J. Ind. Geophys. Union (January 2016)
v.20, no.1, pp: 19-32

New structural facts from audio-magnetotelluric (AMT) data interpretation in the Yaoundé-Nkolafamba area (Centre Cameroon)

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ABSTRACT
Several geological models that explain the tectonic evolution of the Central Africa Pan-African Belt are discussed, each one having both outstanding results and unresolved questions. To improve the knowledge of the Pan-African domain in Cameroon, especially within the Yaoundé series, a geophysical investigation of shallow crustal structures was carried out in Nkolafamba, 26 km away from Yaoundé on the Yaoundé-Akonolinga highway, between the northing latitudes 03°45 and 04°, and easting longitudes 11°30 to 12° area during August 2011. The study combines field geological observations with twenty-three tensor Audio-magnetotelluric/Controlled source audio-magnetotelluric (AMT/CSAMT) experiments along four north 135° trending profiles, using a Geometric's Stratagem EH4 resistivitymeter. The 2D modelling of geophysical data exhibits: (1) That the formations encountered in the area are a mixture of both Pan-African and Congo Craton formations; (2) Many folding patterns and a set of strike-slip conductive faults and fractures that correlate the field observations. From the outcome of the study, we state that the study area belongs to the transition zone between the Congo Craton and the Pan-African belt. We propose that many of these faults form a southwest-northeast shallow tectonic line, seem to be related to the enhancement of the Centre Cameroon Shear Zone within the Yaoundé area. These facts demonstrate that the region has been affected by the collision between the Pan-African and the steady Congo Craton, followed by post Pan-African transpressional evolution characterized by dextral and sinistral strike-slips along the southwest-northeast trend. Therefore, we opine that the indentation tectonics model, earlier proposed through some geological studies, is more suitable in describing the geological evolution. It is also evident that geophysics played significant role in better understanding of the Yaoundé series' structural geology.

Keywords: Tensor audio-magnetotelluric experiment, Controlled source audio-magnetotelluric experiment, 2D modelling, tectonic line, Pan-African belt, Congo Craton, Yaoundé series.

INTRODUCTION

Structural geology divides South-Cameroon into two major sets: (**a**) The Congo Craton (CC)in the Southern part, represented by the Ntem complex, which has not been affected by the Pan-African thermo-tectonic event; (**b**) The central and northern parts that correspond to the Central African mobile zone, where the Pan-African orogeny occurs. This E-W orogenic zone, the Central Africa Pan-African Belt (CAPAB), is sited at the Northern edge of the CC and stretches from Cameroon to Sudan (Poidevin, 1985; Nzenti et al., 1988; Rolin, 1992 and 1995; Penaye et al., 1993). The study area is located 26 km away from Yaoundé on the Yaoundé-Akonolinga highway, between north-latitudes 03°45 and 04°, and east-longitudes 11°30 to 12°. It belongs to the Yaoundé series, a unit of the Yaoundé Group, which is part of the CAPAB. The Yaoundé series is a Neoproterozoic feature located at the North of the CC, which stretches from west to east. It is made up of gneisses and migmatitic garnets coming from old granitised and metamorphosed sediments in the high pressure granulite facies. It constitutes the heart of the Pan-African thrust (Nzenti et al, 1984 and 1988; Nédelec et al, 1986). The Precambrian basement of the area, as that of the whole Yaoundé series (Figure 1), comprises two geological facies: gneisses associated with micaschists (ectinites), and migmatitic garnetiferous gneisses (migmatites).

The Neoproterozoic Yaoundé series has undergone structurally sub-horizontal tangential tectonics, which is the origin of its position as a sheet on the northern edge of the CC (Bessoles et Trompette, 1980; Nédelec et al 1986; Nzenti et al, 1988; Ngako et al., 2008) .Tectonics in the region can then be described as corresponding to alternative east-west to northwest-southeast contractions and to north-south to northeast-southwest parallel orogenic stretches. Olinga et al. (2010) state that the tectonics corresponds to: the thrusting of the Yaoundé nappe over the CC; and the strike-slip shearing in ductile to brittle-ductile conditions, characterized by penetrative foliation dipping north or south, an associated east-northeast-west-southwest

