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Audiomagnetotellurics (A.M.T) soundings based on the Bostick approach and evidence of tectonic features along the northern edge of the Congo Craton, in the Messamena/Abong-Mbang area (Cameroon)

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ABSTRACT

An Audio-Magnetotelluric (A.M.T) study is carried out in the Messamena/Abong-Mbang area in Cameroon. It consists of two measurement profiles S-N. The A.M.T data sets are collected using a resistivity meter with frequencies ranging from 4.1 Hz to 2300 Hz. The frequency range used has permitted to reach some important depths because of high resistivity values of the metamorphic rocks. A 1D linearized inversion and 2D modelling of data led to attain a granitic basement at 9 km on one hand, and to put in evidence an important buried fault structure at Abong-Mbang in another hand. From a 2D modelling of pseudo-sections of resistivity and phase, a system of folds has been discovered at Messamena. The tectonic structures put in evidence in the Messamena/Abong-Mbang area are perfectly linked to the collision between the Pan-African Belt and the Congo Craton. The pseudo sections of phase for the two profiles permitted to propose two geological models of rock layers distribution.

INTRODUCTION

Interpretation of audio-magnetotelluric (Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009) covering the east of the Akonolinga/Ayos area enabled to put in evidence a buried fault oriented W-E in Ayos, and a system of crushing structures.

A 1D and 2D modelling of magnetotelluric (MT) data for geological prospecting based on the study of the behaviour of the electrical conductivity in the subsurface in many areas around the world (Ritz 1982; Bayrak et al., 2006) has been for the authors a motivation for the actual study. Phase values have derived from the combination of the resistivity mean value principle (Ranganayaki 1984; Campos-Enriquez et al., 1997; Bisso et al., 2004) and the Hilbert transform (Delgado-Rodrigez et al., 2001; Bostick 1977). The proposed 2D geological models of the subsurface in the Messamena/Abong-Mbang area, is based on the interpretation of audiomagnetotellurics (AMT) data collected using an apparatus that measures simultaneously the electric and magnetic fields (Meying et al., 2009; Delgado-Rodrigez et al., 2001; Cagniard 1953; Vozoff 1991 & 1972).

GEOLOGY OF THE STUDY AREA

The area under study is situated between the latitudes 3°30'N and 4°30'N and the longitudes12°30'E and 13°30'E (Figs. 1a & 1b), and covers approximately a surface area of 70 km (W-E) x 50 km (S-N). It belongs to the Central African fold belt (CAFB) (Ngako et al., 2003; Mvondo, Den-Brok& Mvondo-Ondoa 2003; Mvondo et al., 2007).

The Messamena/Abong-Mbang area which is adjacent to the Akonolinga-Ayos's, is situated at the northern edge of the Congo Craton (Rolin 1995; Cornachia & Dars 1983). This area is also bounded on the north by the Cameroon faulting zone (CFZ) linked to the Cameroon volcanic line (CVL). According to geological investigations (Mvondo, Den-Brok & Mvondo-Ondoa 2003 Mvondo et al., 2007; Regnoult 1986; Olinga et al., 2010), the area is included in the Yaoundé series and it is constituted

(Fig.1b) of garnetiferous gneiss and migmatite embrechites, and of garnetiferous migmatite and micaschists (Gazel & Guiraudie 1965). The basement appears by some granite outcrops in the northerneast (Fig.1b). The observed granites are calco-alcaline with biotite or monzanite. Many quartz veins are observed above the 4° parallel. These veins can be source of gold bearing indices (Gazel & Guiraudie 1965).

The tectonic facts revealed that, the area of study is characterized by four phases of deformations D_1-D_4 (Mvondo, Den-Brok & Mvondo-Ondoa 2003; Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009; Olinga et al., 2010). The observed tectonic lines are directed SW-NE below and turned to be SE-NW above the 4°N parallel (Fig. 1b). Geophysical studies along the 4° parallel in the western adjacent areas (Mbom-Abane 1997; Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009; Ndougsa et al., 2003) have shown evidence of some buried faults directed W-E and have confirmed tectonic napes with a southern vergency. According to Olinga et al.(2010), the Pan-African deformation affected the study area which appertains to the southern segment of the Neoproterozoic fold belt of Cameroon, Central Africa, is controlled by thrust tectonics and late strike-slip shear zones: the thrusting of the Pan-African Nappe over the Congo Craton (D2 deformation phase) is followed by a strike-slip shearing trending ENE-WSW (D3 deformation phase). During these stages deforming conditions were ductile to brittle-ductile. The dominant structural features of the D3 phase are penetrative foliation steeply dipping N or S, an associate ENE-WSW trending stretching lineation, and an N-S to NE-SW directed folding. Deformation criteria in the distinguished rock units indicate dextral sense of shear. A dextral trans-pressional model is assumed by Olinga et al.(2010) to explain the observed thrust and shear movements. The geological-and tectonic facts summarized above show the complexity of the Messamena/Abong-Mbang area.

MATERIAL AND METHOD

The Magnetotelluric (MT) method discovered by Cagniard (1953) is applied for geophysical and structural geology prospecting (Bostick 1977; Ritz 1982; Jones 1983; Vozoff 1972 & 1990; Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992; Manguelle-Dicoum et al., 1993; Campos-Enriquez et al., 1997; Delgado-Rodrigez et al., 2001; Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009). It consists of the simultaneous measurements of electric and magnetic natural fields at any point on the surface of the Earth, in order to deduce the resistivity of rocks of the homogeneous subsurface. But in the real case the subsurface is inhomogeneous and the determination of the apparent resistivity is

