# Ground magnetic and resistivity surveys for groundwater exploration

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**Abstract**

Ground magnetic and resistivity surveys were conducted for groundwater exploration. Magnetic survey was used to delineate the basement structures which control the groundwater flow. The magnetic data were subjected to statistical and analytic signal analysis, where it showed clearly the complexity of the studied area. Resistivity profiling and sounding were used to investigate and ensure the potentiality of the groundwater occurrence in the structurally complex basement. Resistivity profiling was used to define the effect of the basement structures on the groundwater distribution. Vertical Electrical Sounding was conducted at selected sites along the magnetic and resistivity profiles. The integration of the obtained results from these two methods was successful to define the sites for drilling wells for the groundwater supply.

**Introduction**

The study area lies in Huambo City, Province of same name, situated in the central region of Angola, approximately 450 km southeast of the capital, Luanda. Province of Huambo features a subtropical highland climate, with a wet season from October through April and a dry season between May and September. Despite its location in the tropics, due to its high altitude, Huambo City features spring-like temperatures throughout the course of the year. The city sees plentiful precipitation during the course of the year, averaging nearly 1500 mm of rain.

The main water treatment plant has not functioned properly since 1975 and the population is currently dependent on wells for water access. However the sub-surface geologic formation has groundwater in sufficient quantities to be used for drinking don’t have potential to be used for commercial and industrial purposes. Therefore, the present study was suggested to determine the more preferable locations to drill new wells for water supply to Nocebo Brewery Factory situated in that city .

In groundwater exploration, in a hard rock media, it is very important to delineate structures such as geological contacts, faults and joints. Huambo City, which lies within the granitic shield, the groundwater potentiality is strongly controlled by these structures. Therefore, magnetic method was employed to delineate these structures, which are considered as a pre-requisite for groundwater exploration. Resistivity methods have been conducted afterward at sites suggested by the magnetic survey.

**Study area**

The region under consideration (Fig.1) in study area has the particularity to be composed by crystalline rocks of Precambrian period, distributed by the formations of the complex of base, at east-northeast and the eruptive granitic massif at west-southwest. The old massif is related to quartzy sedimentary formations and schist-clayey found in central-western area, besides the occurrence of basaltic rocks widely scattered outcrops in small sites in the granite formations of Cuima, the most representative.

The study area includes older formations representing the complex of base corresponding to metamorphosed rocks or rocks showing some degree of metamorphism and the granite-gneiss, orthogenesis, granites, granite-diorite, diorite-quartzy, and other rocks showing quartzy characteristics are the most abundant geological materials. It is noted that the locations of granitic rocks in the western of the area represent the complex of volcanic rocks, which characteristics vary from granite to granitic-diorite and diorite-quartzy, difficult to be distinguished macroscopically. At south of Benguela railway the outcrops of diorite-quartzy and granite-diorite are predominant. At north granites are more abundant and, given its importance the granite-porphyry nominated "Granito da Quibala", found at northwest is the most important.

Precambrian sedimentary rocks are included in the Oendolongo Group of lower Proterozoic period. This group is constituted by a series of volcano-sedimentary with thickness varying from 350 to 1000 m. These formations are scattered across numerous sites in the middle of the eruptive batholiths and, when culminate in quartzite or sandstones-quartzy, originate the very pronounced forms which result in expressive relieves, constituting mountains rising from the granitic plain. The coverage formations are deposits of sand-quartzose fan produced from the coverage of the old lateralized highland surfaces. These deposits are less thick and cover the old massif.

**Ground magnetic survey**

The geological features in the study area, as discussed before, make the geological contacts interesting targets for mapping the structures which are favorable for groundwater exploration.

Thus, ground magnetic survey was carried out to delineate these structures which could be the favorable targets to evaluate the groundwater potentiality within the study area. Eight magnetic profiles were conducted crossing perpendicularly the Caluapanda River with the spacing interval of 50 m and 800 measurements of magnetic data were taken.