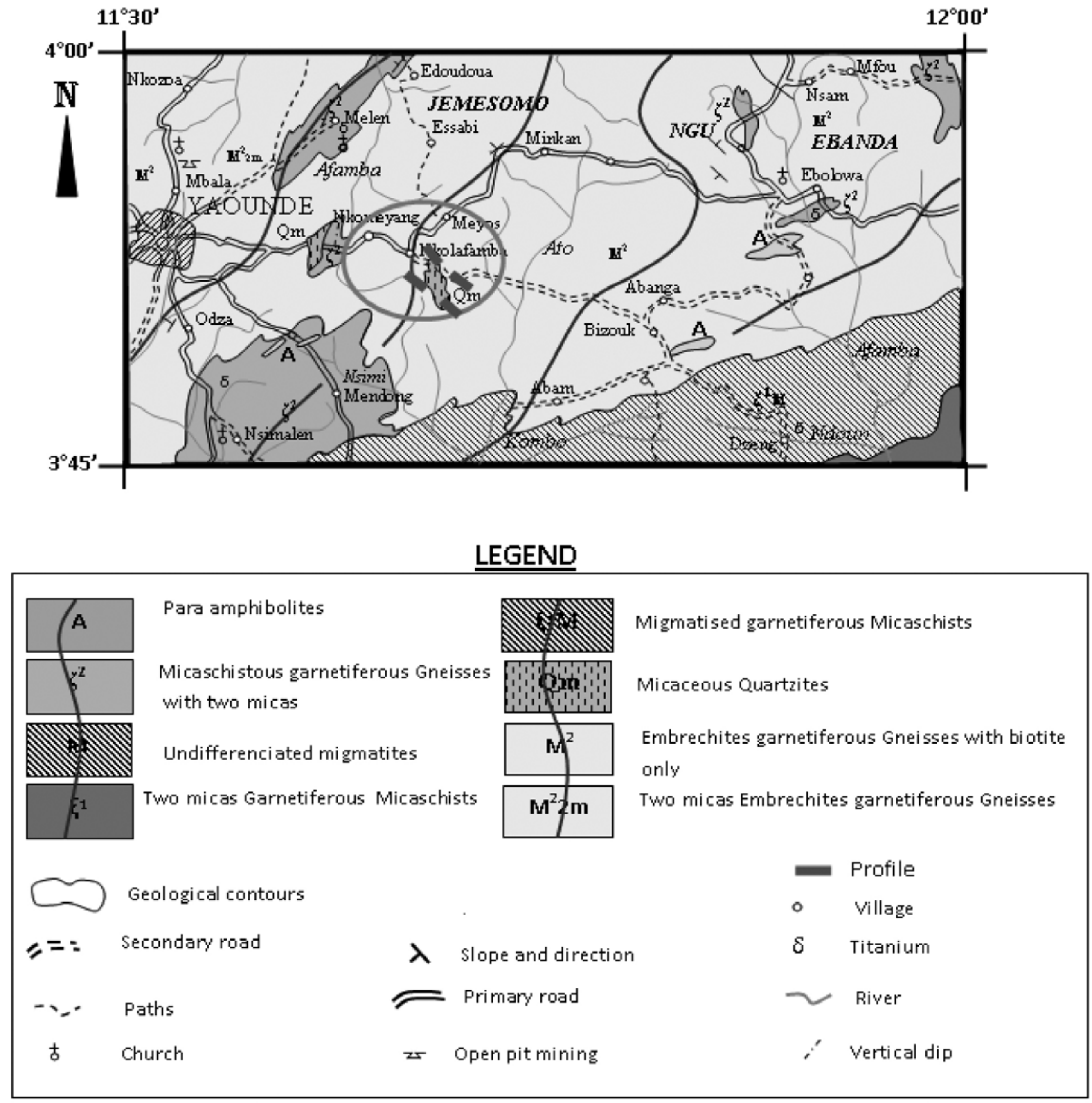

Figure 1. Geologic map of the study area (after Champetier de Ribes & Aubagues, 1956)

stretching lineation and north-south to northeast-southwest folding.

Geophysical inputs involving the CC/CAPAB transition zone are mainly from gravity studies. Early interpretations of gravity anomaly maps (Collignon, 1968) revealed E-W strong anomaly gradients in the Akonolinga/Ayos/Nguelemendouka/Abong-Mbang area, which were interpreted as an E-W tectonic activity along parallel 04°N (Mbom-Abane, 1997), while Ndougsa et al. (2003) suggest an E-W normal fault in the Mengueme/Abong-Mbang area. More recent studies by Shandini et al. (2010 & 2011) confirmed the CC/CAPAB boundary and highlighted NE-SW and NW-SE basement lineaments that Basseka et al. (2011) suggested to be related to faulting associated with the granitic rocks in the upper brittle crust. Hence, crustal faulting in the northern margin of the CC is assumed to be associated with deep-seated structures (Feumoe et al., 2012; Ndougsa et al., 2012; Shandini and Tadjou, 2012) related to the CC/CAPAB collision.

Magnetotellurics (MT) revealed the CAPAB's overthrust line onto the CC corresponding to the Eseka-Dja faults line (Manguelle-Dicoum et al., 1993) and a major E-W (N105°)

general trending lineament corresponding to the CC/CAPAB boundary and secondary ENE-WSW to NNW-SSE lineaments (Meying et al 2009) at Ayos, in the southern edge of the CAPAB. The E-W lineament corresponding to the CC/CAPAB boundary was confirmed by Tadjou et al. (2008), who additionally detailed about subsidence within the basement associated with intrusions of low resistive materials beneath the CAPAB domain in the Abong-Mbang/Akonolinga area, located east of our study area. Recent investigations in the CC/CAPAB transition zone using Audiomagnetotellurics confirmed that the E-W event associated with fault structures is related to the inferred tectonic boundary separating CC and CAPAB ,while NNW-SSE to ENE-WSW structures are related to post-collision tectonics occurring in the area (Meying et al., 2009; Ndougsa et al., 2011; Meying et al., 2013). It is important to state that the area under study has not been clearly subjected to AMT investigations. It is subjected to these geophysical investigations, in the recent past, as detailed above.

Studies of the CAPAB reveal that it collides with the CC. However, to date, in spite of its proximity with the CC/CAPAB limit, finer details of the Yaoundé series could not be obtained due to insufficiency of geophysical studies, to explicitly explain the tectonics. We have interpreted an AMT dataset and found evidences of CC/CAPAB collision in the Yaoundé-Nkolafamba area that belongs to the southern margin of the CAPAB. The results are correlated with geological observations made simultaneously in the area.

METHOD AND DATA ACQUISITION

Method

The Magnetotelluric (MT) method separately developed both by Thikonov (1950) and Cagniard (1953) is applied for geophysical and structural geology prospecting (Bostick, 1977; Vozoff, 1972 & 1990; Manguelle-Dicoum et al., 1992 & 1993; Meying et al., 2009 and references therein, Meying et al., 2013). It consists of 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. For the real case, subsurface is inhomogeneous and apparent resistivity is determined using the Bostick law (1977) derived from the Cagniard's fundamental formula (Ndougsa et al., 2011).

Data Acquisition

In this work, the high frequency MT or Audio-magnetotelluric (AMT) method was used to image the subsurface structure of the Yaoundé/Nkol-Afamba area using a Geometrics' Stratagem EH4 AMT/CSAMT system. The data were acquired during six days of field work conducted during the first half of August 2011. The method has been chosen because of its reliability and its fast handling even in remote and hostile areas. We lately combined geophysical studies with some field geological levees to strengthen our statements.

The Geometrics Stratagem EH4 unit measures electrical resistivity with orthogonal electrical and magnetic field changes to depths ranging from few meters to more than 1 km in the frequency range of 10 Hz to 92 kHz. Data collected are processed to provide tensor impedance measurements, which allow full complex 2D structures interpretation (Geometrics, 2000). Nevertheless, natural signals are generally weak in the higher frequency range; hence the use of artificial signals (Vozoff, 1972; 1990 and 1991; Strangway et al., 1973; Goldstein and Strangway, 1975; Zonge and Hugues, 1991; Garcia and Jones, 2002; Zhdanov, 2009) produced by a transmitter to strengthen weak background field signals. The Geometrics Stratagem EH4 transmitter, when used, was assembled at least 300 m away from the receiver site to enable the plane wave assumption to be valid. AMT/CSAMT data were collected along four profiles; these profiles were parallel with a two by two recording pattern. They followed a NW-SE (N135°) direction based on the assumption that structural features in the Pan-African are generally E-W and/or NE-SW. The profiles were indexed from 1 to 4. The profile1, profile3 and profile 4 were 500 m in length and contained six sounding stations each, with a station-station spacing of 100 m. Profile 2 was 400 m in length with five stations at a constant separation distance of 100 m. Soundings data were acquired at each station with 25 m dipoles length both in the X and Y directions (however, dipoles length was 25 m in the Y direction and 50 m along the X direction in profile1). The X dipole was parallel to the profiles' trend. Data collected have been initially processed using the Bostick's transform, and then interpreted with Imagem software within the Stratagem EH4. We used Plot2D and Surfer 9.0 software, which provided the geoelectrical sections and pseudo sections, respectively for analyses. The frequencies ranged between 25.12 Hz to 39810 Hz, assuming a penetration depth from 8 m to 10000 m. The details presented below focus only on the upper 1000 m.

