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GEOLOGICAL AND GEOPHYSICAL INVESTIGATION OF A LATE MAASTRICHTIAN COAL SEAM AT EHA-ALUMONA/ORBA ENVIRONS, ANAMBRA BASIN, NIGERIA

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Abstract

Late Maastrichtian coal seam exposures are encountered at Eha-Alumona/Orba environs, Enugu State, Nigeria. This study aims at delineating the extent of the coal seam and estimating the tonnage, by an integrated approach. Core samples were acquired from two wells. Well 1 penetrates thick layers of sandstones of the Ajali Formation, overlying heterolithic beds of shale and siltstone, and a coal seam at a depth of 41 m, part of the Mamu Formation, Anambra Basin. Thickness of the seam is 0.6 m, equivalent to the exposure at Iyi Coal Spring, 417 m southeast of Well 1. No seam was encountered in Well 2 up to a depth of 61 m, suggesting it may have been eroded. Results from four vertical electrodes sounding (VES) and three double-dipole profile surveys show good correlation with core data. Geo-electric sections from VES 1 and VES 4 match significantly with Well 1 core data, with coal seam occurring between 40.7 – 56.6 m. Double-dipole Profile 1 shows that the seam occurs at a depth of 30 m, while Profile 3 revealed resistivity values equivalent to Profile 1, but with seam at 24 m depth. Low resistivity values of Profile 2 suggest absence of the coal seam. Depth slice maps and resistivity profile curves show the northwestern part of the study area as most prospective and the seam having relatively good lateral homogeneity. An estimated 8,719 tonnes was computed within an area of 10,380 m^2, which may be economically viable and harnessed for domestic purposes for Eha-Alumona/Orba environs.

Keywords: Late Maastrichtian; coal seam; vertical electric sounding; double-dipole; tonnage.

1. Introduction

There have been extensive studies on the Cretaceous – Tertiary sediments of the Southern Benue Trough and Anambra Basin. Since the discovery of coal in the basin in 1909, several quantitative and qualitative research works has been done on the basin to delineate, evaluate and analyse the coal seams. The Nigeria coal and lignite resources have an estimated reserve of 1.5 billion tons and 300 million tons, respectively [1], although most of these coal deposits lie unexplored and abandoned. Coal is being mined at Ezimo, 5 km northwest of the area under study. This coal seam is of the Maastrichtian Mamu Formation [2-3], which contains most of the coal seams in the Anambra Basin. Lithofacies and palynological analysis of the lithofacies in the Mamu Formation suggests that the coarsening upward sequence is indicative of a decrease in relative sea level, and the intercalation of siltstone, sandstone and shale, with its high abundance and diversity of palynomorphs suggest a shallow-marine environment with tidal influence [4].

In exploring for coal, electric resistivity technique of geophysical survey is most widely adopted and has proved very effective in most cases. It is a useful tool routinely used under a variety of field conditions and geological settings in environmental geology and geotechnical engineering [5- 7]. It is also useful in developing geologic models such as digital/terrain model for topographic assessment, delineation of resource target areas to include the subcrop line, and to aid mining activities via establishing a wash-out elevation [8]. Owing to the fact that rocks vary in resistance to electrical current flow, coal seams in the subsurface can be delineated. Shales and sandstones generally have lower resistivity values, and such contrast form the basis for the application of electrical resistivity techniques to coal exploration, sometimes with slight modifications [9-10].

From the comparative study of the resolution capacity and efficiency of ten electrode arrays in a numerical modelling study [11], double-dipole, pole-dipole and the gradient arrays were found to be very efficient for 2D resistivity surveying despite their sensitivity to noise, while the Schlumberger array was effective for 1D resistivity surveying. Furthermore, the integration of geological data, such as outcrop measurements and well core data, helps to better constrain geophysical interpretation in the evaluation of coal seams. This study therefore aims at delineating the lateral extent and estimating available tonnage of the coal seam within the Mamu Formation, around Eha-Alumona/Orba and its environs, by an integration of geological (outcrop and well core data) and geophysical (vertical electrical sounding and double-dipole) tools.