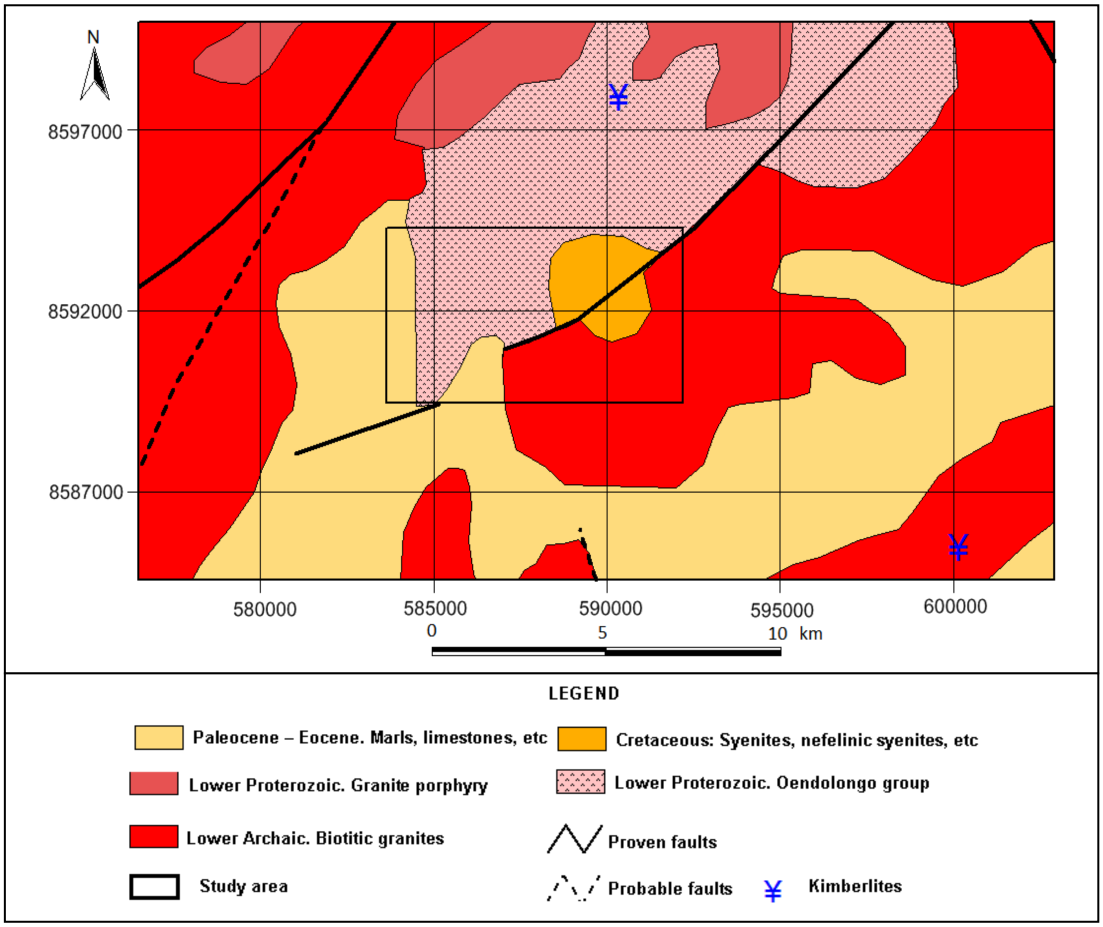


*Figure 1 – Regional geologic features of study area which is highlighted in black rectangle from the “Geologia de Angola. Mapa e Noticia Explicativa da Carta Geológica à Escala 1:1 000.000, Luanda, Angola”. (Araújo & Guimarães, 1992).*

These profiles have been chosen in such a way that they cross different structural elements and subsurface geological contacts.

Ground magnetic data were taken using one portable unit of GSM-19 “Overhauser effect” and other of G-5, all proton precession magnetometers. The GSM-19, providing 0.015 nT√eHz sensitivity and 0.1 nT absolute accuracy, was used to measure the total intensity of the magnetic field at each point of observations along the profiles. The G-5, providing 0.1 nT√eHz sensitivity and 1.0 nT absolute accuracy, was used as a base station to record automatically, every 30 seconds, the diurnal variations of the geomagnetic field. No magnetic storms were recorded during the period of survey.

**Processing and Interpretation of magnetic data**

Statistical analyses of all the measured magnetic data were performed and the results are shown in Table 1.

*Table 1 - Statistical analyses of magnetic data*

| Stat. Par. | N. Values | Max. | Min. | Mean | SD |
|---|---|---|---|---|---|
| nT | 797 | 31814.95 | 31269.86 | 31435.04 | 78 |

These statistical analyses were used to draw a colored anomaly map (Al Garni, 2005). The minimum (Min.) value was considered as a static level to be reduced from each individual data value. The standard deviation (SD) value was considered as an interval for constructing the magnetic total intensity anomaly map (Fig.2).