While collecting field geophysical data, some geological facts have been observed, according to outcrops available in the area. The formation is of gneissic type. The main structures that appear in are: a sub horizontal east-foliation; with an E-W maximal stretch and a N-S minimal stretch; folds, shears (Figure 2a) and fractures (Figure 2c) that include two major families, the first being NE-SW oriented and the second ESE-WSW. The double boudinage (Figure 2b) enables to highlight an extensive tectonics with a vertical maximal deformation. These structures are imprints of a multiphase deformation.

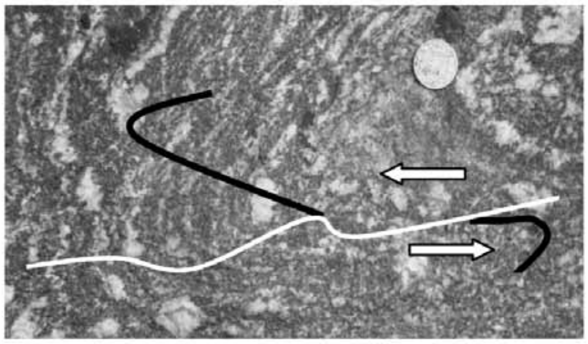

Figure 2a. Recumbent folds crossed by a dextral shear.

Figure 2b. Double boudinage

Figure 2c. ESE-WNW Fracture in the rock

RESULTS

Profile 1:

The pseudo-sections (Figure 3a & 3b) show irregularly shaped iso-contours. They exhibit dislocation patterns of blocks on one hand. They also show that conductive formations are encountered both on surface and at depth. The resistivity pseudo-section particularly presents three concentric anomalies, between OS2 and OS4, from depth to surface with a mean resistivity value of 193.0 Ω.m, forming a conductive channel. This channel may be an up well or intrusion of conductive materials. We also observe that entire near surface is conductive. However, an anomalous resistant structure centred at OS2 is found to continue downwards. The shape of isoresistivity contour

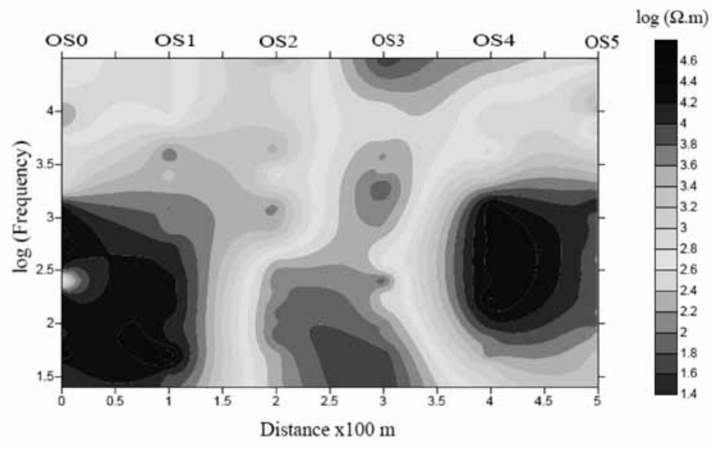

Figure 3a. Resistivity pseudo-section of profile 1

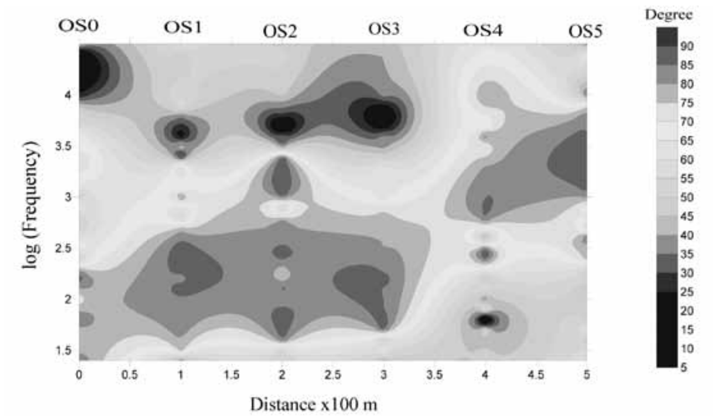

Figure 3b. Phase pseudo-section of profile 1

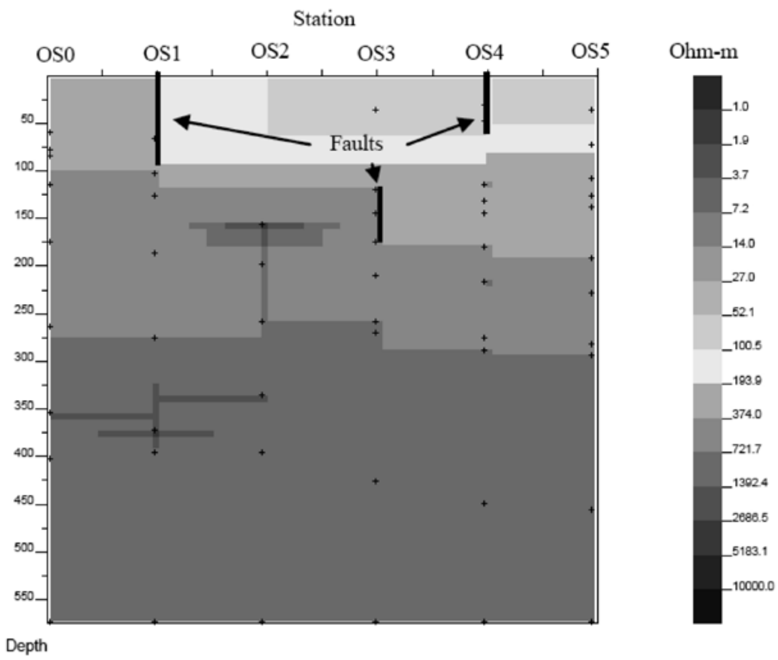

Figure 3c. Geoelectrical section of profile1. Depth in meters

lines suggests that the area might have undergone a folding process. Subvertical isoresistivity lines below OS1 and OS4 suggest the presence of discontinuities that are either faults or contacts.

