Spatial Analyses of Magnetotelluric Data in the Northern Part of Congo Craton in South Cameroon Region

1,2 Jorelle Larissa Meli’i, 1,3 Philippe Nouch Njandjock, 4 Alain François Mbanga and 1,5 Eliézer Manguelle-Dicoum

1Department of Physics, Faculty of Science, University of Yaounde I, Cameroon. 2Department of Physics; Advanced Teachers Training College, University of Yaounde I, Cameroon. 3National Institute of Cartography, Cameroon. 4Institute for Geological and Mining Research, Cameroon. 5Cameroon Academy of Science.

Corresponding Author: Philippe Nouch Njandjock

Abstract
We explored Precambrian crystalline zone conductivity from recent Electromagnetic data combined with geostatistics, in the southern part of Cameroon to guide future hydrologic research. With the Magnetotelluric (MT) data, experimental semivariogram was constructed to analyse spatial variability of the resistivity in this area. Among several models, the Gaussian semivariogram model was used to compute the resistivity map of the studied area. An analysis of these results shows that, the area is characterised by a wide margin of resistivity. The Correlation with some recent results from boreholes suggested that, conductive zones can guide the further exploration research of ground water reservoirs in this area. The inverse operation allows us to estimate the depth of these anomalies.

Keywords: semivariogram, kriging, precambrian, magnetotelluric, groundwater, craton, sangmelina

INTRODUCTION
As Magnetotelluric (MT) techniques are sensitive to the resistivity of rocks, they are used to investigate wave propagation and the rocks behaviour in the northern part of Congo Craton (Figure 1). In this paper, we analyse recent MT recorded data and discuss various models of variograms to construct resistivity map by kriging. The results obtained are presented and discussed.

METHODS
The semivariance plays a central role in the analysis of geostatistical data using kriging techniques (Isaaks and Srivastava 1989; Kumar and Remadevi 2006). The first step in kriging is to calculate the experimental semivariogram (Figure 5) using the following equation:

\[ \gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x_i) - z(x_i + h))^2 \]

where \( \gamma(h) \) represents the estimated value of the semivariance for lag h; N(h) is the number of experimental pairs separated by vector h; z(xi) and z(xi+h) are values of z variable at xi and xi+h, respectively. xi and xi+h represent the position in dimensions two. In the linear kriging method, the interpolated value of z at any point xi is given as the weighted sum of the measured values:

\[ \hat{z}(x_i) = \sum_{i=1}^{n} \lambda_i z(x_i) \]

where \( \lambda_i \) is the weight for the observation z at location xi, calculated by equation (3) and (4) so that \( \hat{z}(x_i) \) is unbiased and optimal (minimum squared error of estimation).}

\[ \sum_{i=1}^{n} \lambda_i = 1, i = 1,2,3,\ldots, n \]

\[ \sum_{i=1}^{n} \lambda_i z(x_i) \]

\( \mu \) is the Lagrange multiplier and \( \gamma(x_i, x_j) \) the semivariogram between two points xi and xj.

STUDY AREA AND DATA USED
The study area is located in the Central part of Africa in the northern part of the Congo Craton. The Congo Craton is covered by the Palaeozoic-to-recent Congo basin, and is an ancient Precambrian Craton that, with four others (the Kaapvaal, Zimbabwe, Tanzania and West African cratons) makes up the modern continent of Africa. This craton was formed between 3.6 and 2.0 billion years ago and have been tectonically stable since that time. It is bounded by younger fold belts formed between 2.0 billion and 300 million years ago. The Congo craton occupies a large part of central southern Africa, extending from
the Kasai region of the Democratic Republic of Congo into Sudan and Angola. It forms part of the Central African Republic, Gabon and Cameroon (Figure 1). The area is covered by various Precambrian rocks (Manguelle-Dicoum al, 1988, 1992; Vicat, 1998) (Figure 2).

Figure 1: Cratons and Mobiles zones in African Continent according to Klitgord et Schouten (1986); Fairhead (1988); Giraud et Maurin (1992)

Figure 2. Nyong basin hydrogeological map (Vicat, 1998) modified.