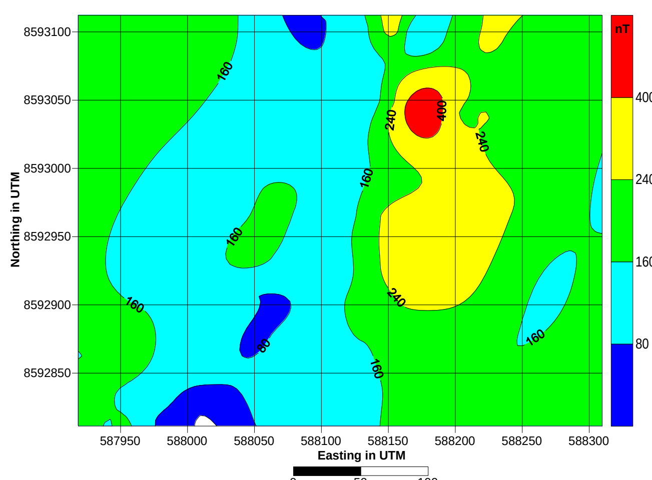


*Figure 2 – Magnetic total intensity anomaly map*

In this map it is evident that the study area is dominated by a main structure in the center with north-south orientation, showing low magnetic anomalies. Also a north-south trended structure with high magnetic values is shown.

Also all the magnetic data were subjected to the analytic signal algorithm, which makes that the maximum amplitude is exactly located over a magnetic contact (Nabighian, 1997). First, regional anomaly was removed from the data using spectral analysis, followed by filtering procedure to enhance the magnetic anomaly and to obtain better trends, locations and disposition of the basement rock structures. The data were then interpreted to show the structural features of the magnetic contacts. The same behavior, illustrated in the map above, can be seemed, where the main structure, showing low magnetic anomaly with north-south orientation, crosses the area. Secondary low magnetic zones with east-west orientation are located in eastern and western sides.

The fractures, which are discontinuities planes in geologic formation, illustrated in this map, form deep fissures in the rock and can be the major path for water movement.

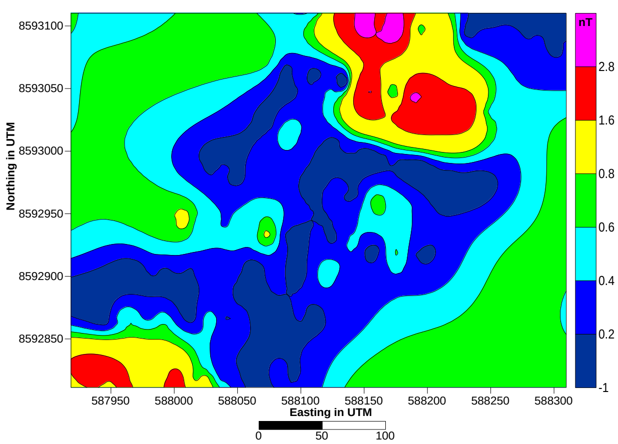


*Figure 3 – 2D analytic signal map.*

Interpretation of both, magnetic total intensity anomaly map and the 2D analytic signal map indicate that the area is inhomogeneous. The magnetic total intensity anomaly map shows roughly these two sets of structural trends, but the 2D analytic signal map shows structures with higher resolution as lineaments, representing the boundaries of these structural zones.

**Resistivity survey**

Resistivity survey was conducted utilizing the Wenner array, for profiling, and Schlumberger array for vertical electrical sounding (VES), both applied using G41 resistivity meter. Resistivity profiling was carried out along the extension of the magnetic profiles to correlate the subsurface structural variations with the groundwater occurrences. Measures were done at 32 points, with a sampling interval varying from 20 to 50m, to investigate the horizontal variations of resistivity along the profiles.

The VES technique was used to investigate the vertical variations of resistivity of the upper 35 m of sediments lying on the bedrock in subsurface. Therefore, nine selective locations were chosen in the study area, three of them were next to the existing boreholes and the other six locations were selected according to the results of the interpretation of the ground magnetic survey and resistivity profiling. These electrical soundings were carried out on the locations of the identified magnetic anomalies and, to reach the bedrock, the electrodic distance AB was varied from 100 to 300 m length.

**Processing and Interpretation of resistivity data**

The interpretation of each wenner curve was carried out in two steps. First, an approximate interpretation was done by the curve-matching methods (Orellena, 1972) and another interpretation was obtained through the use of the an automatic computer program (Zohdy, 1989), the EarthImaGer, form Advanced Geosciences Inc. Based on these interpretations, the parameters apparent resistivity and thickness of a geoelectric model, thought to be closer to reality, were estimated (Rijo *et al*., 1977). To delineate structures such as geological contacts, faults and fractures the parameter thickness was chosen to draw the map showing the depth of the basement rock (Fig.4).