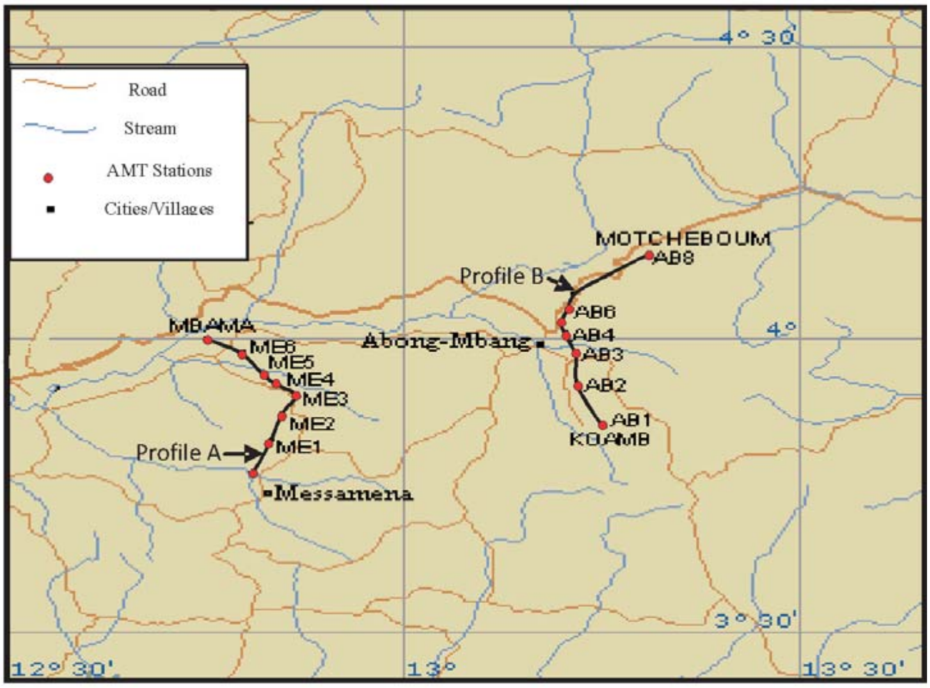

Figure 1a. A.M.T sounding locations map.

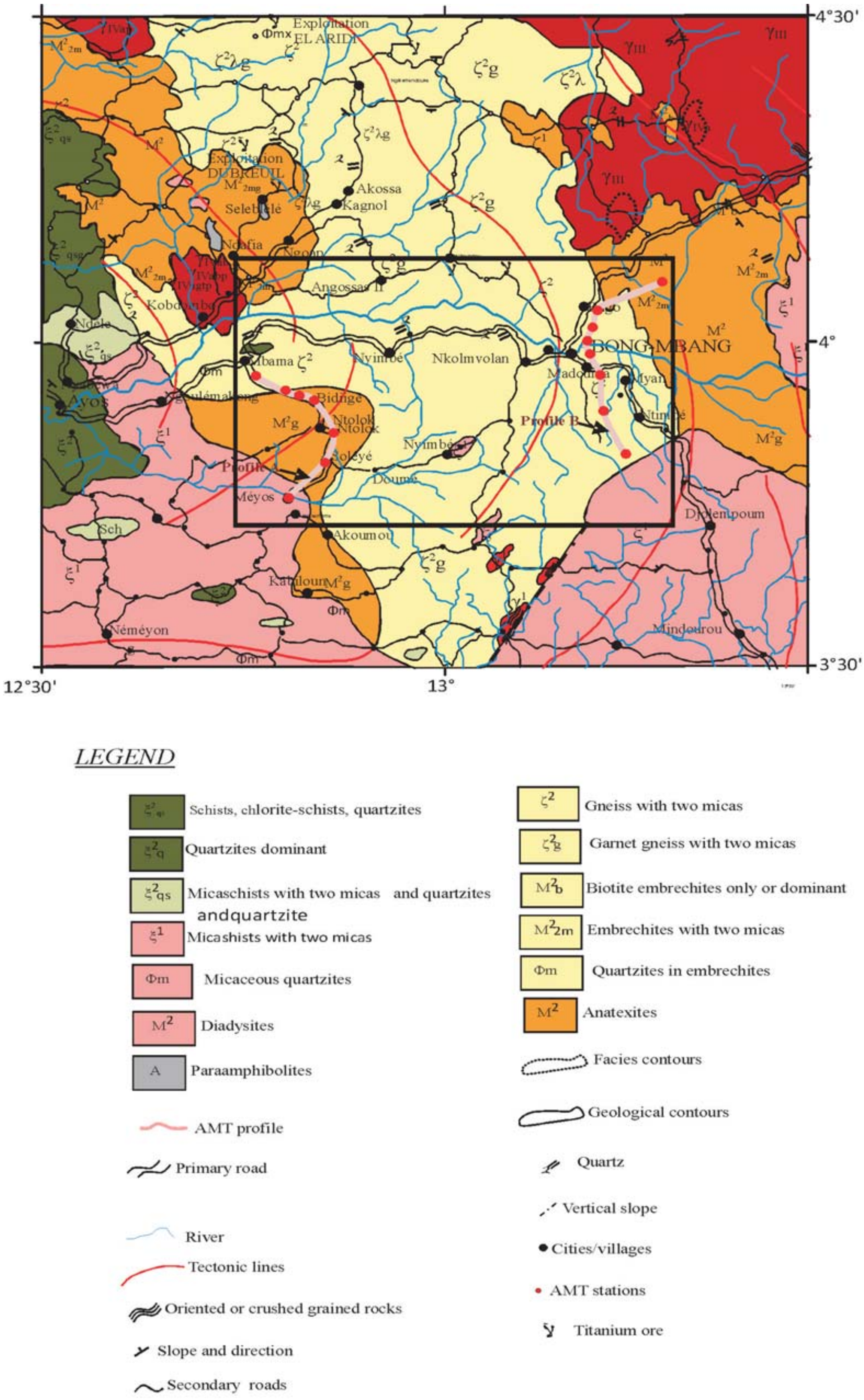

Figure 1b. Geological map of the study area (Gazel & Guiraudie, 1965).

governed by Bostick (1977) law which is derived from the Cagniard fundamental formula (Ballestracci et al., 1985; Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992).

In this work, we have used data collected from the AMT soundings during dry seasons from 1993 to 1996 in the Messamena/Abong-Mbang area, with the help of an ECA 540 resistivity meter, which operates in the frequency range of 4.1-2300 Hz. The resistivity meter consists of a detector to measure one component of the electric field along the x axis, and another detector to measure simultaneously the component of the magnetic field in the y direction at the same frequency of the natural telluric field. A microprocessor uses the electric and magnetic fields measured values to calculate the apparent resistivity according to the Cagniard formula (Ballestracci et al., 1985; Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992).

In a non tabular zone, the relation between the **E** and **H** vectors of the telluric field is tensorial and the tensor is called the impedance tensor (Vozoff 1991).