The geoelectrical section plot (Figure 3c) confirms above observations. It shows two shallow conductive formations of mean resistivity 147.2 Ω.m and 284 Ω.m, respectively. The contacts between these formations are interpreted as faults at OS1 and OS4. The second formation outcrops from station OS0 to OS1. The third formation, with a mean resistivity of 547.9 Ω.m and a variable thickness, is jagged by faults at stations OS1, OS3 and OS4.It shapes like a graben. An intrusion of the underlying material at station OS2 forms a sill of 100 m wide and 25 m thick, near 150 m depth. The fourth formation, with a mean resistivity value of 1057 Ω.m, is marked by faults beneath stations OS2 and OS3. A resistive material embedded at OS0 that splits itself up to OS2, has a mean resistivity value of 3934.8 Ω.m (this fifth formation probably extends beyond 1 km depth and lays on a more resistive structure). This is not shown in the model.

Profile 2:

The apparent resistivity and phase pseudo-sections (Figure 4a & 4b respectively) exhibit a high anomalous zone (both resistivity and phase) from the beginning of the profile until almost the fourth station, where it forms vertical to subvertical contour lines characterizing a major discontinuity. The plot reveals a conductive basin-like feature between stations BE0 and BE1. The near-surface of the whole area seems to be conductive, and it suggests that the area probably experienced a tectonic activity.

The geoelectrical section (Figure 4c) exhibits a subsurface structure comprising some discontinuities, which may be faults or relief scarps. We observe, downward from the top, a conductive layer (mean resistivity 98.9 Ω.m around BE1, and 417.2 Ω.m in almost the whole area until 250 m depth). This formation is marked by many islets of resistive materials at stations BE0, BE2 and around station BE3. Another very thin formation is encountered at around 250 m depth. The fourth formation encountered has a mean thickness of 400 m with a mean resistivity value of 1119.2 Ω.m.It embeds a more resistive formation (1833.1 Ω.m), which seems to correspond to the fifth layer encountered at 725 m depth. The basement lays at 825 m depth with resistivity values ranging between 3728.1 Ω.m and 6105.8 Ω.m. A major discontinuity that seems to be a fault can be observed beneath station BE1, while others may be scarps.

Profile 3:

Analyses from pseudo-sections of profile 3 (Figure 5a & 5b respectively) exhibit two distinctive zones: a very resistive zone at depth (frequencies less than 1200Hz), contrasting with the conductive overburden (frequencies greater than 1200Hz), both separated by a narrow transition zone. Some anomalous isoresistivity values enclosed between stations NK2 and NK4 (with a paroxysmal uplift centred beneath station NK3) may correspond to an uplift of resistive materials in conductive structures. A discontinuity is also highlighted at middle depth below station NK1 and below NK4 by subvertical lines. The shape of isocontours of the overburden formation is an evidence of the folding processes that probably affected the shallow formations.

The geoelectrical section (Figure 5c) presents a first layer of mean resistivity 80.9 Ω.m with an average thickness of 100 m; the second layer has a mean resistivity of 355.5 Ωm; a third thin layer with a mean resistivity of 683.1 Ωm; the fourth layer with a mean resistivity of 1118.9 Ωm is very thick and marked by an intrusion of the underlying material between stations NK3 and NK4; the fifth formation has a mean resistivity of 1832.7 Ωm. It is deformed by the uplift of underlying formations, which have resistivity values ranging between 2275.8 and 10000 Ωm. This uplift can either be seen as an intrusion or channel of resistive materials from the basement. Some discontinuities interpreted as faults or discontinuities are highlighted below NK1 and NK4.

Profile 4:

Data from profile 4 (Figure 6a & 6b respectively) indicate presence of a prominent resistive formation at depth between stations BG1 and BG5; it appears like an intrusion of more resistive materials, compared to the surrounding. This formation is embedded within a less resistive formation covering the entire area, while some very conductive formations appear from station BG0 to station BG1 and between stations BG3 and BG5 on surface; below stations BG0 and BG3 they appear at deeper levels .The intermediate apparent resistivity values dominating the whole pseudo-section, have led us to conclude that the profile is set on an area made up of mixture of both resistive and conductive formations. The phase pseudo-section mainly exhibits a depression or subsidence along the profile from BG0 to BG5. The shape of isocontour lines on the pseudo-sections also show irregular patterns that suggest that formations have been folded.

The geoelectrical section from profile 4 (Figure 6c) outlines a near surface electrical lithology characterized by three main conductive formations. On the top of the plot, we have two formations with mean resistivity 683.4 Ωm and 1119.3 Ωm, respectively, with a fault type contact detected at station BG3; the third formation more conductive than the first two, with a mean resistivity value of 417.2 Ωm is encountered at 75 m depth below BG0.Its roof is jagged by many minor scarps ,which shape