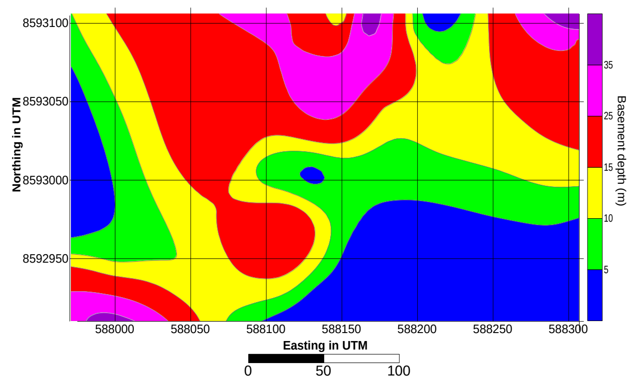


*Figure 4 – Depth of basement rock map*

This map shows that the basement rock is deeper at north, northeast and southwest. The pattern illustrated by these results shows good correlations between the maps from magnetic data. The interpretation is that the potential aquifers are expected to be found at these deeper locations. The sediment section at these locations range between 30 meters thickness or more. The horizons occurring at more than 30 meters depth could be associated to deeper geological contacts, faults or fractures. These results strongly suggest that these aquifers are recharged by infiltration through overlying unconsolidated sediments by water discharges from rainfall and rivers.

To emphasize the vertical limits of the resistivity zones recorded along the profiling surveys VES technique was used which measurements provided a series of apparent resistivity values as a function of electrode spacing at each site. The sounding curves were smoothed and represented as resistivity curves by log-log graphs (Fig.5).

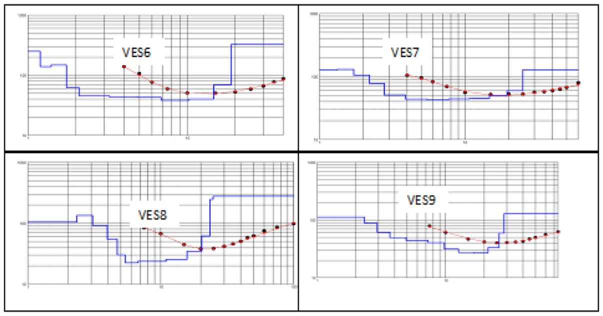


*Figure 5 – VES data. (●) measured (●) modeled (--) layers*

The VES data were interpreted applying the same methods described above, to obtain the equivalent layer models. After the analysis of the VES data recorded at each site, the variations of the resistivity values with depths were correlated with the geological succession (Fig.6). It is noted that these sites are composed of basement rock beneath the sedimentary cover as a result of weathering.

The resistivity values of layers under all VES shows a continuous decreasing with depth increasing, followed by a slight increase until to basement rock.

The high resistivities of the top and bottom layers in the study area are due to the presence of a dry weathered layer and basement rock, respectively.

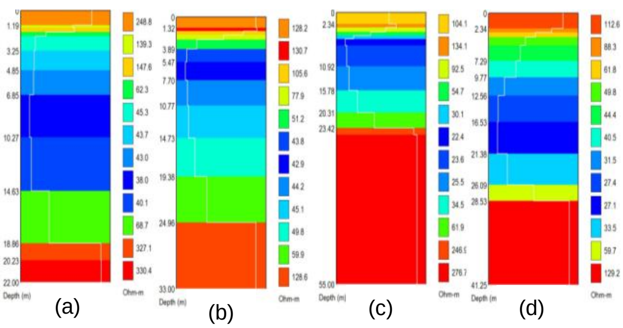


*Figure 6 – Layered resistivity models. (a) VES6 (b) VES7(c) VES8 (d) VES9. Color bars indicate the layers resistivity increase from blue to red.*

Under the VES6 and VES7 there are a low resistivity layers which start from the depth of 1.0 m and continues in resistivity decreasing with depth to 10 m. In addition, under the VES8 and VES9 these low resistivity layers start from the depth of 2 m and the resistivity values decreases continually until 20 m depth. This phenomenon indicates that a suitable groundwater potential exists under this sites.

The integration of the results from ground magnetic survey, resistivity profiling and resistivity sounding show that the groundwater saturated zones are related to the boundaries of the structural zones recharged during the rainy season.

**Conclusions**

Ground magnetic and resistivity surveys were conducted to understand and locate the structures that control the groundwater flow and the more favorable sites for the groundwater accumulation. The ground magnetic survey showed a main north-south structure crossing the study area that it is highly fractured. Resistivity profiling shows north and southwest structures. On the other hand, resistivity sounding results show that the most favorable location for drilling is in that fractured structures illustrated by magnetic and resistivity profile data. The resistivity recommended sites shows higher potentiality of groundwater occurrences, hence, they are strongly recommended locations for drilling.

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