2. Location and Geological Setting

The study covers an area of about 85 km^2 within latitudes N 6° 44' 55.71'' to N 6° 49' 10.94'' and longitudes E 7° 29' 40.57'' and E 7° 35' 29.68'' (Fig. 1).

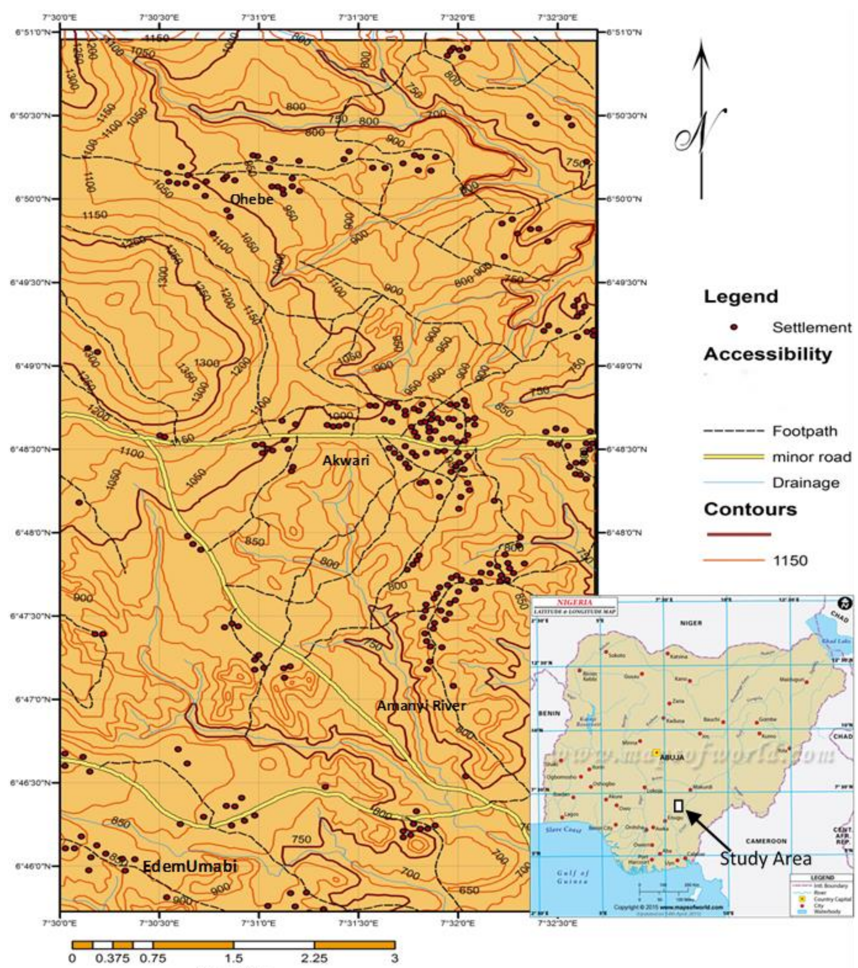

Fig. 1. Map of the study area showing relief, drainage, settlement and accessibility. *Note: Contours are in feet*

This area lies within two towns – Eha-Alumona in Nsukka Local Government Area and Orba in Udenu Local Government Area, both in Enugu State, Nigeria. It can be accessed through the minor roads and dirt tracks leading from Orba and Eha-Alumona Junctions along the Enugu – Makurdi Road. The topo-graphy of the area is an undulating one; with elevation ranging from more than 450 m in the northwest to 180 m around stream channels. The study area is drained by rivers and streams running down from the Enugu escarpment at the west, to the east and southeast. The drainage pattern is dendritic, scarring the Ajali Formation in the western region and flowing at a relative lesser gradient over the more resistant mudstone and claystones of the Mamu Formation in the east. The rivers encountered include the Amanyi, Iyi Otu, Kokoro etc. The vegetation of the area consists of slightly thick forests of the Guinea (tropical) Savannah, with sparse nucleated village settlements within their farmlands.