During the field campaign, the measurements have been made far away from the circuits of distribution of electricity network to avoid the interference of other electrical field generated by the presence of the high tension electrical cables to the natural telluric fields. The measurements have been done so that the principal directions of the suspected structure are determined indirectly by using a rotation method (Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992; Manguelle-Dicoum et al., 1993). In this, the apparent resistivity is measured as a function of the orientation angle of the telluric line, and the principal directions are deduced as those corresponding to the resistivity maximum and minimum which are perpendicular to each other (Adam et al., 1982; Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992; Manguelle-Dicoum et al.,1993). For the data set uses in this study, a discussion focused on that aspect was carried out in Meying, Ndougsa-Mbarga & Manguelle-Dicoum (2009).

We can therefore determine the succession of the layers of the Earth supposed to be inhomogeneous but contrasted by their different thicknesses and their corresponding resistivities.

Two profiles (Figs.1a & 1b) having a total of 15 stations of AMT soundings are realized along some roads, by taking into account the fact that they are transverse to the W-E direction which is suspected to be the direction of the geological structures. Each station is identified by its geographic coordinates determined by the Garmin GPS with a precision of ± 13m.

The processing of data has been done as follows : (i) The apparent resistivity obtain from the field have permitted to deduce the mean apparent resistivity given by the formula below : $\tilde{n}_m = (\tilde{n}_t.\tilde{n}_{//})^{1/2}$, where $\tilde{n}_t$ is the resistivity perpendicular to the principal direction of the structure and $\tilde{n}_{//}$ is the resistivity parallel to the principal direction (Ranganayaki 1984; Bisso et al., 2004), (ii) The calculated $\tilde{n}_m$ above has been used to determine the Bostick resistivities for each profile and the Hilbert transform (Bostick 1977; Jones 1983) has permitted us to obtain the phase values from which the pseudo-sections of resistivities and phases have been drawn. From the pseudo-sections of the phase, geological models of the subsoil have been sketched, (iii) To avoid the 2D nature of the geologic structure effect on 1D modelling, the following facts have been considered : (a) The data have been collected using the rotational sounding method (Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009; Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992; Manguelle-Dicoum et al., 1993), which enable the determination of the principal trend of the suspected structure, (b) The choice of profile direction is run roughly perpendicular to the suspected trends of the faulting structure and (c) The dimensionality of each profile was determined by inspecting data, through a 1D model calculated at each station and the principal criteria found on the goodness of the fit of the model response supported by the RMS and mean damping factor values and the geological acceptability of the model. In the present case, the area covered is relatively large, so that the study is classified as a regional lone, where the interval between stations of measurements is varying from 2.3 to 3.8 km for profile A, and from 1 to 5 km for profile B. The inter profile distance is approximately 55 km and (iv) (a) The choice of the number of layers is constrained by the geological knowledge of the area and the models are validated by the values of the RMS and the mean-damping factor, which have to be respectively closed to zero and 1. In the present case the two values for all the models are varied respectively from 0.024 to 0.081 and 0.99 to 1. The geological constraints are based on the formations identified in the area which are: gneiss, schists, micaschists underlying a granite basement (Olinga et al., 2010; Gazel & Guiraudie 1965), (b) The optimization has been focused on both (thickness and resistivity) until the two curves (calculated and measured) for the resistivity and phase are superimposed. The best model is that which gives the smallest number of layers with a good fit of curves and respecting the values of RMS and mean-damping factor cited above.

RESULTS

Description of profiles

Profile A (Figs.1a and1b) is located in the south of parallel 4°N and consists of 7 measurement stations noted MS1 to MS7. According to the geological map (Mbom-Abane 1997) they are situated respectively on garnetiferous micaschists (MS1), embrechite Gneiss (MS2 to MS6) and garnetiferous gneiss (MS7). This profile runs across two metamorphic contacts which are found between embrechite gneiss (MS2) and micashists (MS1) directed NW, and between embrechites gneiss (MS6) and garnetiferous gneiss (MS7) with SSW-NNE orientation.

Profile B is approximately S-N and on horseback on the parallel 4°N. It's has a total number of 8 stations, identified by AB1 to AB8 (Figs. 1a & 1b). From AB1 to AB3, stations of measurement are situated in the south of parallel 4°N, and AB4 is in the north of the Nyong stream bank. From a geological point of view, AB1 to AB7 are situated on the garnetiferous gneiss with two micas, while AB8 is located on embrechite gneiss. This profile therefore crosses a metamorphic contact between AB7 and AB8.

Sounding curves

The interpretation of AMT sounding curves is done by using the AMTINV program (Pirttijärvi 2004) for the two (02) profiles. It has led to the identification of 3 and 4 layers (Figs. 2a and 2b) based on the geological constraints of four or three rocks formations identified in the area under study (Olinga et al., 2010; Guiraudie & Gazel 1965).The resistivity and the thickness of the concern layers are summarized in Table 1. The analysis of this table has drawn our attention on these facts which are as follows: (i) The resistivity of the third layer for the model with four layers is lower than the value of the second layer, (ii) The resistivity is increasing with the depth, (iii) The comparison of the resistivities obtained with those from standard literature (Telford, Geldart & Sheriff 1990; (Parasnis 1997) has led to sketch a lithostratigraphic column which is constituted, from the bottom to the top, of: granite, schist, micaschist, gneiss and those rocks of cover formations and (iv) The resistivities in the area are in general, relatively high compare to those from similar terrains in southern part of Cameroon (Manguelle-Dicoum, Bokossah & Kwende-Mbanwi 1992).

