Groundwater exploration in the Wilgerivier Formation

PMPB Meulenbeld[1] and PJ Hattingh[2]*
[1] PO Box 1675, Bronkhorstspruit 1020, South Africa
[2] Department of Geology, University of Pretoria, Pretoria 0002, South Africa

Abstract

A number of existing boreholes with known characteristics were studied, to evaluate the effectiveness of different low-cost geophysical techniques in the Wilgerivier Formation of the Waterberg Group. Aquifer type was the most important parameter studied. The results indicate that weathered diabase sills in the sedimentary rocks of the Wilgerivier Formation at a given depth and with a given resistivity value yield the most favourable results in terms of water quantity. Geophysical techniques, which can be used in an effective manner to exploit such aquifers, are the Schlumberger depth sounding technique, the electromagnetic EM-34 profiling technique and the magnetic technique. The limitation of the last two techniques is that artificial noise restricts their effective use at a number of sites.

Samevatting

Om die doeltreffendheid van verskillende lae-koste geofisiese tegnieke in die Wilgerivier Formasie van die Waterberg Groep te bepaal, is 'n aantal boorgate in hierdie formasie, waarvan gegewens bekend is, bestudeer. Die belangrikste parameter wat bestudeer is, is die akwifeertipe. Die resultate dui daarop dat verweerde diabaasplate in die sedimentêre gesteentes van die Wilgerivier Formasie by 'n gegewe diepte en met 'n gegewe soortlike elektriese weerstand, die beste resultate lewer in terme van grondwaterkwantiteit. Geofisiese tegnieke wat aangewend kan word om sulke akwifere mee op te spoor is die Schlumberger sonderingstegniek, die elektromagnetiese EM-34 profileringstegniek en die magnetiese tegniek. Laasgenoemde twee tegnieke het die beperking dat dit nie by bronne van kunsmatige geruis gebruik kan word nie, soos ondervind is by 'n aantal gebiede.

Introduction

The purpose of this study was to determine how effective existing low-cost survey techniques are in groundwater exploration, in the Wilgerivier Formation in the Bronkhorstspruit-Middelburg area (Fig. 1). The existing techniques used in groundwater exploration normally comprise geological, photo-geological and geobotanical investigatons of a terrain as well as geophysical ground surveys to delineate groundwater targets.

It was further hoped to create a groundwater database for this portion of the Wilgerivier Formation (Fig. 1). Such a database will improve the success rate of any future groundwater exploration in the study area. Previous groundwater studies in this area were done as long ago as 1937 by Frommurze (1937). The latter was not a detailed groundwater investigation. It is essentially a summary of results obtained by regional drilling in the area, and no geophysical data are presented.

To attain the above objectives, boreholes in a portion of the Wilgerivier Formation (Fig. 1), on 32 farms were investigated. Where reference