Geologically, the study area lies within the Campano-Maastrichtian Anambra Basin which is genetically linked to and overlies the Southern Benue Trough (Figs. 2, 3). The Basin is a NE-SW trending syncline which developed in response to the stretching and subsidence of major crustal blocks along the Central African Rift System during a Lower Cretaceous break-up phase of the Gondwana supercontinent [4, 12]. Subsidence continued in the Southern Benue Trough and this corresponds to the time of the initiation of the Anambra Basin, which began during the Coniacian and reached its peak at the Santonian thermo-tectonic event [13].

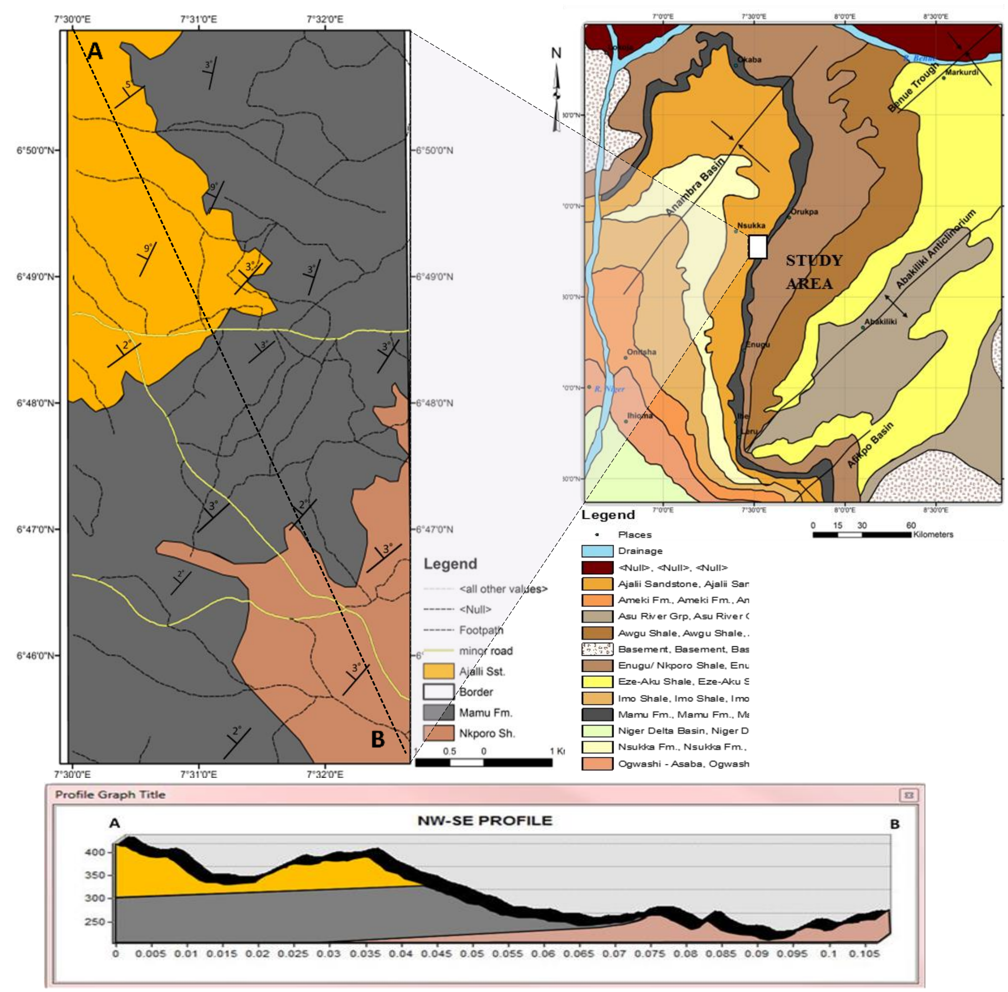

Fig. 2. Geological map of the study area with a NW-SE cross section. Inset is the geologic map of the Southern Benue Trough (modified from Akande [2])

