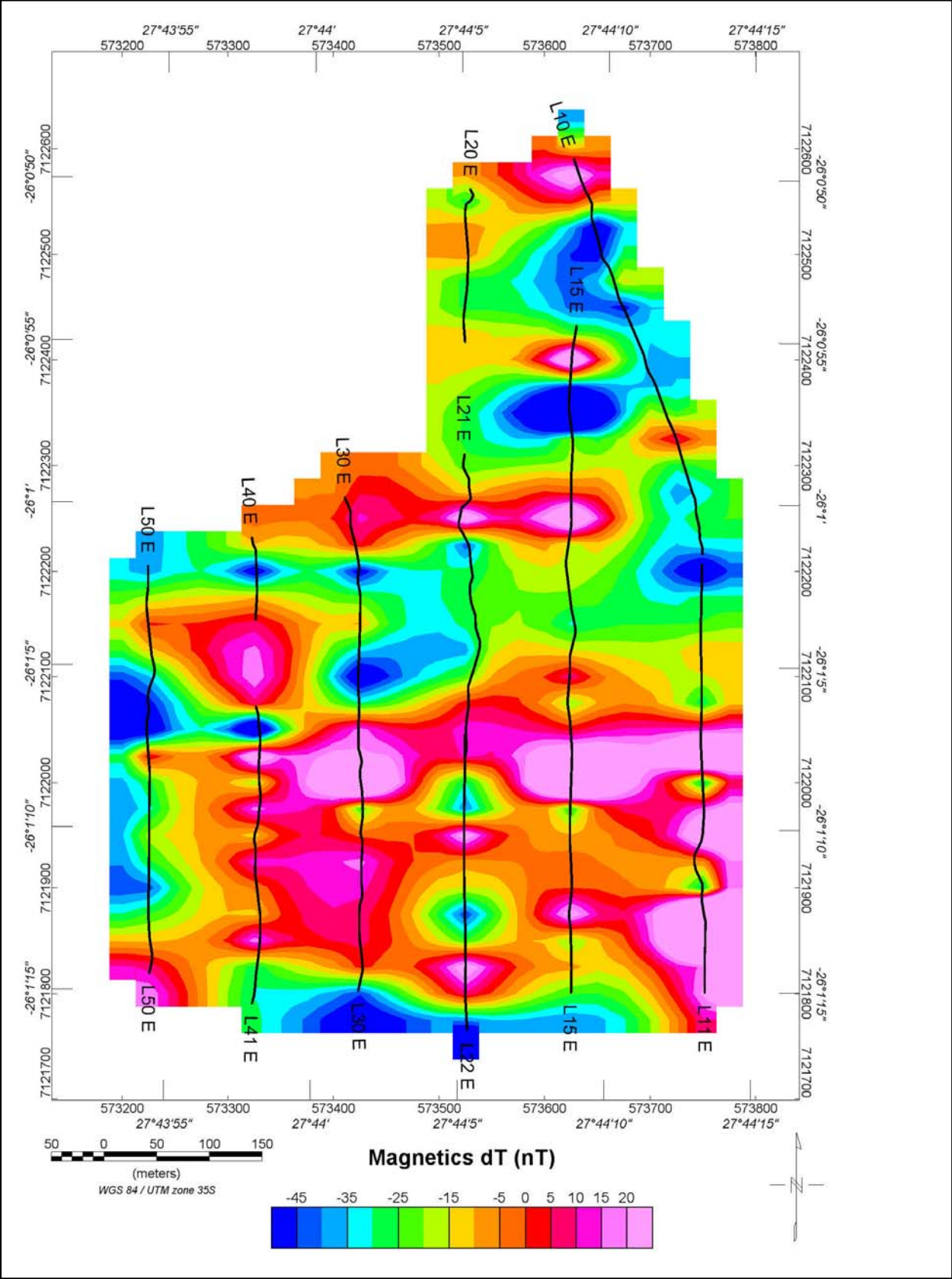