The plutonic formations consist of granitoid belonging to two lines installation at successive episodes: charnockites (towards 2900 Ma), and more potassic and leucocratic granites (2700-2600 Ma). Within these rocks, frequent intrusions in relation with various tectonic events can be found: gneisses, shales, dolerite, gabbro, and peridotites. The following geological formations are generally observed: lateritic cover, gravel, granite, clay and fractured granite (Figure 3).

Figure 3 : Logs of some boreholes

The MT data were recorded between 2009, 2010 and 2011, according to the relation:

\[ \rho_a = 0.2 \times T \times \left( \frac{E}{H} \right)^2 \]

where \( \rho_a \) represents the apparent resistivity of the ground in \( \Omega \cdot m \), \( T \) the period of the wave in (s), \( E \) the electric field in mV/km and \( H \) the magnetic field in gamma (Cagniard, 1953). This non destructive method is frequently used for subsurface investigation. The presence of conductive structure in variable proportion in the ground involves contrasts of electrical resistance which can be measured on the surface (Bernard, 2003; Béhaegel, 2006). The data were collected approximately in 1km grid in dry land areas.

RESULTS

Topographic and MT Stations Localisation Maps

Figure 4 presents the topographic map of the area from mean sea level. We can observe that, the high altitudes values (more than 700m) are observed in Atong Mimbanga and Mekomesse zones. The low altitudes 685 m values are located around Adjaye-Cetic zone. But in general, the altitudes difference is about 20m.

Figure 4: Topographic map of the studied area
The data were collected in the frequency range of 4.1 to 2300 Hz in the dryland areas, along the tracks and in the plantations for which the access was granted on an approximate 1km grid (Meli’i et al 2011).

The Variograms
The experimental semivariograms were fitted with various theoretical models like spherical, exponential, gaussian, linear and power by the weighted least square method. A lag distance of 1km and a tolerance of 0.5 km were used for the calculation. The theoretical model that gave minimum standard error is chosen for further analysis. The gaussian model (Figure 5) appears to be the best fit model and it is expressed:

$$\gamma(h) = \frac{3.6}{10^5 \lambda} \left[ 1 - \exp\left(-3.5 \left( \frac{h}{\lambda} \right)^{0.5} \right) \right]$$

Figure 5: Experimental variograms models obtained from resistivity data.

Resistivity Map
The resistivity map is plotted for the frequency 730 Hz by kriging at the nodes of the square grid of 1km x 1km with the gaussian model of variogram. These estimated mean values are used with the (Surfer software, 2002) to draw the iso-contour map (Figure 6). This map shows that, the resistivities are generally high (more than 4000 Ω.m) in the whole area. But in the central part of the study area, around Adjaye, Bidjom and CETIC, the structures are relatively conductive with the resistivity values some time less than 100 Ω.m. Then, inverse methods are applied to estimate the depth of the probable conductive causative bodies. The following relation (Vozoff, 1972) has been used:

$$P = \frac{\gamma \omega}{\mu_0 2\pi \sigma \tau}$$

Where P is the depth of the causative body in km; ω is the angular frequency in rad/s; μ0 is the magnetic permeability in H, σ is the apparent conductivity of the body in Ω.m and τ is the period of the MT wave in s. Tables 1 to 4 present characteristics of the layers obtained from inverse evaluation of MT soundings in the central part of the study area, where the conductivity observations were particularly high (Figure 7).

Figure 6: Resistivity contours map around the conductive area of Sangmelima

Figure 7: Geoelectrical cross section
In addition to that, we realised that, around Adjaye and CETIC where the low altitudes values are observed (Figures 2 and 4), the resistivity is low 100 $\Omega\cdot$m principally where two deep groundwater reservoirs structures are located. The water wells realised in these zones with more than 40 m depth are fruitfull and the pumping tests have revealed that, the flow of water is relatively high as reported by Meli’i et al. 2011.