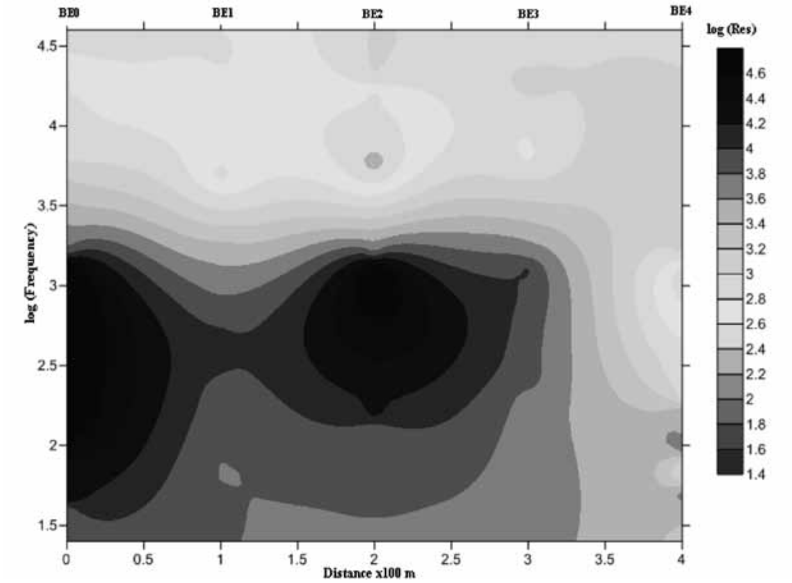

Figure 4a. pseudo-section of profile 2

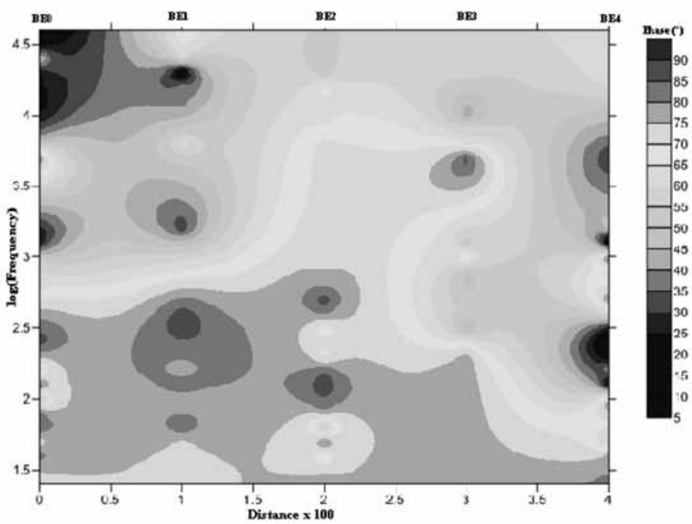

Figure 4b. Phase pseudo-section of profile 2

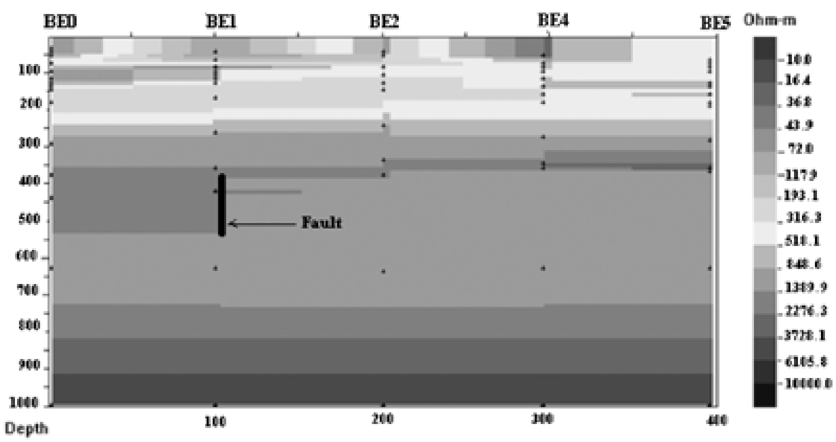

Figure 4c. Geoelectrical section of profile 2. Depth in meters.

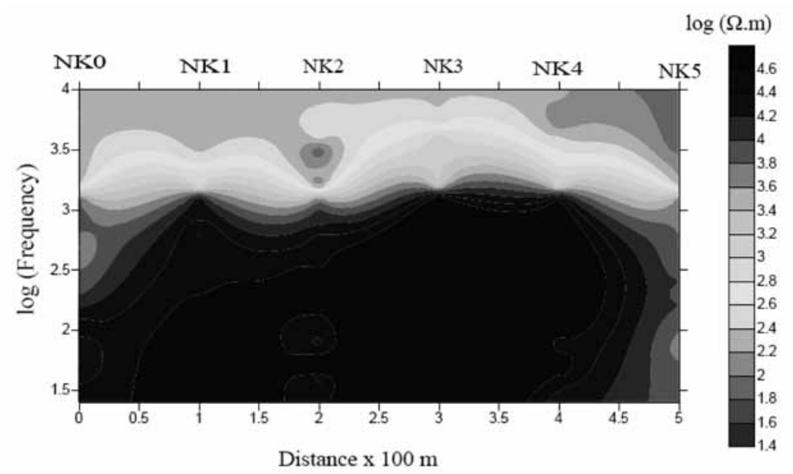

Figure 5a. Resistivity pseudo-section of profile 3

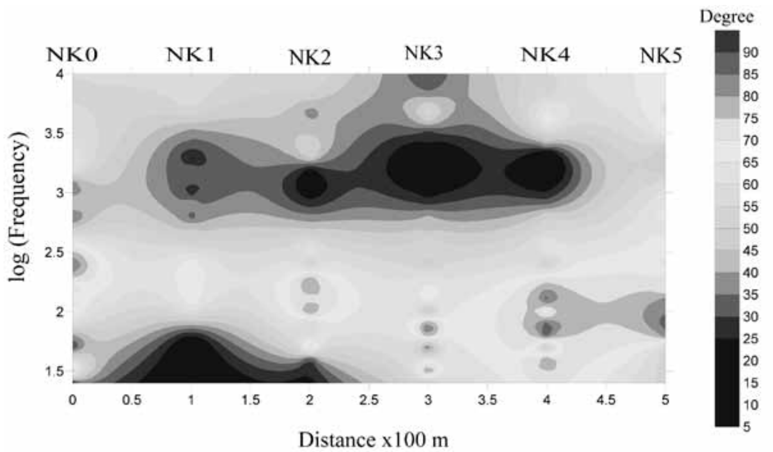

Figure 5b. Phase pseudo-section of profile 3

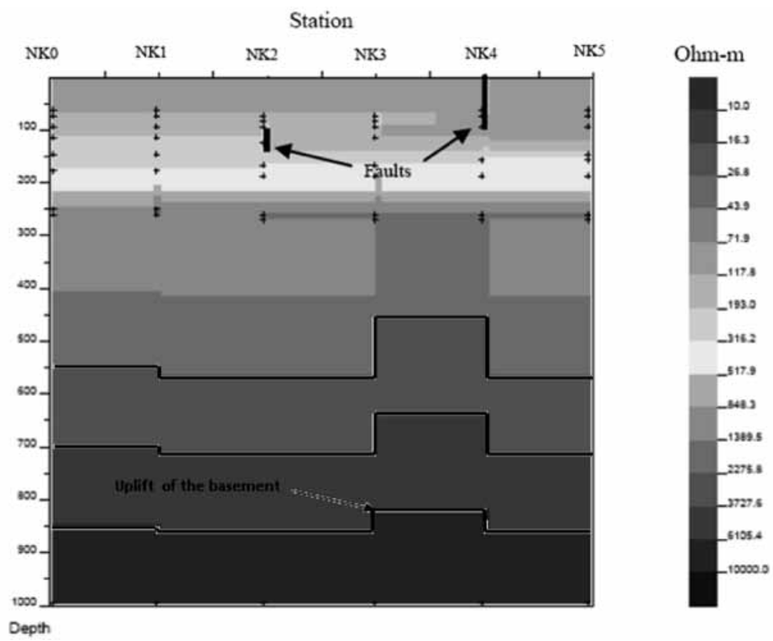

Figure 5c. Figure 5c. Geoelectrical section of profile 3. Depth in meters.