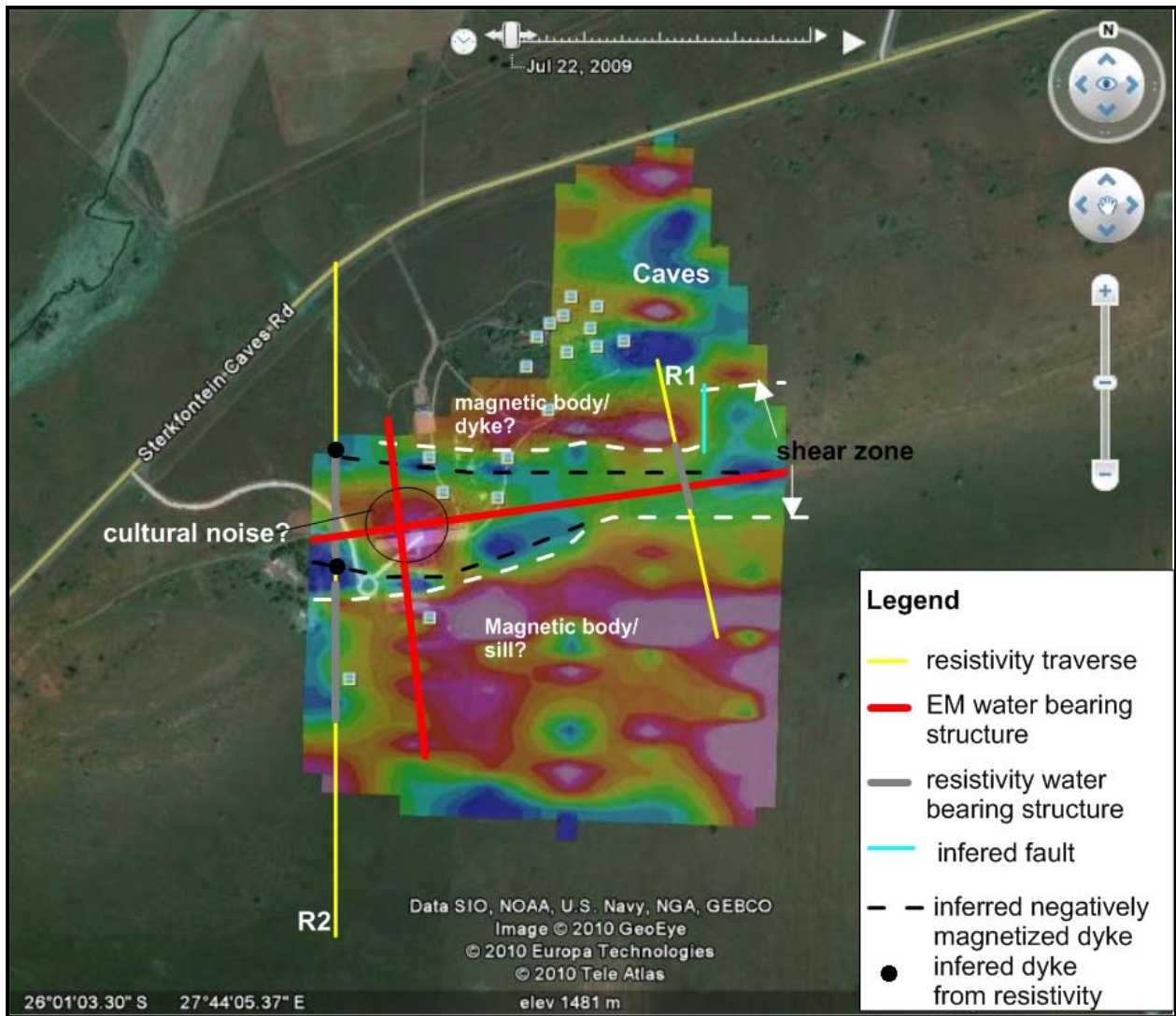