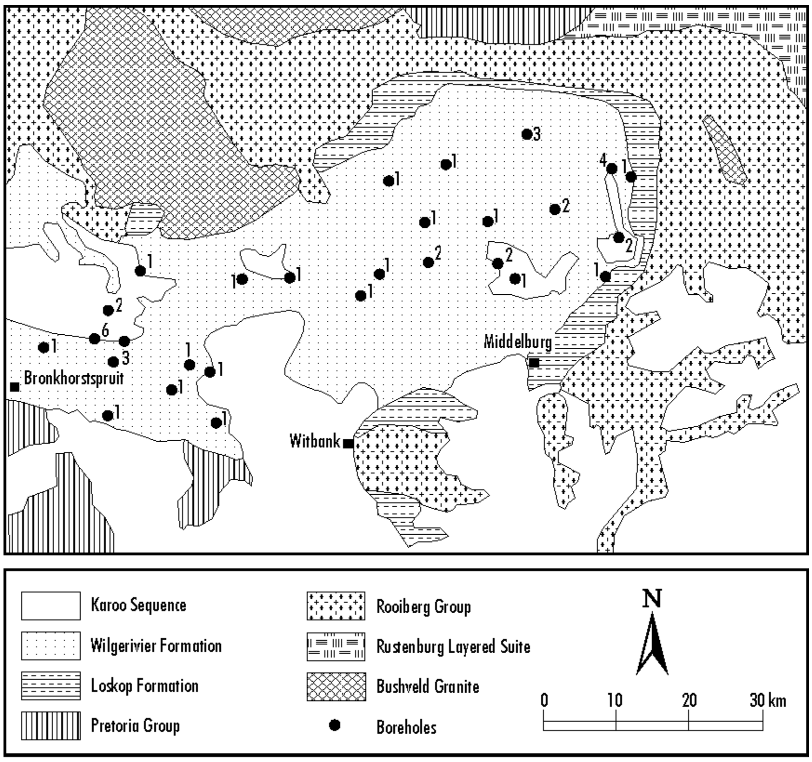

Figure 1
Simplified geological map of the Bronkhorstspruit-Middelburg area. Borehole sites and number of boreholes are indicated by •3.

* To whom all correspondence should be addressed.
☎ (012) 420-2282; fax (012) 352-5219;
e-mail: Hattingh@scientia.up.ac.za
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is made to boreholes on specific farms, the reader is referred to the 1:250 000 geological map, Pretoria 2528 (Geological Survey, 1978).

Geology

The Wilgerivier Formation of the Waterberg Group forms a regional basin in the area to the north of Bronkhorstspruit and Middelburg (Fig. 1). It rests unconformably on the rocks of the Pretoria Group, the Selonsrivier Formation and the Loskop Formation (SACS, 1980) and displays dips of about five degrees to the centre of the basin. The sedimentary rocks of the Wilgerivier Formation are dominantly arenaceous and consists mainly of reddish brown, purple medium to coarse grained quartzitic sandstone, gritstone with interlayered conglomerate and shale.

The maximum thickness of the Formation is about 2 000 m (SACS, 1980; Visser, 1989) and it is intruded by numerous diabase sills and dykes. Inspection of borehole logs indicates that the sills can vary in thickness from less than a metre to more than 150 m. The sills are usually weathered on the contact with the country rock. Geophysical measurements found dykes as thin as 10 m and as wide as 150 m in the study area. Although weathering of the dyke/ country contact rock is the norm, exceptions do occur.

Geohydrology

Groundwater in sedimentary rocks is generally encountered in cracks, fissures, bedding planes, pore space and contact zones with intrusions (Hattingh, 1996). Sedimentary rocks of the Wilgerivier Formation are generaly weak aquifers as the following sections will show.

Palaeoweathering, deeply weathered overburden, fissures and cracks in intrusive rocks are the main aquifers found in the Wilgerivier Formation in the study area. Interpreted geophysical data were used to indicate the type of aquifer present at each borehole.

Methodology

Forty-four boreholes on 32 farms, with a wide spatial distribution over the entire Wilgerivier Formation (Fig. 1), were investigated. First a desk study of previous geological geohydrological and geophysical work in these surroundings was done. The National Groundwater Database (1997), a descriptive database of the Department of Water Affairs and Forestry, was consulted. The latter contains borehole information of all State drilled boreholes in the study area.

As a second step, aerial photographs covering all the farms were studied to delineate structural elements such as lineaments, deformation patterns as well as geobotanical indicators.

The next step involved the description of the boreholes in the field. To this end a field checklist was completed at each site. This included notes on the borehole's co-ordinates (obtained with a GPS), the borehole's yield, depth, geological log and the depth at which water was struck, notes on the geobotany, geomorphology, geohydrology as well as the preferred geophysical technique for the site which depended on the above parameters.