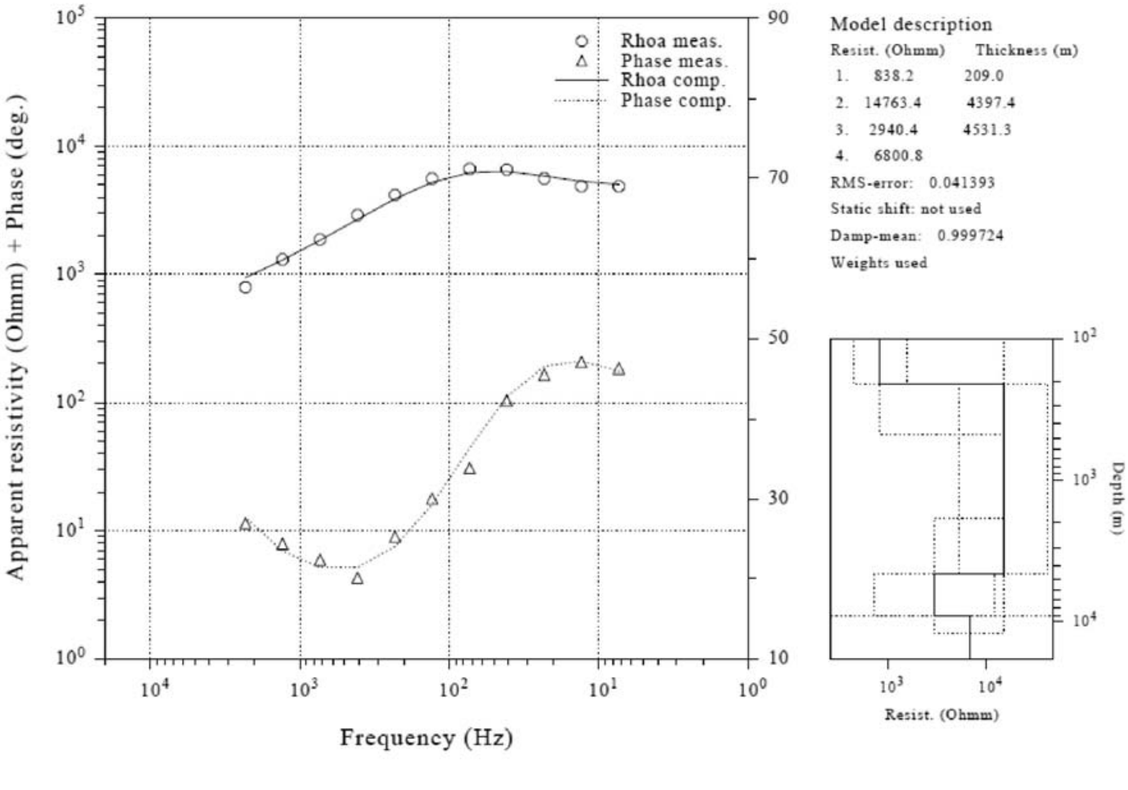

Figure 2a. Sounding curve illustrating a model of 4 layers (AB3 station).

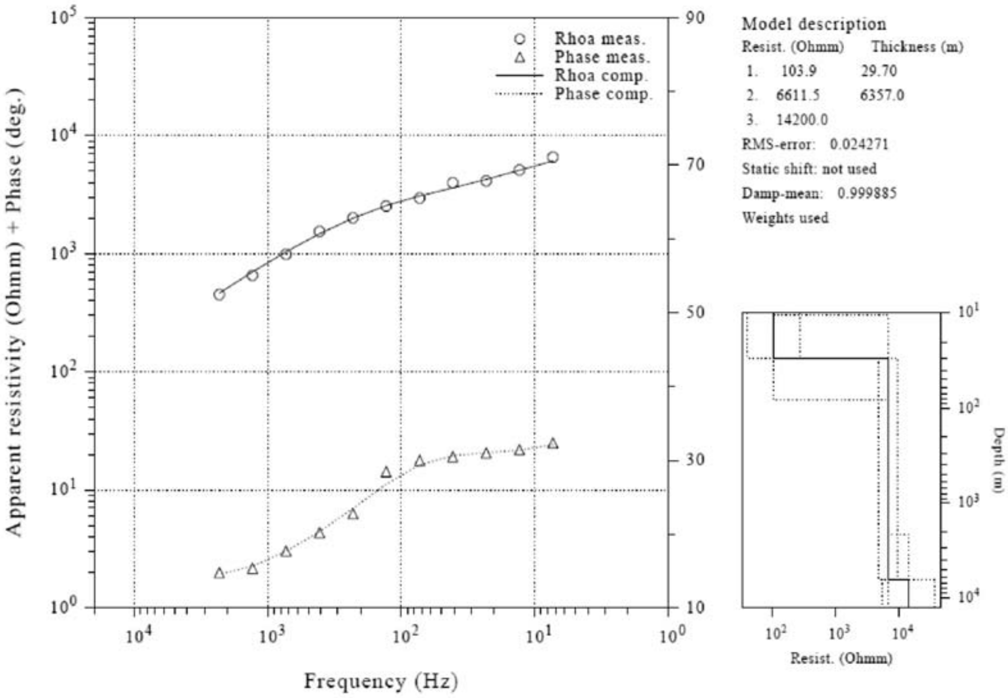

Figure 2b. Sounding curve illustrating a model of 3 layers (ME2 station).

Table 1. Layers and thicknesses for each station for the two profiles from 1D modelling.

Profile A			Profile B		
Station	Resistivity (0hm-m)	Thickness (m)	Station	Resistivity (0hm-m)	Thickness (m)
ME1	400	200	AB1	372	186
	3300	855		1237	1657
	980	1791		150	175
	4700	infinite		7383	infinite
ME2	104	30	AB2	600	190
	6611	6357		10572	4351
	14200	infinite		500	644
ME3	394	167		8004	infinite
	2004	1478	AB3	838	209
	474	613		14763	4397
	4706	infinite		2940	4531
ME4	92	93		6800	infinite
	2227	1021	AB4	435	180
	256	894		2157	3627
	1491	infinite		5913	infinite
ME5	230	119	AB5	275	163
	1718	1249		2212	2188
	90	265		1205	infinite
	2105	infinite	AB6	148	116
ME6	779	210		1593	1886
	4422	1025		11262	infinite
	361	2200	AB7	341	191
	2554	infinite		2851	3072
ME7	261	91		30050	infinite
	5342	6068	AB8	688	242
	27260	infinite		2748	3500
				30490	infinite

Resistivity profiling curves

The resistivity profiling curves of profile A (Figs.3a & 3b) show a discontinuity between ME3 and ME5 characterized by a high resistivity value from the superficial layers toward the deeper layers with a maximum in ME4. A second discontinuity is observed between ME5 and ME7 and it is characterized by high relatively resistivity values in ME6 which decreases greater from the surface downward. These two discontinuities are separated by decreasing of resistivity in ME5. In general, the resistivity variations along the profile are quasi-sinusoidal.

The resistivity profiling curves obtained from profile B (Figs.4a & 4b) reveal a remarkable discontinuity between AB2 and AB4 for the near surface, which extends to AB5 in deep structures. This discontinuity is a characteristic of a resistivity passageway that covers the AB2 to AB5. It has the highest resistivity values in AB3 and seems to announce fractures. These curves present an important drop which is followed by increasing low of the resistivity values from AB6 to AB8.