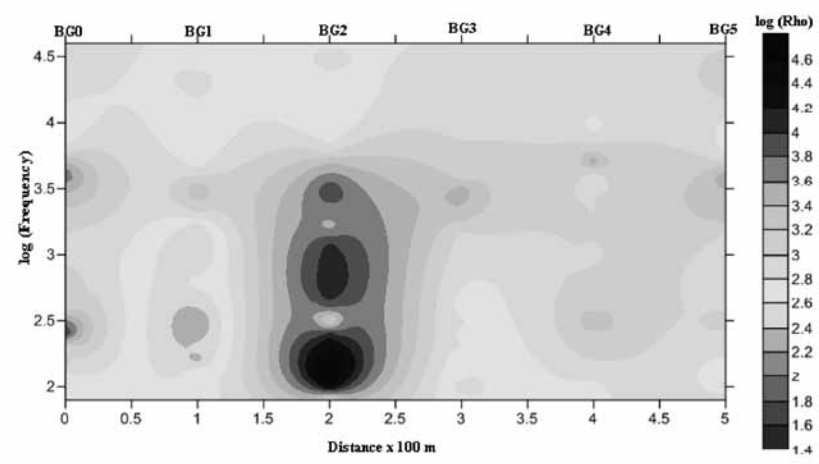

Figure 6a. Resistivity pseudo-section of profile 4

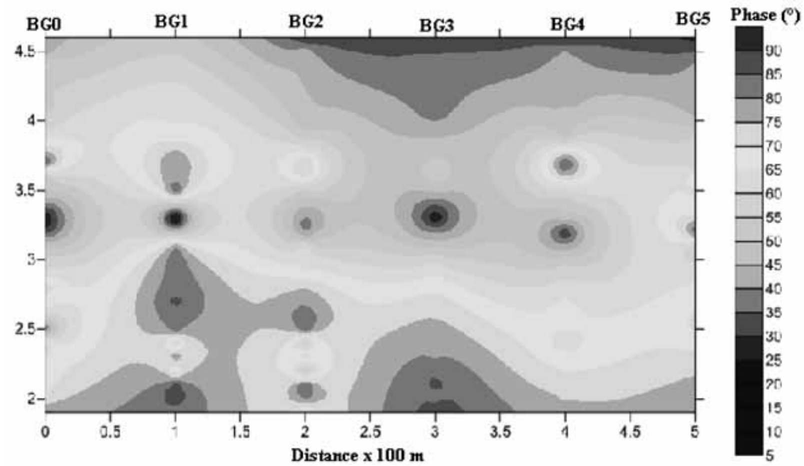

Figure 6b. Phase pseudo-section of profile 4

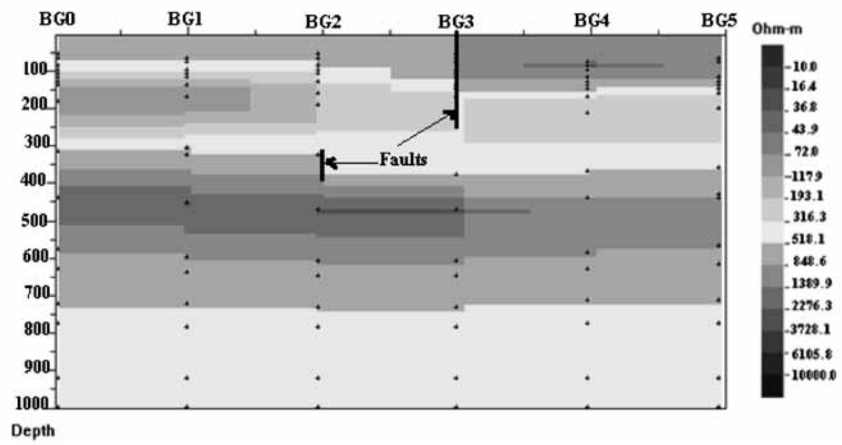

Figure 6c. Figure 6c. Geoelectrical section of profile 4. Depth in meters

it like downstairs from BG2 to BG5 while a fault type discontinuity is identified around 300 m depth under BG2; the first formation is encountered again at 300 m and extends up to 750 m depth enclosing the second formation (350 m to 600 m depth) within which a resistive structure (3002.2 Ωm mean resistivity) is embedded from BG0 to BG3 with a mean thickness of 100 m (from 400 m to 500 m depth). It appears from the geoelectrical section that there is a graben-like structure in near subsurface from BG2 to BG5, as shown in the phase pseudo-section.

DISCUSSION

AMT analyses

Analyses of results from the current study suggest that profiles 1, 2 and 4 are located on the same geological environment, where as profile 3 on a different environ. Soundings from profiles 1, 2 and 4 are made on fairly conductive areas, with a range of resistivity values that correspond to a weathered gneissic environment (Palacky, 1987). Profile 3 seems to be located on micaceous quartzites. It appears that the study area is composed of a mixture of both very resistive and conductive formations. The basement appears at 1400 m in profile 1, 825 m in profile 2, 550 m in profile 3 and deeper (more than 1400 m) in profile 4. This indicates that the basement rises up in some parts, while it collapses in other parts. This in turn might have induced thickening of overlying materials. The observed uplift of the basement may also be attributed to cooled intrusions beneath it. The subsidence and uplift of the basement probably attest the existence of a depressed structure (graben or basin), as evidenced by pseudo-sections. This shows a rugged subsurface structure of the area. The roughness of this subsurface structure is also emphasized by the shape of isocontour lines on all the pseudo-sections, hence suggesting that the formations in the area have been folded. The folding process is originated from a shortening,a priori, parallel to the direction of all the profiles (N135°). This shortening was caused probably by the collision between the CC and the CAPAB. In addition, many faults, scarps and fractures have been inferred in all the profiles. Some of the faults show significant throw (e.g. 150 m below station OS4 in profile1; 50 m and 100 m beneath BG2 and BG3 respectively in profile 4; 175 m below BE1 in profile 3).