During the final stage of the investigation a second visit to the borehole was made to investigate the substratum by means of either Schlumberger electrical depth soundings, magnetic profiling and/or electromagnetic profiling. The depth soundings were performed parallel to the strike of the formation to minimise the influence of anisotropy on the obtained sounding curve (Van Zijl, 1987). The depth sounding curves were then classified according to the resistivity contrasts between the layers as H, K, A, Q or multiples thereof, following the classification by Keller and Frischknecht (1970), and Van Zijl (1987). All obtained data sets were then interpreted with computer programs such as RESIXP (Interpex, 1988) and programs developed from an algorithm for magnetic anomalies (Talwani, 1985). All interpretations were calibrated against known layer parameters from the National Groundwater Database (NGDB).

Results

The Schlumberger depth soundings produced a wide variety of sounding curves. Aquifers with boreholes (6 boreholes) which yield more than 2.8 ℓ/s, manifest itself through types KQHK and KQH sounding curves (e.g. Figs. 2 and 3). However, QQ and KHA type curves are also present. If all boreholes with yields of 0.98 ℓ/s and higher are considered (18 boreholes), the above types of

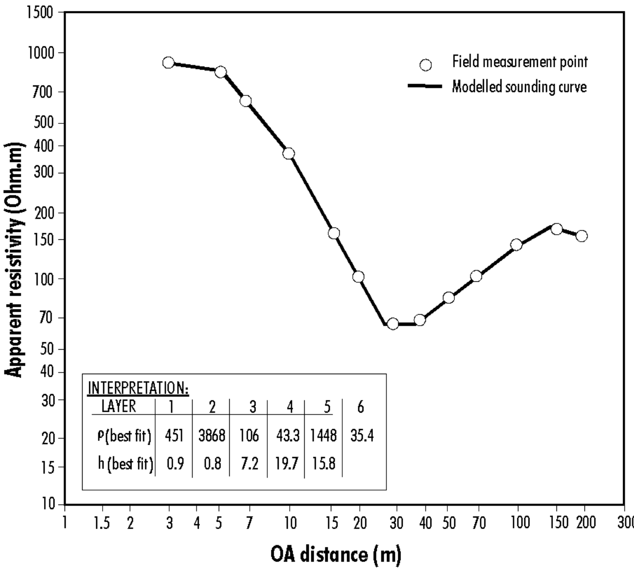

Figure 2
Schlumberger depth sounding curve obtained at Borehole 1, on the farm Wonderboom 249 JS
a) Field sounding curve
b) Interpretation: h = layer thickness; P = layer resistivity.

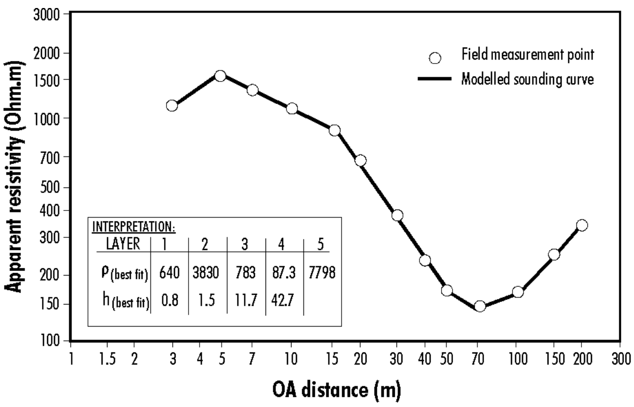

Figure 3
Schlumberger depth sounding curve at Borehole 2, on the farm Wonderboom 249 JS. Legend as in Fig. 2.

sounding curves are still present, but HKH type curves become the dominant type (e.g. Fig. 4). For boreholes with yields progressively lower than 0.98 ℓ/s the type of curves associated with these boreholes becomes less sophisticated and 4- or 3-layer type curves (typically 4-layer combinations of HA and HK as well as 3 layer H (type curves) are the most common (Figs. 5a, b, c).