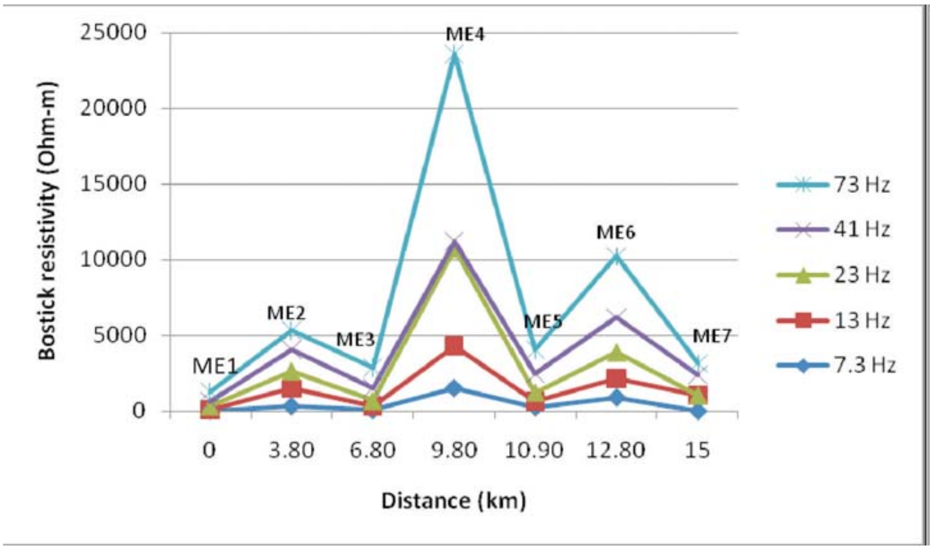

Figure 3a. Resistivity profiling curves for profile A (low frequencies).

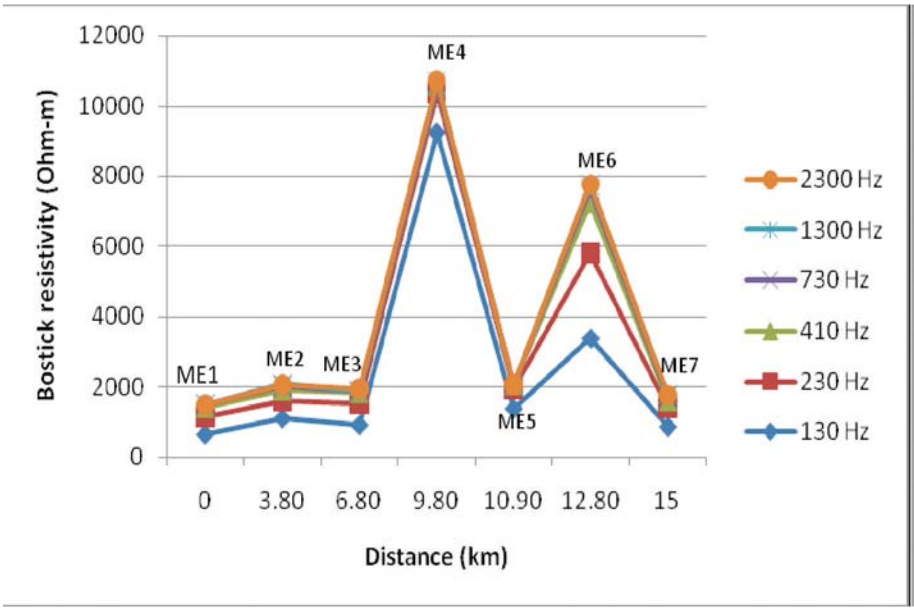

Figure 3b. Resistivity profiling curves for profile A (high frequencies).

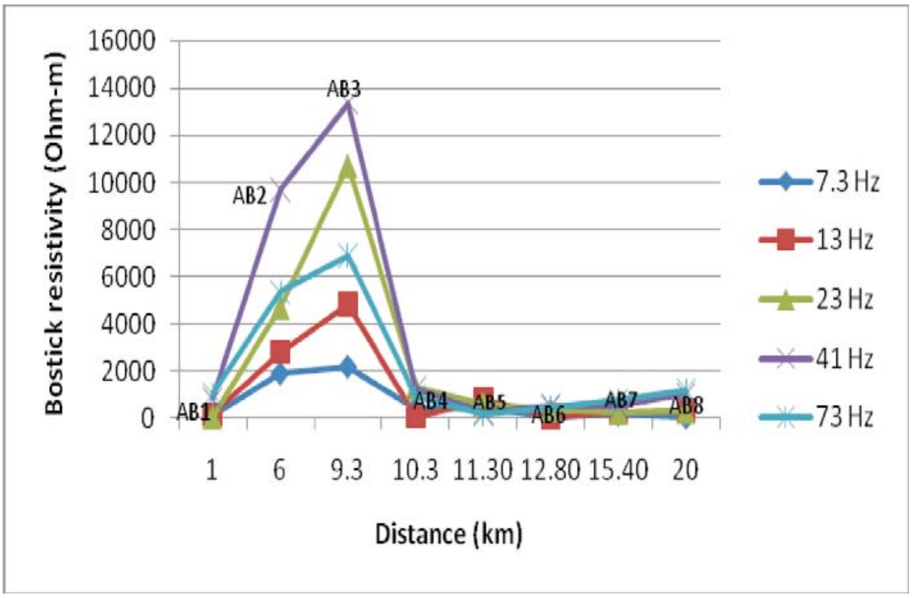

Figure 4a. Resistivity profiling curves for profile B (low frequencies).

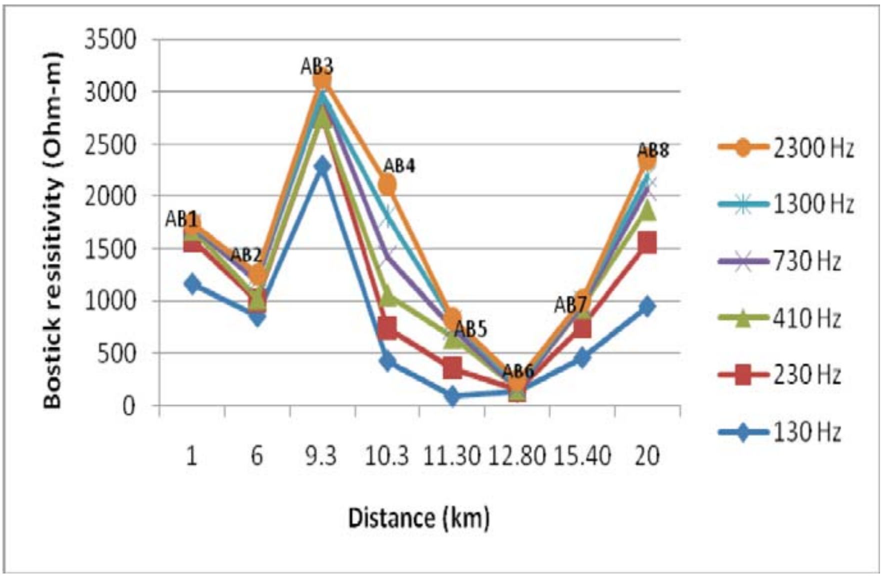

Figure 4b. Resistivity profiling curves for profile B (high frequencies).