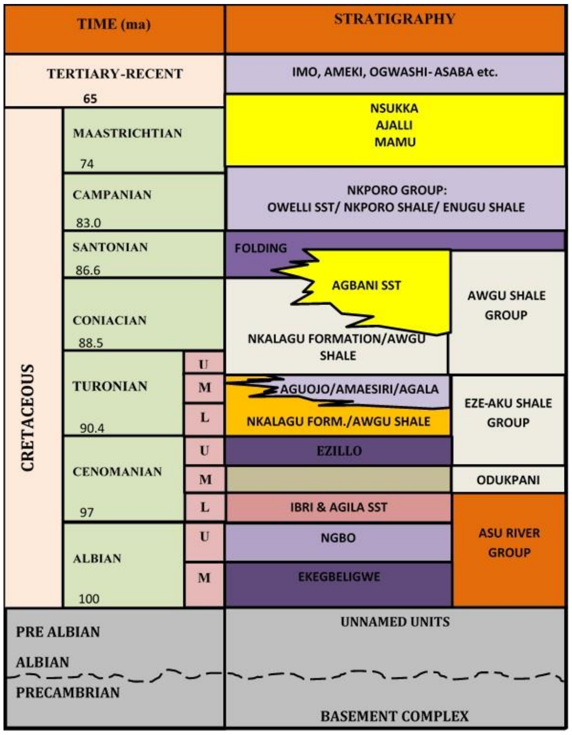

Fig. 3. Age relationship and the lithostratigraphic units of sediments in southeastern Nigeria (after Nwajide [14])

Deposition during the Albian to Santonian in the Abakaliki-Benue sector of the Benue Trough was synchronous with deposition of thin sediments on the proto-Anambra Basin [14]. Deposition eventually slowed down or ceased as a result of regression of the sea. In Turonian times, the sea again invaded large areas, and marine sedimentation continued well into Santonian. This was followed by uplift, renewed folding and erosion in certain areas. In Campanian to Maastrichtian times, another transgression of the sea took place and marine sediments were laid down. In some areas, these rest unconformably on the underlying beds, while in others there appears to have been no break in sedimentation. The sea slowly regressed towards the close of Maastrichtian leading to the formation of an extensive, low-lying coastal area with lagoons and swamps, on which a thick succession of coal measures formed. Fresh-water sandstones were deposited, extending to the north and west on to the Precambrian Basement. Sedimentation was entirely non-marine until the deposition of the Nsukka Formation, in which marine intercalations indicate a gradual encroachment of the sea, and marks the end of deposition in the Anambra Basin [14]. Subsequently, sedimentation was renewed in Tertiary times within the onshore Niger Delta.

3. Methodology

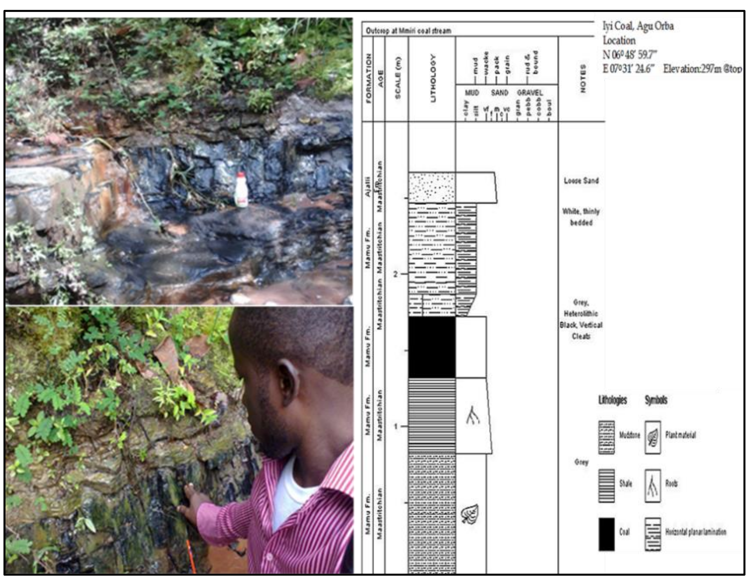

Fig. 4. Outcrop showing coal seam at the Iyi Coal Spring (left). Outcrop litholog showing the coal seam encoun-tered at this location (right)