Attempts to find a correlation between the resistivity (ρ) of the aquifer as interpreted from the Schlumberger depth sounding curves and the borehole yields were not successful. The data on the 44 boreholes produce an insignificant correlation coefficient between ρ and borehole yield in ℓ/s of only 0.22. If the yields of the boreholes are grouped in intervals of 0.28 ℓ/s and the corresponding average ρ of the aquifers for each interval are calculated (Table 1) it can generally be concluded that for a borehole to yield more than 0.98 ℓ/s, the resistivity interpreted from the sounding curve for the aquifer must be less than 240 Ωm.

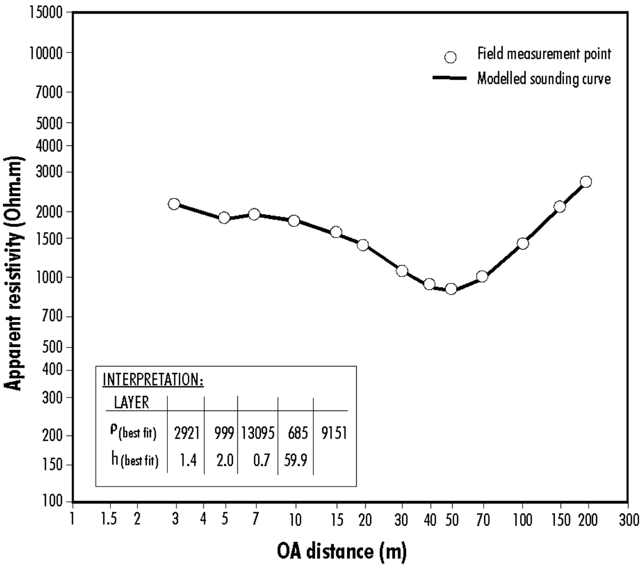

Figure 4
Schlumberger depth sounding curve obtained on the farm Kwarsspruit 261 JS. Legend as in Fig. 2.

TABLE 1
LIST OF BOREHOLE YIELDS, DEPTHS AND AVERAGE RESISTIVITY

Number of boreholes	Yield (ℓ/s)	Average borehole depth (m)	Average ρ (Ω.m.)	δ_E(± 95%)
5	0.28	98	959	457
5	0.28 - 0.56	51	572	216
13	0.56 - 0.83	61	347	84
6	0.83 - 1.11	49	240	90
2	1.11 - 1.39	50	23	-
1	1.39 - 1.67	70	124	-
0	1.67 - 1.94	-	-	-
2	1.94 - 2.22	33	161	-
2	2.22 - 2.5	105	51	-
0	2.5 - 2.8	-	-	-
3	2.8 - 5.55	108	124	-
4	5.55 - 8.33	83	162	112
1	+8.33	85	41	-

The geoelectrical sections obtained from the interpretation of the depth sounding curves at each borehole were matched to the geological log of the borehole (if available) or to the mapped geology or to the geological stratigraphy and structure in the vicinity of the borehole. This was done to determine the