**CONCLUSION**

In this study, we explored the resistivity of the northern margin of Congo craton in the southern part of Cameroon, from Electromagnetic data recently recorded over this region combined with geostatistical available information. The Gaussian variogram model is found to be the best model representing the spatial variability of the resistivity, for this reason, it is used to plot resistivity map by kriging method for this region. This new map permitted us to identify resistive and conductive zones in this area. Inversion of the recorded data allows us to evaluate the depths of these two causatives bodies. The comparison of these results with the preceding one suggest that, the causative source anomalies can correlate with two deep groundwater reservoirs located in the fractured rocks. So, this investigation can guide the further groundwater research in this Precambrian area.

**REFERENCES**


---

**Table 1**: Parameters obtained from interprétation of sounding $S_7$ (Adjaye)

<table>
<thead>
<tr>
<th>Number</th>
<th>Resistivity ±10(Ω·m)</th>
<th>Thickness ±1 (m)</th>
<th>Depth ±1 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>225</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>2670</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>922</td>
<td>42</td>
<td>79</td>
</tr>
<tr>
<td>5</td>
<td>8.2 E + 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2**: Parameters obtained from interprétation of sounding $S_8$ (Bidjom)

<table>
<thead>
<tr>
<th>Number</th>
<th>Resistivity ±10(Ω·m)</th>
<th>Thickness ±1 (m)</th>
<th>Depth ±1 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>228</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>2683</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>4</td>
<td>978</td>
<td>65</td>
<td>104</td>
</tr>
<tr>
<td>5</td>
<td>6.8 E + 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3**: Parameters obtained from interprétation of sounding $S_9$ (Kamelon)

<table>
<thead>
<tr>
<th>Number</th>
<th>Resistivity ±10(Ω·m)</th>
<th>Thickness ±1 (m)</th>
<th>Depth ±1 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>234</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>2637</td>
<td>29</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>960</td>
<td>29</td>
<td>70</td>
</tr>
<tr>
<td>5</td>
<td>2.6 E + 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4**: Parameters obtained from interprétation of sounding $S_6$ (Mang)

<table>
<thead>
<tr>
<th>Number</th>
<th>Resistivity ±10(Ω·m)</th>
<th>Thickness ±1 (m)</th>
<th>Depth ±1 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>2700</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>978</td>
<td>37</td>
<td>73</td>
</tr>
<tr>
<td>5</td>
<td>59501</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

This study, based on recent MT data has permitted us to plot topographic map, resistivity map based on geostatistical approach and geoelectrical cross-section map in the northern part of Congo Craton in Sangmelima zone (Figures 4, 5, 6 and 7). These figures show that, the area is characterised by conductive and resistive zones. The resistive zone is interpreted as the MT responses of dry structures like consolidated Granite, gravel and lateritic materials. These materials according to figures 2 and 3 are common in this zone. The granite structure is in general of Precambrian. But lateritic materials are in general of recent age and are due to the decomposition of some old structures under the effect of geological cycles. The conductive zone is on the other hand, the MT responses of low resistive material. From 0 to 50 meters under the lateritic cover (Tables 1, 2, 3 and 4), these geological formations consist of sandstone in general, lateritic cover and fractured granite when they enclose water. In addition to that, we realised that, around Adjaye and CETIC where the low altitudes values are observed (Figures 2 and 4), the resistivity is low 100 $\Omega\cdot$m principally where two deep groundwater reservoirs structures are located. The water wells realised in these zones with more than 40 m depth are fruitfull and the pumping tests have revealed that, the flow of water is relatively high as reported by Meli’i et al. 2011.

CONCLUSION

In this study, we explored the resistivity of the northern margin of Congo craton in the southern part of Cameroon, from Electromagnetic data recently recorded over this region combined with geostatistical available information. The Gaussian variogram model is found to be the best model representing the spatial variability of the resistivity, for this reason, it is used to plot resistivity map by kriging method for this region. This new map permitted us to identify resistive and conductive zones in this area. Inversion of the recorded data allows us to evaluate the depths of these two causatives bodies. The comparison of these results with the preceding one suggest that, the causative source anomalies can correlate with two deep groundwater reservoirs located in the fractured rocks. So, this investigation can guide the further groundwater research in this Precambrian area.

REFERENCES


---

634