The coal seam outcrop at Iyi Coal Spring (Fig. 4) attracted reconnaissance study and subsequently, detailed geologic mapping on traverses running from west to east of the study area. Location and attitude of the outcrops were recorded using the GARMIN GPS map76CSx device and a geologic compass. The XY200C Hydraulic Rotary drilling rig was mounted and used in drilling two vertical boreholes and cores of 76 mm diameter acquired at two locations with coordinates N 6° 49' 3.75"/E 7° 31'11.25" (Well 1) and N 6° 49' 18.80" / E 7° 31' 11.20" (Well 2). Electrical resistivity survey was carried out along traverses, employing the Omega terrameter. Two double- dipole profiles were carried out in the south east direction and one profile was run in a north east direction (three surveys altogether), following the method described in Keller [15]. Two vertical electrical soundings were carried out in the southeast direction and another two in the northeast direction (four soundings altogether), using the Schlumberger array, as described in Keller [15]. Total length of all double-dipole traverses was 3 km with each 1 km in length, while the total length of the Schlumberger traverses was 2.96 km with each 740 m in length. The data were analysed using RES2DINV v. 3.58 of Geotomo Software co., IPI2Winver 3.0.1 of Moscow State University and Surfer 11 of the Golden software Inc. Resistivity data from profiles were plotted on pseudo-sections to investigate lateral variation in resistivity. In pseudo-sections, values of apparent resistivity are plotted on contours along the profile length. Because pseudo-sections are difficult to interpret, an inversion of the data was done to determine the electrical properties that give rise to the measured (apparent) electrical resistivity. Inversion of data provides a model of the resistivity characteristics (electrical properties) of the subsurface. The inversion routine is based on the smoothness-constrained least-squares method [16]. The inversion program used [17-18] requires electrode spacing to be held constant and divides the subsurface into rectangular blocks, therefore, the inversion of resistivity data is not affected by the geometry of subsurface resistivity anomalies. The purpose of the program is to determine a resistivity of each block such that the apparent-resistivity pseudo section agrees with the actual measurements [18]. Vertical electrical sounding (VES) curves were plotted on graphs of apparent resistivity against electrode spacing to investigate 1-D vertical variation in resistivity, thereby constraining the validity of the 2-D sections.

Lithology logs obtained from the various outcrops and well core data were correlated with the VES curves and the pseudo-sections of the profiling data points and was used to delineate the coal seam in the subsurface. Through resistivity models developed, an estimate of the coal tonnage available in the study area was done to determine its economic viability.

4. Results and discussion

4.1 Outcrop description

Detailed geologic mapping of the study area formed the basis for onward geophysical investigation. Three formations outcrop in the study area (Fig. 2) – Nkporo Shale Formation (oldest), Mamu Formation, and Ajali Formation (youngest). Generally, the beds strike in a NE-SW direction and dip relatively gently (< 10º) to the NW direction. The lithologic characteristics of the facies encountered within these formations and the beds associated with them are described below and "type" stratigraphic logs presented in Figures 4 and 5.

4.1.1. Nkporo Shale Formation

This formation is recorded at the stratigraphic base and forms low-lying topography in the southeastern corner of the study area. It is overlain by the Mamu Formation. The Nkporo Shale consists dominantly of shales and associated siltstones that dip gently in a direction conformable to other overlying formations. The dip amount varies from 7º - 8º with a dip direction of 288º NW and strike of 18º NE – 198º SW. A shale outcrop encountered is about 1.5 cm thick, dark grey and fissile, and at another location is almost black, platy, fissile and typically broken into flat pieces. Near the top, the mottling of the shale is more evident, reflecting bioturbation by organisms. Weathered colours include yellow, brown and red, the red being concentrations in small pockets. At the surface where oxidation may have gone far, the red patches have hardened into ironstones strewn about or coalesced into spongy laterite characteristic of the overburden.