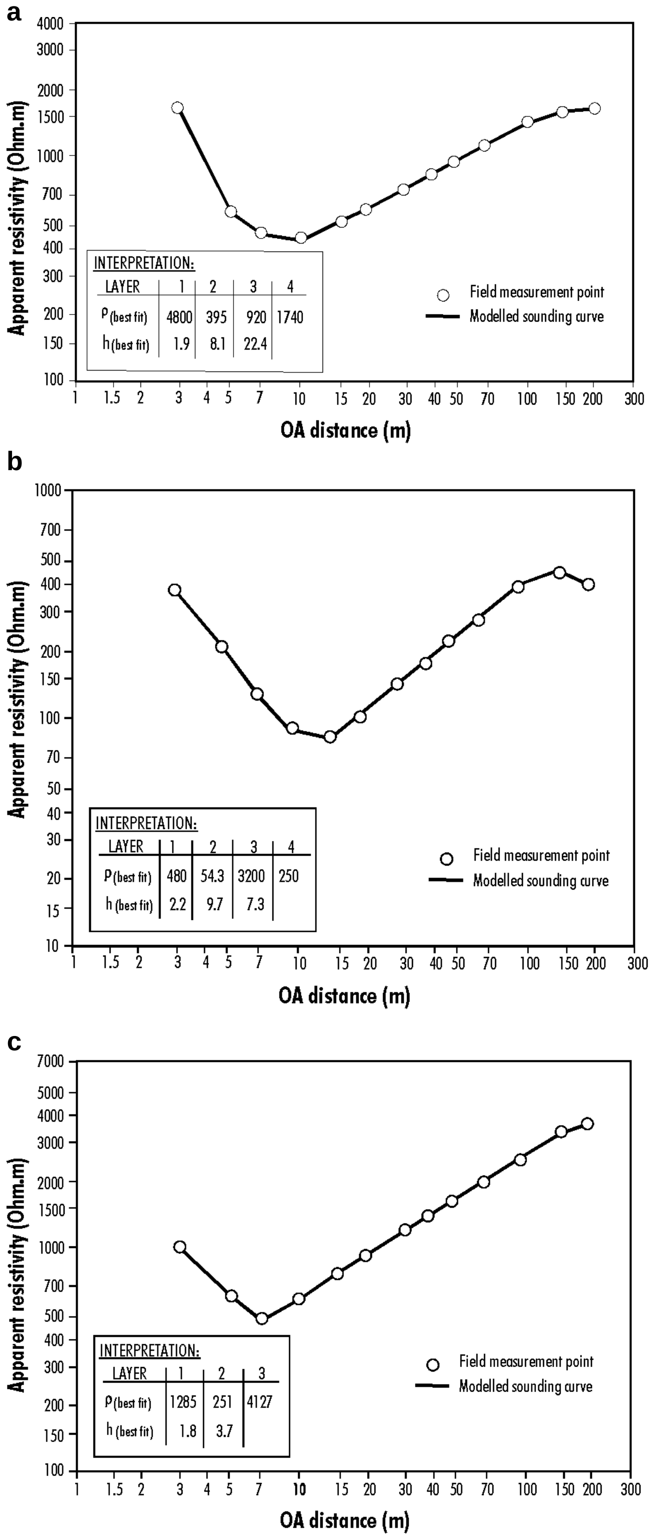

Figure 5
Schlumberger depth sounding curves on a) Leeuwfontein 492 JR (Borehole 1); b) Leeuwfontein 492 JR (Borehole 2); and c) Trigaardspoort 451 JR. Legends as in Fig. 2.

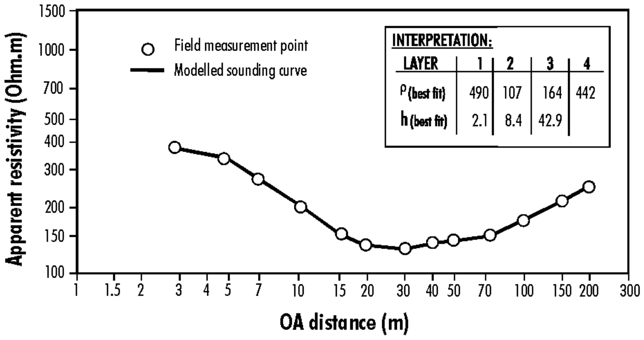

Figure 6
Schlumberger depth sounding curve obtained on Goedvertrouwd 499 JR. Legend as in Fig. 2.