As, the general trend of profiles is N135°, faults and fractures highlighted are generally SW-NE to WSW-ENE oriented through other faults with different trends (E-W direction probably). The conductive channel seen on profile 1 (figure 3a) could be either an intrusion or an active fault. The shape of apparent resistivity isocontours, faults and fractures detected by our study suggest that tectonics of the study area occurred in brittle to brittle-ductile conditions, as in the Yaoundé Group. Besides, the geoelectrical section of profile 4 shows that resistive formations alternate with conductive ones, suggesting a reversal phenomenon within superficial formations in the area. This reversal suggests operation of the folding and thrust processes of the Yaoundé series' nappes onto the CC. The investigated area is located near the latitude N04°, the CC/CAPAB limit identified by previous geophysical studies (Tadjou et al., 2008; Ndougsa et al., 2010; Basseka et al., 2011 and Shandini et al., 2012). It is considered as a major discontinuity oriented in E-W direction. This discontinuity limit is assumed to be a suture line between those aforesaid units below the CAPAB. The CC subducts approximately from 50 to 100 km beneath the CAPAB. Resistivity values show the signature of rock mixture from the Pan African (conductive) and the CC (resistive) materials. It is seated at the transition zone between the CC and the CAPAB, as suggested by Meying et al. (2013), over a closed eastward (Ayos-Nguelemendouka) area. The current geophysical analysis could not clearly detect events coeval to the CC/CAPAB limit (E-W faults), compared to the geoelectrical model defined by Tadjou et al. (2008). In Tadjou et al.(2008) model, the CC is a resistive block in the south and the CAPAB a conductive block to the north.

The study has highlighted folding patterns within the Yaoundé-Nkolafamba subsurface at shallower depth. The folding system occurs along profiles strike i.e. they are locally caused by NW-SE to N-S compressional movements of the crustal blocks. This result is consistent with those from previous AMT investigations (Ndougsa et al., 2011 and Meying et al., 2013), which highlighted folding at the scale of the Yaoundé series, but eastward of the present study. The present study shows significant geoelectrical shallow discontinuities. These shallower discontinuities oriented from SW-NE to WSW-ENE (perpendicular to the profiles which are directed NW-SE), are interpreted as faults and folds. These folds may constitute local signatures of deep faults (along the same broad directions). Such signatures were also noticed both by Basseka et al. (2011) and Shandini & Tadjou (2012), through a gravity study that encompassed the present sudy area (from nearly N02° to N05° latitudes and from E11° to 13° longitudes). The aforesaid NE-SW to ENE-WSW events form a NE trending structural lineament (Figure 7).This is coeval to the NE secondary tectonic line suggested by Meying et al. (2013).It is linked to the setup of the Centre Cameroon Shear Zone (CCSZ), at a regional scale. The NE tectonic lineament is assumed to be a strike-slip fault system. This is in agreement with earlier geoelectrical studies by Mbom Abane (1997). It proves the existence of E-W and NE-SW oriented wrench fault sets: (a) the first one extends as far as to the Abong-Mbang area, east of Ayos, and (b) the second one runs parallel to the trend of the Trans-African strike-slip. The finding supports the results from the isoresistivity map analyses , carried out by Njinti-Nfor et al. (2001), over an adjacent area (Akonolinga/Abong-Mbang). The study also brought out presence of, E-W and NE-SW trending wrench faults.

In addition, the study reveals the occurrences of uplifts and collapses of the basement in the Yaoundé-Nkolafamba area. Taking into consideration the importance of the highlighted faults and folds that exhibit vertical to subvertical dips, we infer that the subsurface topography is probably controlled by grabens and horsts. According to the coverage of the profiles (oriented NW-SE), the basin and horst-like subsurface structures are elongated in the SW-NE direction. Gravity studies (Shandini at al., 2010; Basseka et al., 2011 and Shandini and Tadjou, 2012) highlighted presence of similarly trending features .It is further inferred that the basement collapse occurred during the CC and the CAPAB collision process. We also brought in to light qualitatively presence of a conductive channel from depth to surface on profile 1 pseudo-section, which can be either seen as an intrusion or a signature of an active faulting process. In the case of an intrusion, this result is in agreement at the local scale, with Basseka et al. (2012) who indicated the presence of granitic intrusions in the northern margin of the CC. If the faulting process is admitted, this channel correlated with horizontal movements linked to shearing processes along the NE-SW direction, as seen by Basseka et al. (2012). These NE shears correspond to horizontal trans-current movements occurring in the Yaoundé series coeval to the CCSZ. The NE tectonic lineament (Figure 7) is correlated to the CCSZ and inferred from the conductive channel as previously mentioned by some authors (Ndougsa et al., 2010; Bisso et al., 2004), who predicted the seismic activity generated on the Sanaga fault (SF) in 2005. The Yaoundé series investigated by AMT soundings over the Yaoundé-Nkolafamba area has provided evidence of collapses and uplifts of the basement. The study also helped in imaging near-subsurface folds and faults. The faults span from the SW-NE to WSW-ENE directions and have vertical to subvertical dips (i.e. they are nearly to normal faults).These faults, when considered together and correlated with geological observations, are linked to the NE shallow lineament (Figure 7) coeval to the setup of the CCSZ characterized by the Sanaga Fault, which is passing north of the study area. The results therefore are in agreement, at the local scale, with the previous geophysical studies. The folding and faulting processes bear witness to intense tectonic movement in the brittle to brittle-ductile conditions that have affected the area at shallow depths. These facts support presence of the multistage tectonic activities (including the CC/CAPAB collision) that occurred in the area, as well as in the whole CAPAB or the Mobile belt at the regional scale. The length of profiles (500 m) as well as the use of high frequencies may constitute a critical limitation to the current geophysical analysis. Inspite of this limitation, the study has detected new faults and clearly imaged folds affecting the near subsurface. These results are supported both at the local and the regional scale by previous geophysical studies , namely the gravity and farther located magnetotelluric (MT) studies.

Geological data integration

Geological data collected through direct observations during the field campaign coincides with results obtained from AMT analyses. The interpretation of AMT data suggests that profiles were laid on a terrain of gneissic and quartzite formations. This fact is supported by the presence of gneissic formations outcrops. These gneisses are of three types: clinopyroxene amphibolic gneiss, biotite gneiss and garnetiferous biotite gneiss. The gneissic fabric presents a double boudinage (Figure 2b) with E-W maximal stretch (B_1) and an N-S minimal stretch (B_2). The folding patterns, corresponding to another deformation stage, are also observed. These folds are cross-cut by many shears (Figure 2a). Besides, many veins and families of fractures characterising the fourth deformation stage have been recorded. Among these fractures' families, the most interesting sets follow the NE-SW and ESE-WNW trends with vertical to subvertical dips. The NE-SW set correlates the faults highlighted by the AMT interpretation (Figure 7). The ESE-WNW family may represent faults nearly parallel to the AMT profiles. The folding and faulting underline the presence of medium to high grade conditions experienced by the area .These conditions facilitated the amphibolite and the granulites facies formations, characterized respectively by amphibolic gneisses, and, biotite gneisses and biotite garnetiferous gneisses, which are herein reported. The strength of tectonic forces occurred in the area has been recorded in the surrounding topography. Indeed, the study area topography is very rough with too many undulations .Even rivers like the Afamba and Ato kept those imprints as they flow in the NE direction. The double boudinage helped to bring to light role of an extensive tectonic activity that resulted in the NE-SW tectonic line suggested by the AMT study. The NE-SW line may constitute strike slip system, owing to the shears observed (Figure 2a). At the outcrop scale, the Yaoundé-Nkolafamba area experienced many deformation stages, as reported on the entire PanAfrican belt in southern Cameroon.