Figure 2. Residual total magnetic field contour map; black N-S oriented lines indicate traverse positions.



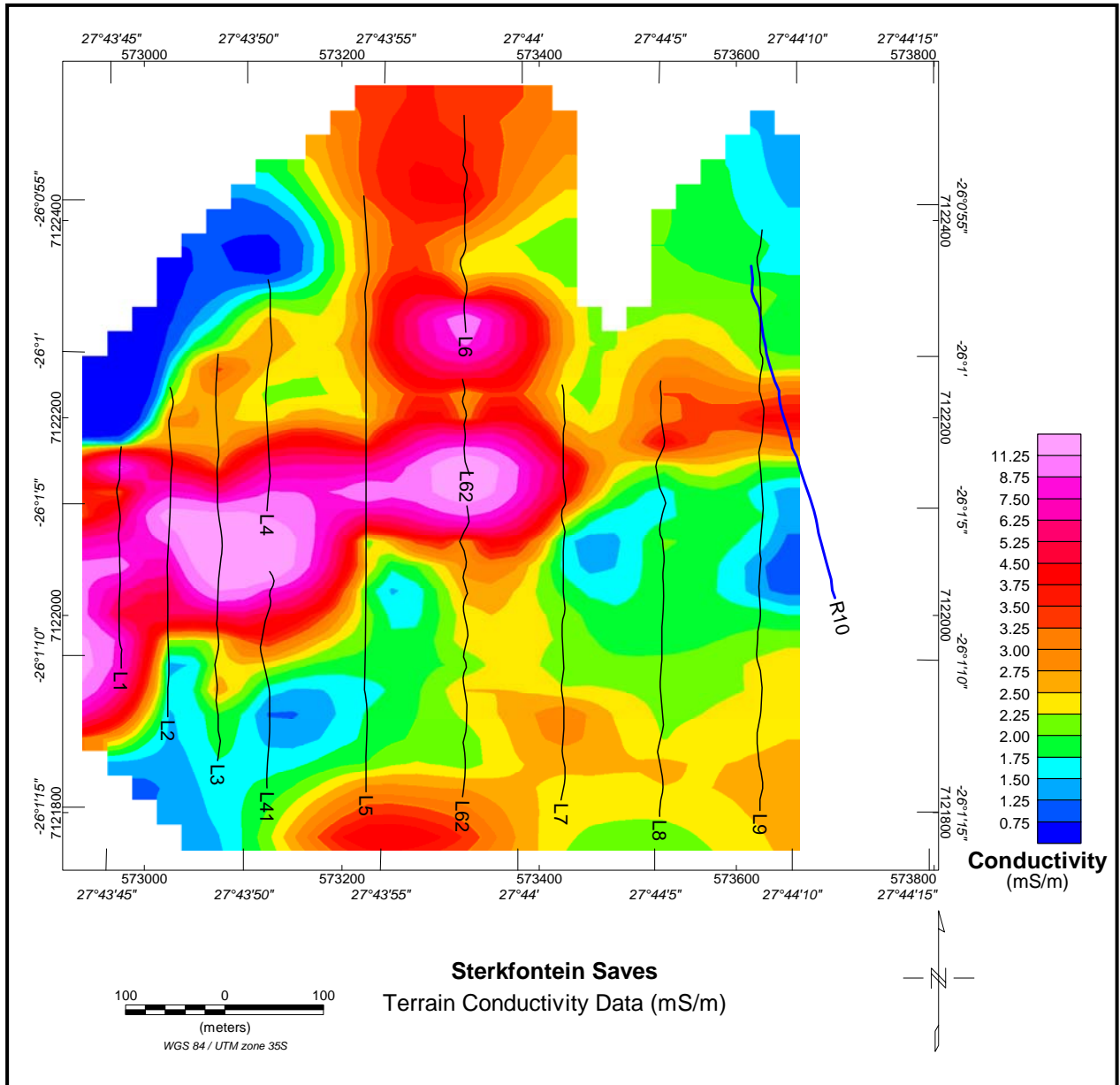
**Figure 3. Interpreted residual total magnetic field contour map; yellow lines R1 and R2 with grey interpretation markings, indicate the direct current resistivity traverse locality.**

### 3.2 Electromagnetic Survey

The orientation and position of the electromagnetic survey traverses is shown in Figure 4, which also shows the terrain conductivity contour map generated from the EM survey data. As shown in Figure 5, the contour map reveals the presence of two linear zones of higher conductivity that bisect the survey area in roughly equal quadrants. The more prominent of these is the WSW-ENE striking zone, which intersects a SSE-NNW striking zone at the eastern end of the tourist complex on the property. The anomalies gain (increase) in conductivity westwards and northwards respectively. The congruence of the more prominent WSW-ENE anomaly with the similarly oriented magnetic anomaly (Figure 3) is self-evident.

The southern portion of the SSE-NNW trending EM anomaly approximates the western boundary of the extensive magnetic body that underlies the south-eastern portion of the survey area (Figure 3). The southern margin of the extensive magnetic body similarly coincides with an E-W striking EM anomaly (Figure 5).

On the basis of available information, the significance of the inferred EM anomalies for groundwater occurrence and flow is inscrutable.