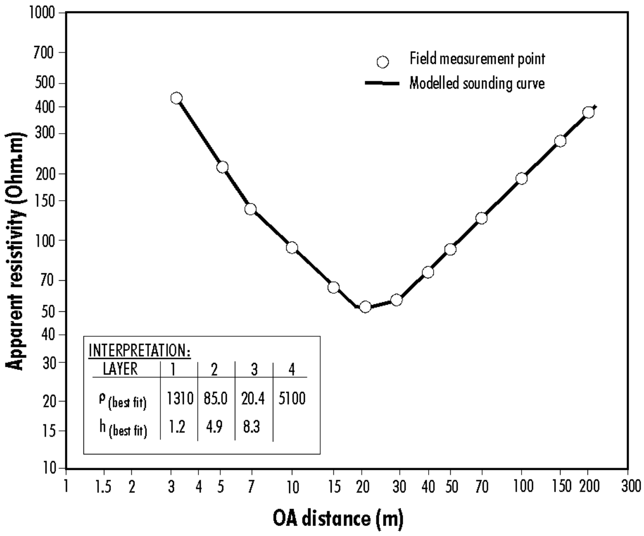

Figure 7
Schlumberger depth sounding curve obtained at Leeuwfontein 492 JR (Borehole 3). Legend as in Fig. 2.

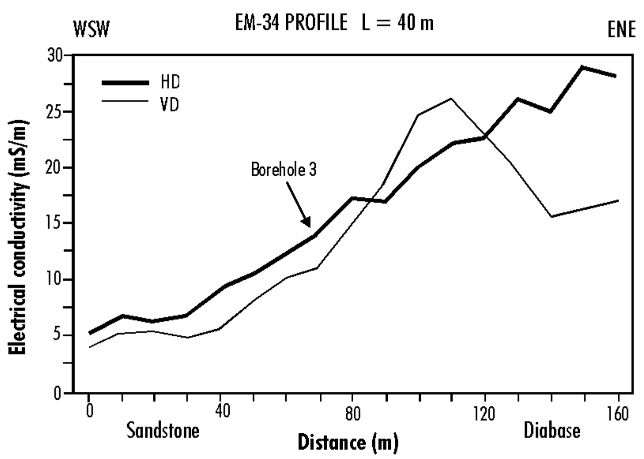

Figure 8
Electromagnetic traverse (Geonics EM34) on the farm Buffelskloof 342 JS (Borehole 3).
= horizontal dipole, — = vertical dipole.

characteristics of the aquifer as closely as possible. Of the 44 boreholes studied, at least 41 show the main aquifer to be weathered diabase material. A typical case is shown in Fig. 6. Here the first layer is residual soil with a thickness of 2.1 m, followed downwards by a shale layer with a thickness of 8.4 m, which in turn is in contact with a thick (42.9 m) layer of weathered diabase. The latter is the aquifer. This borehole yields approximately 1.7 ℓ/s. On the farm Leeuwfontein 492 JR a depth sounding was done on a dry borehole. The interpretation (Fig. 7) indicates the possible existence of a weathered diabase layer at a depth of 6.1 m with a thickness of 8.3 m. Here the weathered diabase is situated too shallow and is above the piezometric water level, thus resulting in a dry borehole.

Electromagnetic measurements (EM 34) found that the conductivity of the Wilgerivier sandstone is low, with values in the order of 3 mS/m (Fig. 8). Where weathered diabase was encountered, the conductivity rose to values as high as 30 mS/m (Fig. 8). This contrast indicates that the positions of sandstone/diabase contact zones will readily be delineated by electromagnetic surveys.

In total, twelve traverse lines were surveyed with the magnetic method. Of these lines only one produced a clearly defined anomaly which could be interpreted as resulting from a dyke (Fig. 9). The borehole associated with this dyke/country rock contact zone yields 2.1 ℓ/s. Some of the traverse lines produced no well-defined anomaly, but the areas underlain by sandstone or diabase can qualitatively be delineated by inspection of the data (Fig. 10). Most of the traverse lines produced data containing only magnetic noise which in some instances may mask the presence of low amplitude anomalies. Due to metallic objects normally present at and around existing boreholes, the presence of magnetic noise is to be expected.

At seven boreholes a geobotanical indicator was observed. *Dichapetalum cymosum* (gifblaar) and *Burkea africana* (red syringa) were observed at four boreholes, while *Acacia karroo* indicates weathered diabase beneath the surface. The apparent paucity of these indicators can be described to human destruction of the natural vegetation near existing boreholes.