In agreement with geological studies, the faulting system proposed correlates at a local scale, with the SW-NE faults within the Yaoundé domain (significant to the Awaé-Ayos strike-slip shear zones in the late Pan-African tectonics)- (Olinga et al., 2010). At the regional scale, the fault system seems to be correlative with the Centre Cameroon Shear Zone, whose local segment is the Sanaga Fault. The strain field that affected the area is on the scale of that of Central African Fold Belt (Olinga et al., 2010) and consistent with the northeast-southwest Trans-Saharan collision system proposed by Mvondo et al. (2007 & 2009). Further, the NE-SW tectonic line proposed by this study is within the Yaoundé series, imprint of a remarkable extension due to dextral wrenches still occurring in the African plate as witnessed by earthquakes, which struck the Yaoundé region in March, 2005 (Ndougsa et al., 2010). This extension is the modern outcome of the breakup of Gondwana and probably a consequence of the currently occurring NE movements of the African plate towards the Eurasian plate. The NE-SW tectonic line is then correlative to the general NE-SW trending lineaments system running W-E from the Gulf of Guinea to the Aden Gulf (Genik, 1992; Mvondo et al., 2007 & 2009; Olinga et al., 2010).

CONCLUSIONS

The AMT imaging has enabled to highlight folds that affected near subsurface formations. They are assumed to be caused by the Congo Craton/Panafrican collision.

Some geoelectric sections show graben-like topography due to the basement collapses and upward transport of resistive materials to shallow depth, forming basement uplifts.

The analyses have outlined a family of hidden strike-slip normal faults, which form a shallow structural line oriented NE-SW. This faulting network suggests extensive tectonic movement in the Pan African Yaoundé series, and correlates with the Centre Cameroon Shear Zone, while linked to the general NE-SW trending lineaments system running west-east from the Gulf of Guinea to the Aden Gulf.

The fault system, the uplifting of the basement and folding support the intense multistage tectonic activity, including the CC/CAPAB collision that occurs in the Yaoundé-Nkolafamba area, at the regional scale. The seismic activity recorded in Yaoundé in 2005 suggests ongoing tectonic activity. The CC and the CAPAB continue to collide, as part of continent-continent convergence activity.

ACKNOWLEDGEMENTS

The authors respectfully thank Mr Ava Christophe, Country Manager of Harvest Mining Corporation for the logistical support provided to facilitate the AMT survey. Thanks are due to the anonymous reviewer and Editor of JIGU for valuable remarks that enabled to improve the quality of this paper.

REFERENCES

Basseka, C. A., Shandini, Y. and Tadjou, J.M., 2011. Subsurface structural mapping using gravity data of the northern edge of the Congo craton, South Cameroon, Geofizika, v.28, pp: 229-245.

Bessoles, B. & Trompette, M., 1980. Géologie de l'Afrique. La chaîne Pan-Africaine « Zone Mobile » d'Afrique Centrale (partie sud) et zone mobile soudanaise, Mémoires du Bureau de Recherches Géologiques et Minières,Orléans, v.19, pp: 396.

Bisso D., Manguelle-Dicoum E., Ndougsa-Mbarga T., Tabod C. T., Njandjock N. P., Njingti N., Tadjou J. M. and Essono J., 2004.Geophysical Determination of the Sanaga Fault using Audio-magnetotelluric soundings in the Ebebda region, Cameroon, Segmite International, v.1, no.1, pp: 31-34

Bostick, F. X., 1977. A Simple Almost Exact Method of MT Analysis, Workshop on Electrical Methods in Geothermal Exploration, US Geological Survey, Contract No.14080001-8, pp:174-183.

Cagniard, L., 1953. Basic Theory of the Magneto Telluric Method of Geophysical Prospecting, Geophysics, v.18, no.3, pp: 605-635.

Champetier De Ribes, G. and Aubague, M., 1956. Notice explicative sur la feuille Yaoundé-Est (1/500 000), Bulletin Direction des Mines et de la Géologie, Yaoundé, Cameroun, pp: 35.

Feumoe Siyapdje, A.N., Ndougsa Mbarga, T., Manguelle-Dicoum, E. and Fairhead, J. D., 2012. Delineation of tectonic lineaments using aeromagnetic data for the south-east Cameroon area. Geofizika. v.29, pp: 175-192.

Garcia, X. and Jones, A.G., 2002. Atmospheric sources for audio-magnetotelluric (AMT) sounding, Geophysics, v.67, no.2, pp: 448-458.

Genik, G. J., 1992. Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic (C.A.R.), Tectonophysics, v.213, pp:169-185.

Geometrics, 2000. Operation manual for Stratagem systems running IMAGEM, ver. 2.16, Geometrics Printing Press, San Jose, California, pp: 16.

Goldstein, M.A. and Strangway, D. W., 1975. Audio-frequency magnetotellurics with a grounded electric dipole source, Geophysics, v.40, no.4, pp: 669-683.

Manguelle-Dicoum, E., Nouayou, R., Bokossah, A. S. and Kwende-Mbanwi T. E., 1993. Audio-magnetotelluric Soundings on the Basement-Sedimentary Transition Zone around the Eastern Margin of the Douala Basin in Cameroun, Journal of African Earth Sciences, v.17, no.4, pp: 487-496.

Manguelle-Dicoum, E., Bokossah, A.S., and Kwende-Mbanwi, T.E., 1992. Geophysical evidence for a major Precambrian schist-granite boundary in Southern Cameroon, Tectonophysics, v.205, pp: 437-446.

Mbome Abane, S., 1997. Investigations géophysiques en bordure du Craton du Congo et implications structurales. Thèse de Doctorat es sciences, Université de Yaoundé 1., pp: 180.

Meying, A., Ndougsa-Mbarga, T., and Manguelle-Dicoum, E., 2009. Evidence of fractures from the image of the subsurface in the Akonolinga-Ayos area (Cameroon) by combining the Classical and the Bostick approaches in the interpretation of