Pseudo-sections

A general analysis of the two types of the pseudo-sections (resistivity and phase) has enabled us to observe the presence of folds and fractures which are indications that the area has been a theatre of collision between the Pan-African belt and the Congo Cratonic formations.

The resistivity and phase pseudo sections of profile A (Figs.5a & 5b) show an uprise of deeper layers towards the surface and are embedded within each others. This ascent has opened a passageway at average depth to a block of rocks presenting low resistivity values. This block of rocks is enveloped by a layer having a mean resistivity and phase values respectively 750 ohm-m and 24°.

The resistivity and phase pseudo sections obtain from profile B (Figs. 6a & 6b) has enabled to identify a fracture of near vertical dip, from depth to the near surface in the AB4 station. This fracturing is characterized by a passageway of which its mean resistivity value is about 500 ohm-m. This passageway separates two blocks having identical characteristics.

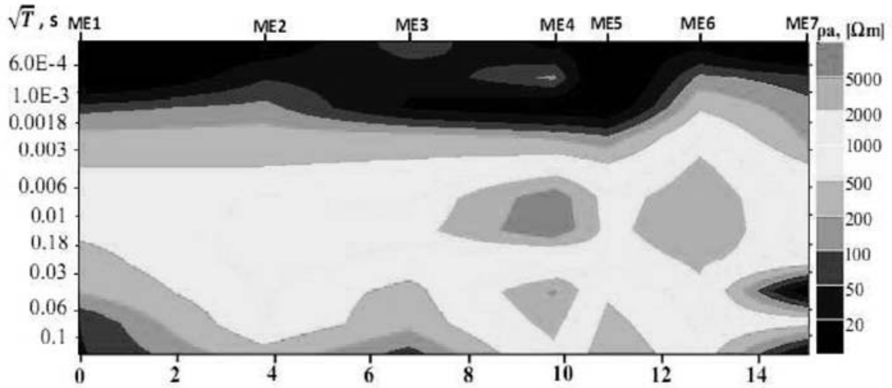

Figure 5a. Bostick resistivity pseudo-section of profile A.

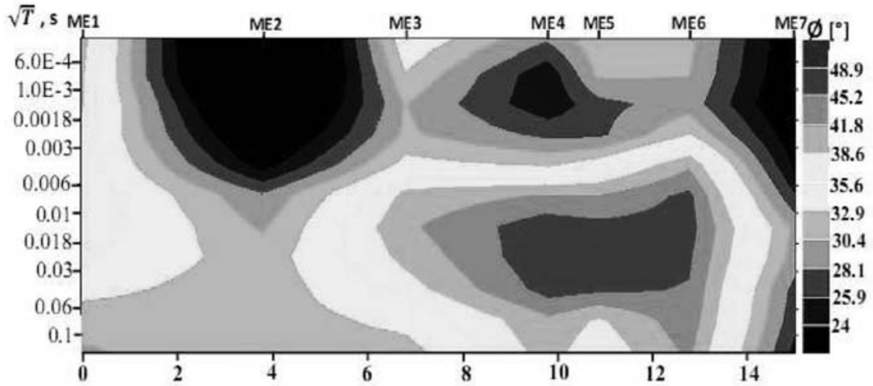

Figure 5b. Phase pseudo-section of profile A.

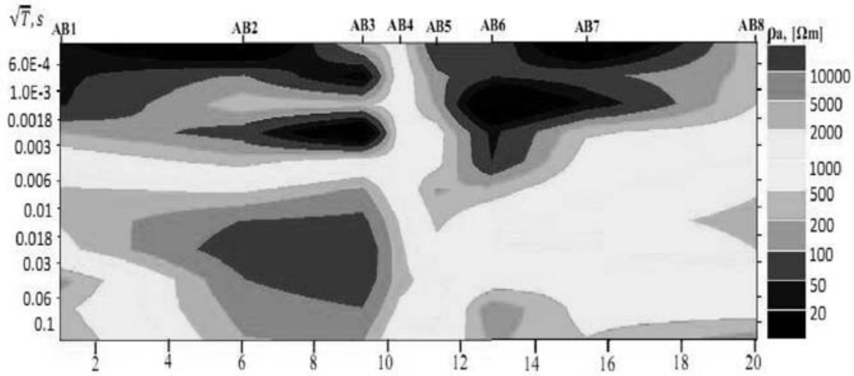

Figure 6a. Bostick resistivity pseudo-section of profile B.

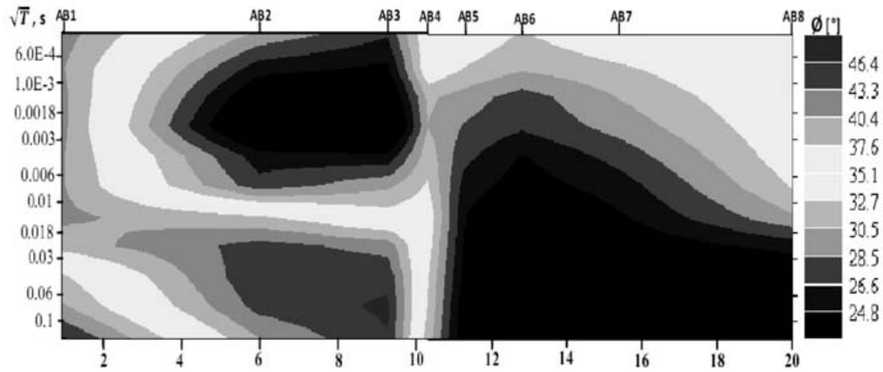

Figure 6b. Phase pseudo-section of profile B.

DISCUSSION

Of everything that precedes and with the help of the phase pseudo sections, we proposed 2D geological models for each profile (Figs. 7 & 8).