4.1.2. Mamu Formation

Heterolithic Siltstone/Claystone facies

This facies is dominant in the upper units of the Mamu Formation. The beds are made up of thin, light grey to whitish intercalations of siltstones, claystones, shales and sometimes sandstones. Its average thickness is about 2 m. It is generally light in colour and pink in ferruginized zones. Generally, the beds strike 72º NE / 252º SW and dip 3º to the NW.

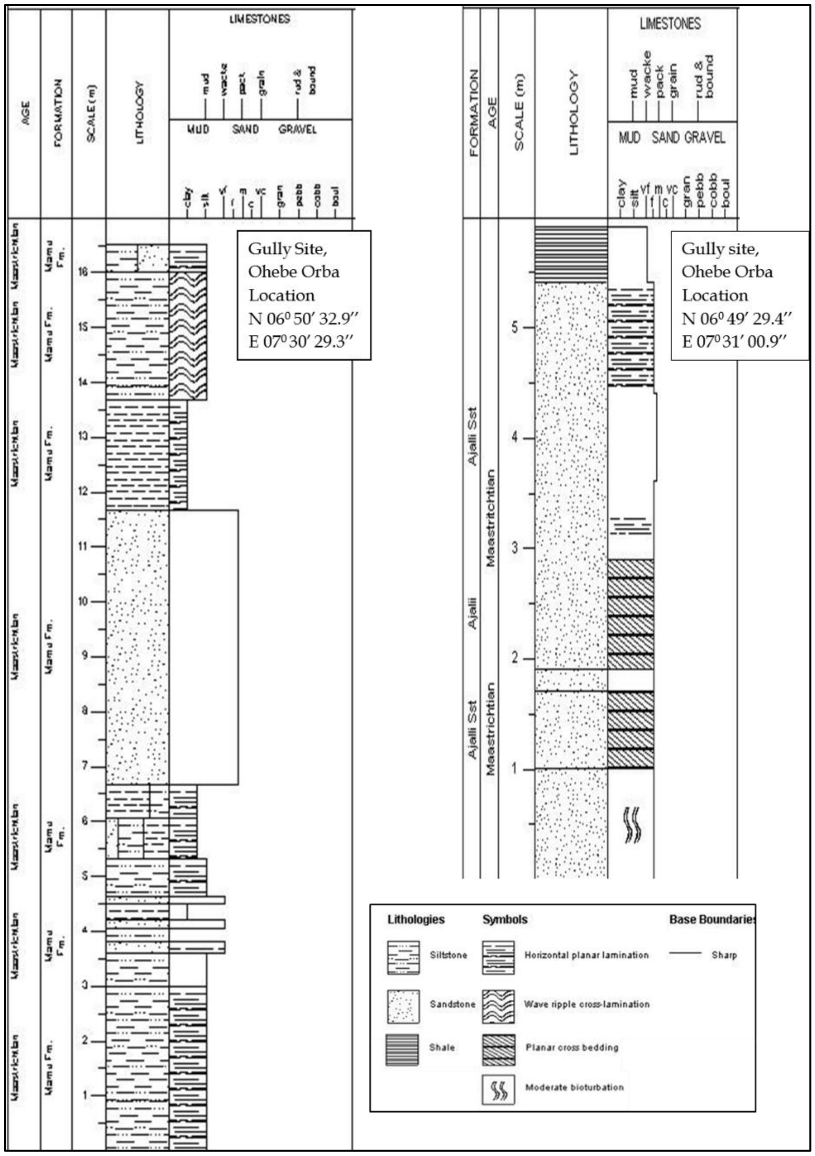

Fig. 5.“Type” stratigraphic logs of outcrops exposed at Amanyi River and Ohebe Orba gully site

Coal Facies

This is the uppermost coal seam in the Mamu formation. It underlies the silty heterolithic bed and outcrops at stream cuts in the central part of the study area at coordinate N 06º 48' 59.7" and E 07º 31' 24.6". The seam is about 0.5 m thick. The average attitude of the bed is: strike 151º SE / 331º NW, dip 241º SW, and dip amount 5º. This facies is very dark in colour and made up of coals that slightly stain the fingers suggesting they might be of the sub-bituminous rank. The coals are relatively less dense than the carbonaceous shale facies that underlie it. This coal seams acts as an impermeable layer on which groundwater which percolates through the permeable overburden flows and underlies the point source of the Iyi Coal Spring (Fig. 4).