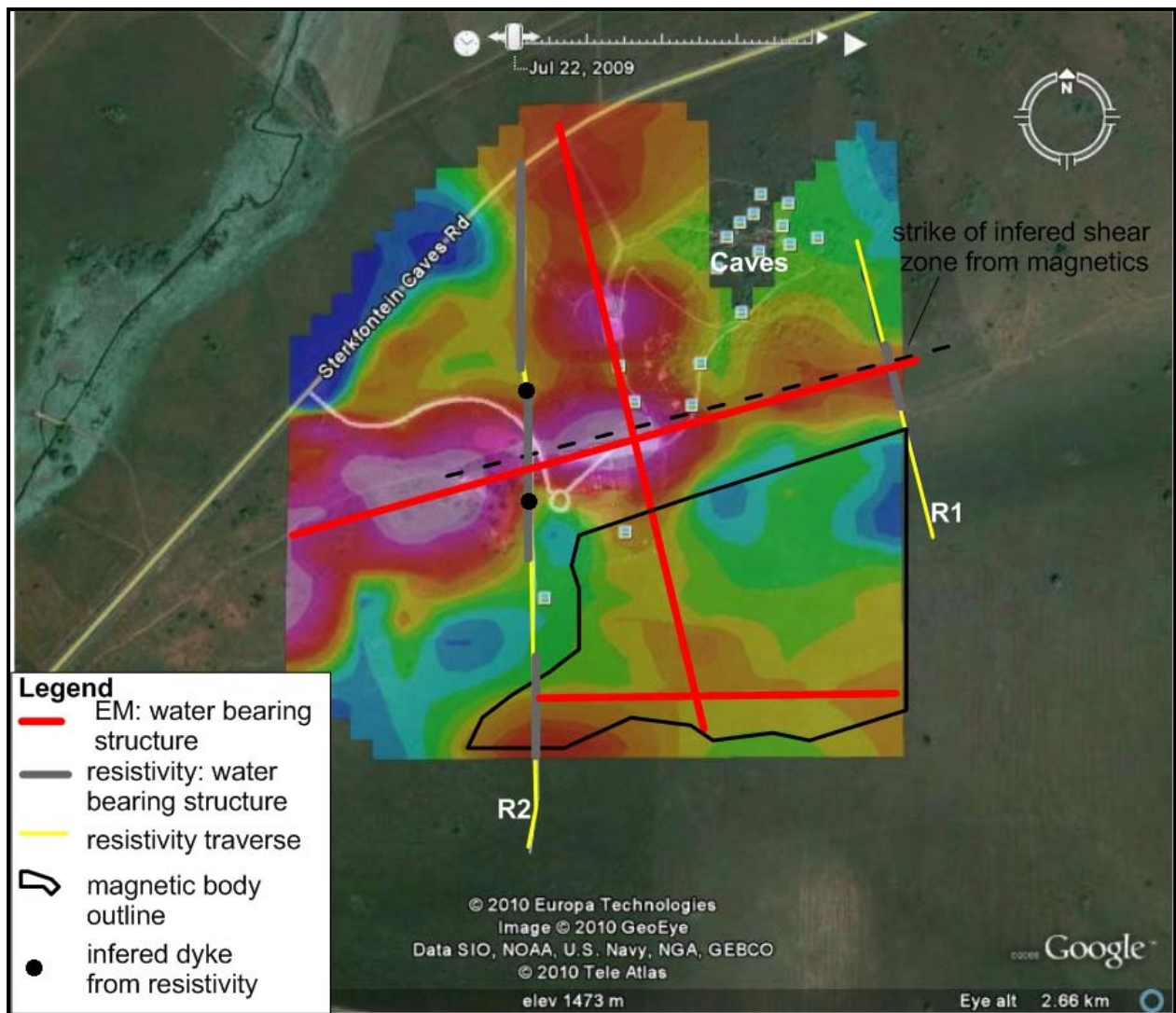


**Figure 4. Terrain conductivity contour map; black N-S oriented lines indicate the electromagnetic traverse locality. Blue line R10 is the position of resistivity traverse R1.**

### 3.3 Resistivity Survey

The results of the electrical resistivity survey are portrayed as cross-sections (profiles) for traverses R1 (Figure 6) and R2 (Figure 7) located as shown in Figure 5.

The results of traverse R1 (Figure 6) confirm the strike extension of the interpreted shear zone inferred from the magnetic survey (Figure 3), the EM survey (Figure 5) and resistivity traverse R2 (Figure 7). By extrapolation the highly conductive zone most likely corresponds to compartment 3 in Figure 7. The resistive body to the south is interpreted to represent the sill structure indicated in Figure 3 and Figure 7.