The analysis of the geological model (Fig.7) derived from AMT data modelling of profile A shows two gneissic intrusions not exceeding 3 km in depth within the schists between ME1 and ME3 and between ME4 and ME5 respectively, and large granite intrusion in the form of a pistol in the schist belt. It extends from ME3 to ME6 and begins from a depth of about 3 km. It seems to be the formation of the mobile zone that was dumped on the Craton during the Panafrican orogeny (Ngako et al., 2003). Three gneiss / schist contacts that present variables dips, thus forming three tectonic corridors and, including that between ME6 and ME7 are comparable to a double-fault form (inverse up to 2 km deep, then becoming normal 2 km to 4 km).

However, geology indicates simple contacts between embrechite gneiss and micaschists, and between embrechite gneiss and garnetiferous gneiss respectively. General geology on which profile B is passing trough, indicates a tectonic line, directed NNE from the south of Abong-Mbang and NNW to the north. This line is parallel to garnetiferous gneiss/ micaschists contact, to the south, and to garnetiferous gneiss/embrechite gneiss contact, to the north. There is no geological indication that suggests a deep seated fault. The 2D geological model (Fig.8) obtained from data analysis and modelling of profile B has revealed a near-vertical fault at AB4 with steeply dipping ramification that seems to emerge between AB5 and AB6; an inverse secondary fault between AB6 and AB7 which extends in depth to AB8; a contact schist/gneiss about 5 km deep between AB5 and AB6; a gneissic intrusion inside a schist block. It is of elongated form, extends approximately 3km between AB2 and AB3, and is located at a depth of 2 km. A normal intraschist fault with an approximate dip of 30 degrees. The fault identified on ME6 station, seems to correspond to the one which has been identified respectively in Akonolinga (A6) and Ayos (B6) (Meying, Ndougsa-Mbarga & Manguelle-Dicoum 2009). These observations show that the area was subjected to a very intense tectonic movement. It is the proof that, there was an intensive shock between the Pan-African belt and the Congo Craton in this area.

The results obtain from the AMT modelling are similar to those from gravity studies using a 2.5 D gravity modelling (Ndougsa et al., 2002), in which a deep seated fold and fault systems (normal and inverse fault) oriented W-E have been identified in one hand; and in other hand those realized by Tadjou et al. (2009) who have combined 2-D spectral analysis and 2.5D modeling for the identification of deep structures and depths of major crustal discontinuities. The later allow the determination of variations in the crustal density across the tectonic boundary between the Congo Craton and the Pan-African fold belt. These reveal that the crust of the Congo Craton is relatively thick and consists predominantly of low-density rocks. In contrast, Pan-African belt rocks are mostly relatively dense. The image suggested by Tadjou et al. (2009) is composed of a fault zone juxtaposed the high-density Pan-African domain in the north against the low-density Archean rocks in the south, with variable crustal depth from 8 km to 20 km. The suggested explanation (Tadjou et al., 2009) for the enhanced low densities is that part of the lower crust beneath the Craton domain is subsiding. In this case, a probable source for the enhanced high-density rocks is Pan-African ocean margin units, as suggested by their location at the edge of the Pan-African continental block. Noutchogwe et al. (2006) trough a gravity analysis show an uplift of dense rocks in the granite–gneiss substratum, found at an average depth of about 8 km. In the regional scale, the post-emplacement thermo-tectonic events affecting the Tonalite-Trondhjemite-Granodiorite (TTG) rocks of the area situated in south of Messamena/Abong-Mbang region were related to the Pan-African orogeny (Shang et al., 2004). Some indices of the northern edge of the Congo Craton put in evidence by Olinga et al., (2010) in the Ayos belt (situated west of the area under study) trough folding and faulting features are in accordance with the results highlighted in this study.

In a large regional scale (including the whole Central Africa region), the above tectonic facts highlighted are fitted into the deformation history of the Central African Fault Belt (CAFB), which is described as corresponding principally to alternating east-west to NW-SE contractions, and north-south to NE-SW orogenic parallel extensions (Mvondo et al., 2007a & 2007b). The tectonic features (folds and faults) identified in the study could be due to the Transaharan east-west collision system (Mvondo et al., 2007b).