Conclusions

This study of 44 boreholes in the Wilgerivier Formation indicates that groundwater exploration in this Formation can successfully be done using relative low-cost geophysical methods such as Schlumberger electrical depth soundings, the magnetic method and the electromagnetic technique, provided that all data acquired are thoroughly interpreted. To achieve this an intimate knowledge of the geology at the site is required.

If future Schlumberger depth soundings from the area are carefully interpreted and compared with sounding data presented in this paper, the type sounding curve as well as the interpreted resistivity of the aquifer can be used to forecast the possible order of water yield of the proposed borehole. It is also clear that the magnetic method can be used as a quick tool even if in certain cases the magnetic data can only be qualitatively interpreted due to the absence of a well-defined anomaly or the presence man-made magnetic noise.

The electromagnetic (EM 34) technique is not essential to groundwater exploration in the Wilgerivier Formation. However, if electromagnetic noise is absent, it can be a rapid technique to find diabase/sandstone contacts which may act as suitable aquifers.

At a large number of boreholes, the aquifers were found to be weathered diabase sills or weathered country rock contact zones with either dykes or sills. The absence of these intrusive rocks in

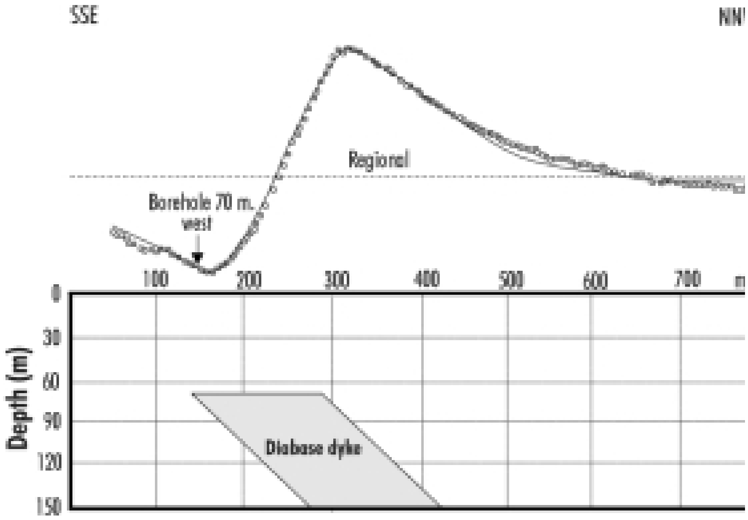

Figure 9
Magnetic traverse on the farm Bankfontein 375 JS, with interpretation

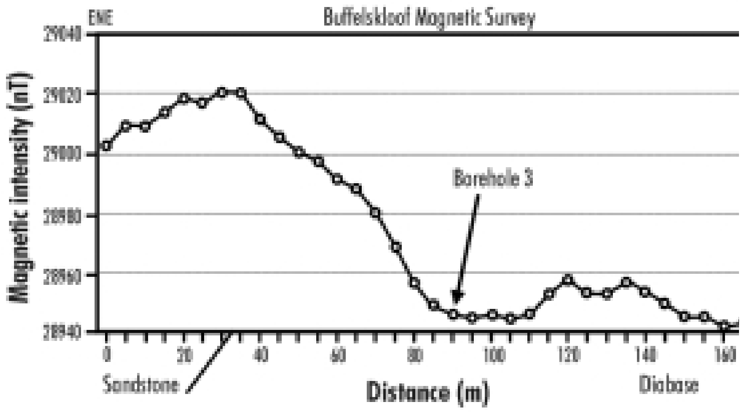

Figure 10
Magnetic traverse on Buffelskloof 342 JS, with qualitative interpretation

the Wilgerivier Formation will lead to a paucity of groundwater in the Formation.

Lastly, it is interesting to note that the blind use of the above-mentioned geophysical techniques, without a knowledge of the geobotany, geology and a study of the aerial photographs, will achieve very little.

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