**Figure 5. Interpreted terrain conductivity results; yellow lines, R1 and R2 with grey interpretation markings, indicate the direct current resistivity traverse locality.**

Resistivity survey R2 (Figure 7) reveals a broad zone of moderate to very low resistivity between stations 280 m and 500 m. This zone is interpreted as coinciding with the shear zone (probably weathered) identified in Figure 3. Figure 7 also shows the subdivision of the cross-section into 4 ‘compartments’ based on zones of contrasting resistivity. The shear zone encompasses two of these ‘compartments’.

The inferred dyke structures located at stations 400 m and 530 m coincide with the linear non-magnetic anomalies interpreted as negatively magnetized dykes (Figure 3). The significant difference in resistivity values associated with the dyke structures suggests a difference in the degree of weathering associated with each. The dyke at station 530 m is considered to be more competent (less weathered), and may therefore constitute a hydraulic barrier. Between the dyke structures, at station 480 m, is a highly conductive ~50 m wide structure located at the centre of ‘compartment’ 3.

A very resistive zone (Figure 7) with a ‘root’ between stations 230 m and 280 m and extending southwards, corresponds to the outline of the extensive magnetic body (Figure 3) that has been interpreted as a sill intruding the dolomite. The ‘root’ of the interpreted sill may similarly act as a hydraulic barrier in the hydrogeologic environment.

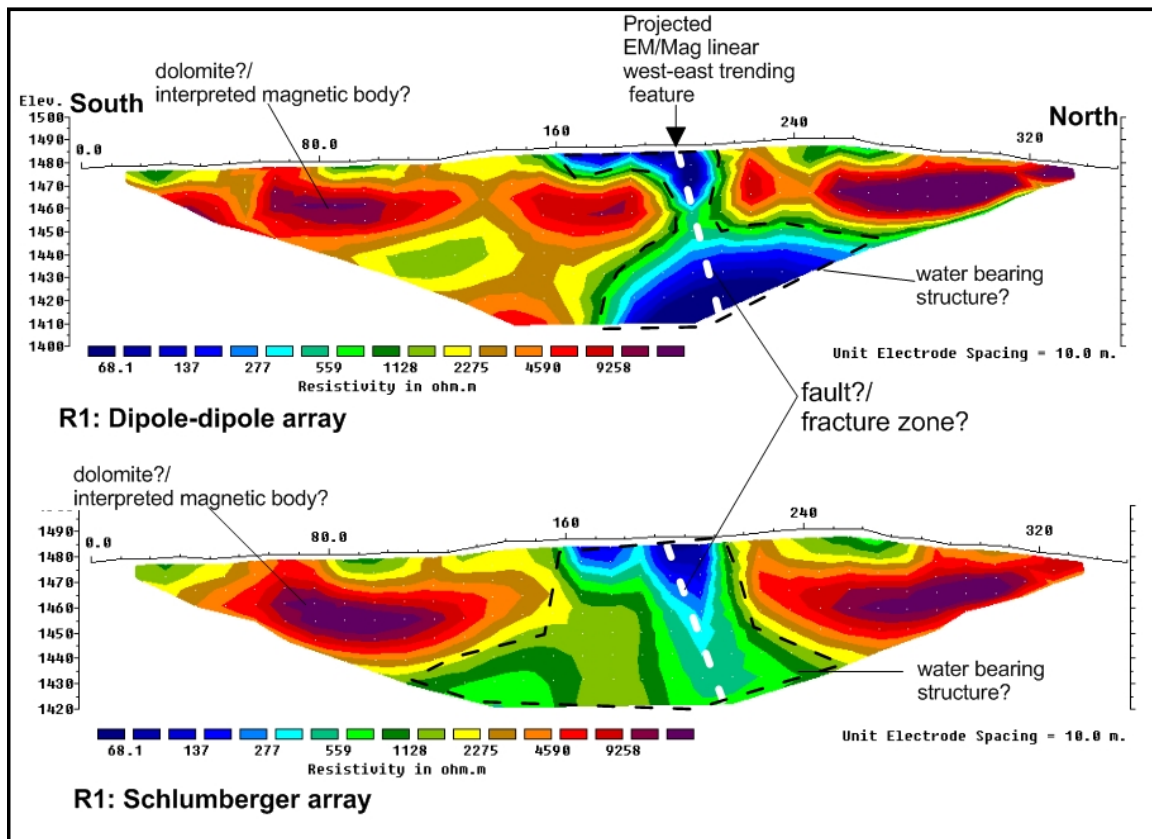


Figure 6. Interpreted resistivity-depth sections for traverse R1; refer to Figure 3 and Figure 5 for traverse locality R1.