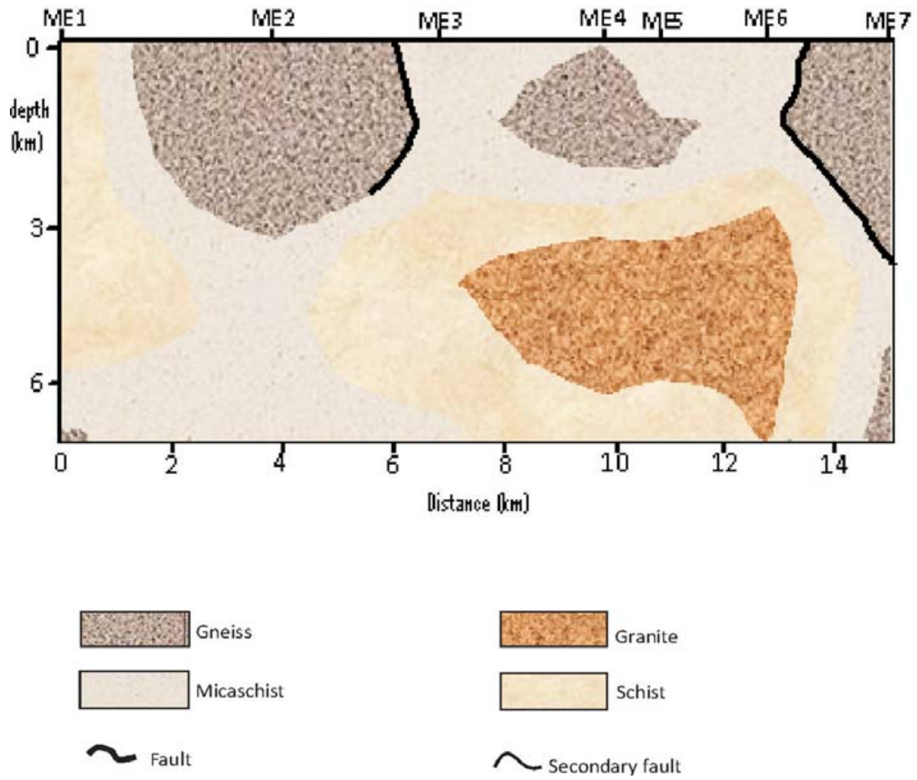

Figure 7. Geological model of profile A

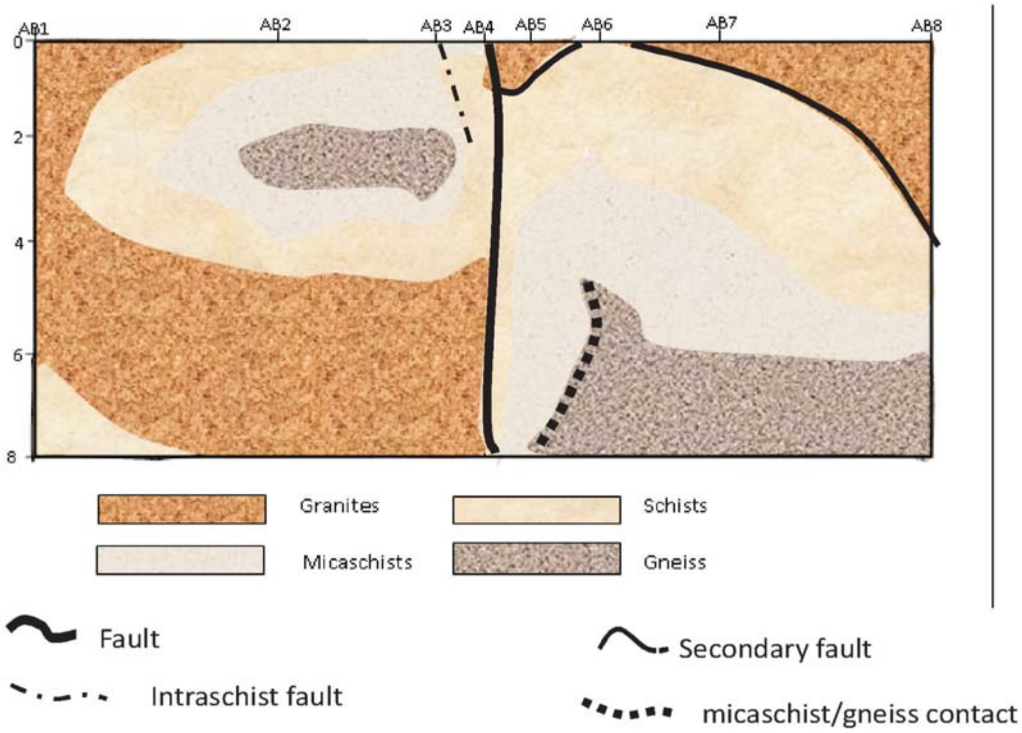

Figure 8. Geological model of profile B.

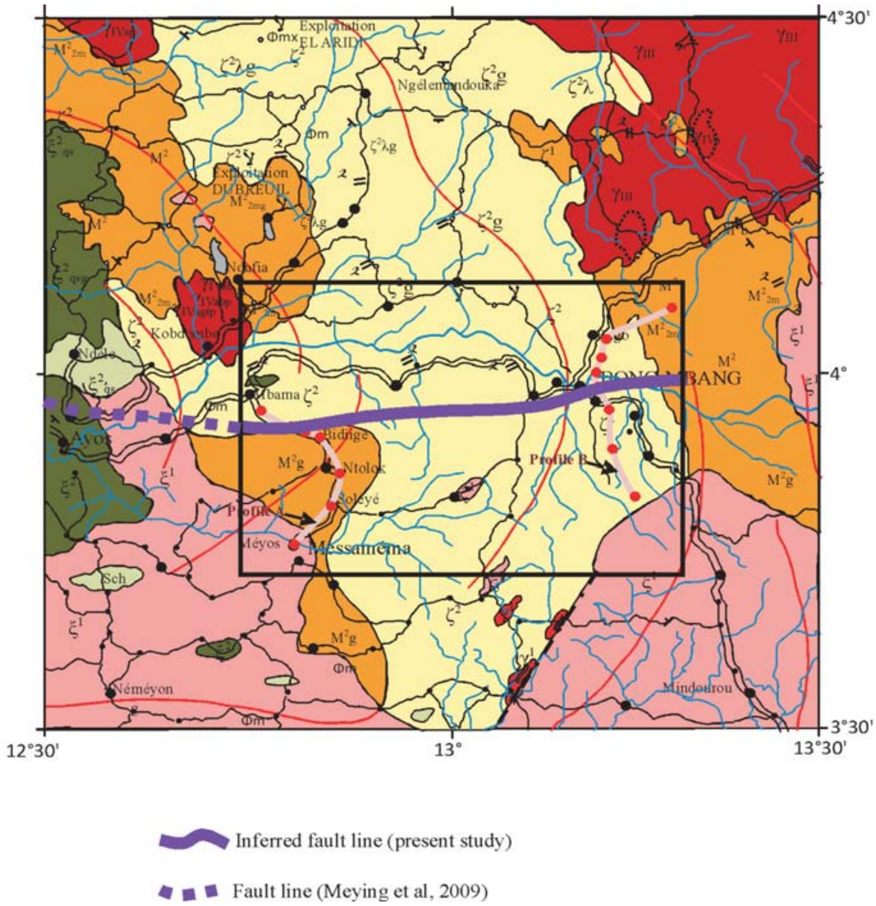

Figure 9. Inferred fault line approximately W-E.

CONCLUSIONS

We have used the Bostick approach for the 1D and 2D modelling of the AMT data of the Messamena/ Abong-Mbang area. This study permitted a better knowledge of the subsurface structure of this area. Indeed, they observed the presence of a major tectonic fact, the fault oriented sensibly E-W that spread from A4 until B6 (Meying et al., 2009) passing by ME6 and A6 (Fig. 9). In the profile A, the interpretation and 1D and 2D modelling of data have led to put in evidence an intense folds system. The results obtained are in agreement with the one derived from gravity studies (Ndougsa et al., 2002) which revealed the deep folds and fault system oriented E-W, and those showing uplifting and a fault zone juxtaposed the high-density Pan-African domain in the north against the low-density Archean rocks in the south, with variable crustal depth from 8 km to 20 km (Noutchogwe, Tabod &Manguelle-Dicoum 2006; Tadjou et al., 2009). The tectonic features (faults and folds) are fitted into the deformation the CAFB's deformation history and could be due to the Transaharan east-west collision system (Mvondo et al., 2007a & 2007b).

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