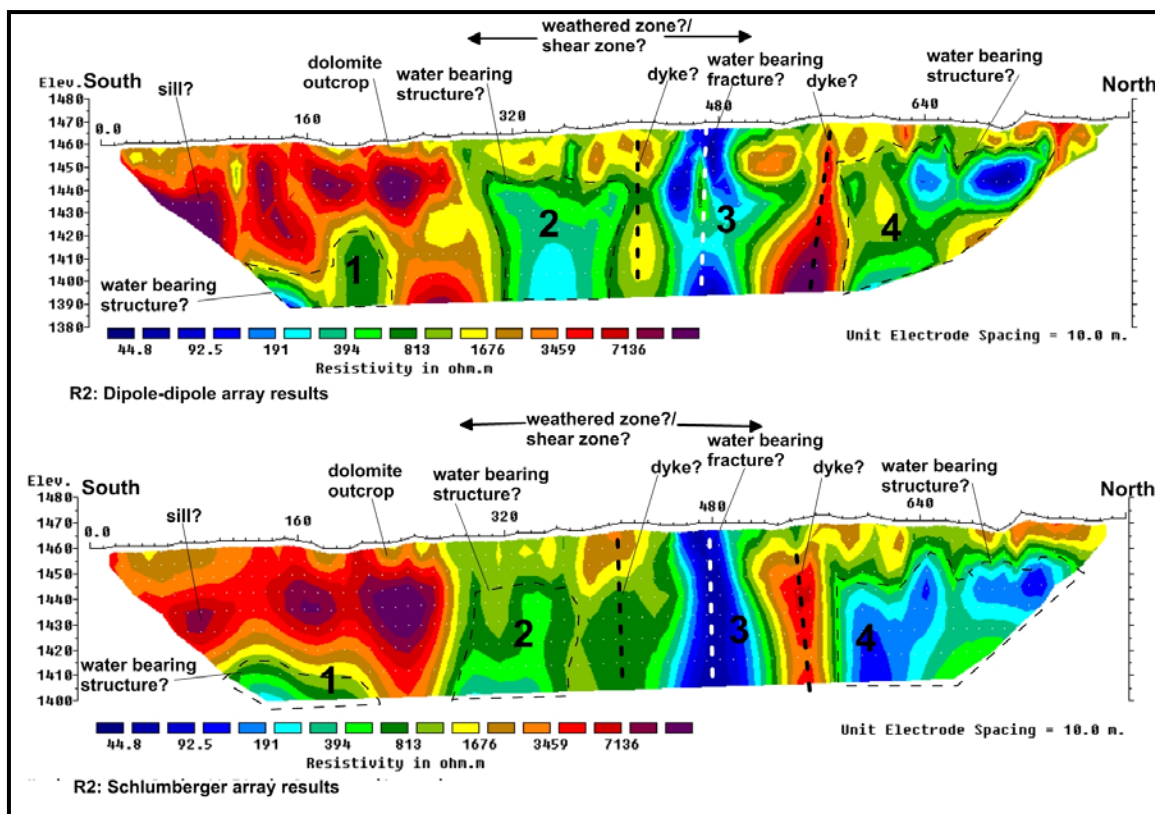


Figure 7. Interpreted resistivity-depth sections for traverse R2; refer to Figure 3 and Figure 5 for R2 traverse locality. Numbers 1 to 4 indicate interpreted 'compartments' discussed in the text.

## 4 CONCLUSIONS

Geophysical surveys entailing the, magnetic, frequency domain electromagnetic and multi-electrode resistivity methods were carried out on the Sterkfontein Caves site in the COH WHS. The outcome precipitates the following main conclusions.

The geophysical surveys provided a quick means of mapping subsurface geological (and possibly hydrogeological) structures with a fair to good correlation in results. These structures, variously interpreted as representing intrusive sills and dykes and a shear zone, were successfully imaged.

The intrusive structures were delineated on the basis of being more magnetic and resistive than the surrounding materials, while the shear zone was delineated as a linear magnetic discontinuity and conductive structure. The resistivity technique mapped the extent and dimensions of the shear zone and the dykes and the probable root of the sill to the south of the study area.

## 5 RECOMMENDATIONS

It is important to carry out more multi-electrode resistivity traverses in order to fully define the outline and characteristics of the interpreted shear zone and the vertical structures. It is therefore recommended that at least one long resistivity traverse be carried out ~300 m east of and parallel to resistivity traverse R2.

There is a need to integrate the geophysical interpretation with hydrogeological and structural geology mapping results of the study area in order to minimize uncertainty associated with geophysical interpretation.

## 6 REFERENCES

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