Carbonaceous Shale Facies

The carbonaceous shale facies underlies the coal facies and grades upwards into it. It has an average thickness of 0.5 m. The bed shows lateral heterogeneity, and is very dark, fissile and contains high amount of carbon. Its thickness increases at some exposures where the overlying coal facies is absent. They have an average general attitude of strike 335º NW /155º SE and dip 3º to the SW. This facies typically gradationally thins out towards the east into underlying shale and mudstone beds.

Dark Mudstone Facies

Underlying the carbonaceous shale facies is the dark mudstone facies. It is basically very fine grained and consolidated. The bed in this facies consists mostly of well laminated, dark grey mudstones and thin claystones, siltstones and shale beds. Some outcrops exhibit planar laminations, while others show wavy laminations. They have an average general attitude of strike 059º NE / 239º SW and dip 4º to the NW. This facies immediately overlies the Nkporo Shale Formation and the transition between them is quite gradational.

4.1.3. Ajali Formation

Friable Sandstone Facies

This friable sandstone facies is the main constituent of the Ajali Formation. The beds in this facies show homogeneity in grain size, though poorly sorted in some beds, and range from fine to coarse grained sandstone beds that are friable. The thicknesses of these beds are enormous, ranging from 3 m to as much as 50 m where they are exposed in gullies. They are highly ferruginized giving the beds a reddish-brown coloration. Structures such as cross and planar laminations and bioturbations are observed. The attitude of the beds consists of an average strike of 330º NW / 150º SE and dip of 4º to the SW. This facies covers most of the northwestern part of the mapped area with very loose red sand and overlies the consolidated sandstone facies.

Consolidated Sandstone Facies

The base of the Ajali Formation is marked by thick consolidated sandstone. They weather in certain locations where they are form boulders and exhibit cross-bedding. In most of the outcrops, especially along river cuts, it overlies ferruginized thick silty and clayey laminated beds of the Mamu Formation. Along contacts with the Mamu Formation, the ferruginization becomes more pronounce with the presence of ironstones. The average thickness is about 2 m. They have an average general attitude striking 318º NW/ 138º SE and dip 3º to the SW.

4.2. Well Core Description

Two wells (Well 1 and 2) were drilled within the study area to depths of 51 m and 68 m, at elevations of 325 m and 313 m, respectively. Well 1, which is 417 m from the location of the outcropping coal facies at Iyi Coal Spring, intercepts a 0.6 m thick coal seam at a depth of about 41 m (Fig. 6). This coal seam is overlain by alternating light and dark grey fractured siltstones, and whitish to light brown fine-grained sandstones, and underlain by carbonaceous shales and dark grey mudstones. Well 2, which is 465 m from Well 1, does not intercept any coal seam, to a depth of 68 m, even though is it as relatively lower elevation (Fig. 6). The absence of a coal seam at this location is more likely due to erosion, than it is due to non-deposition.

4.3. Interpretation from Vertical Electrical Sounding (VES)

Geo-electric sounding curves plotted for four VES points using the IPI2win software [19] were evaluated for signatures diagnostic of coal occurrence in the study area. The inverse problem was solved using a variant of the Newton algorithm of the least number of layers. The results from the VES and their interpretations are summarised in Figure 7. The dots and curves represent the observed and calculated resistivity values, respectively, while the line represents interpreted resistivity and thickness values. The VES 1 and VES 4 show the Type KQ and KA curves, respectively, while the VES 2 and VES 3 show the Type H curve.

From the VES curves, it is evident that the geo-electric sections represents resistivity variation with depth that is associated with the lithologic pattern observed at the various outcrops and the well core logs. The topmost Ajali Sandstone overlies the heterolithic beds of siltstone/claystone with thin shale layers, which in turn rest upon the coal seam and the carbonaceous shale layer. In VES 1 and VES 4 the coal signature was significantly masked by the surrounding shale and the shallow water table.

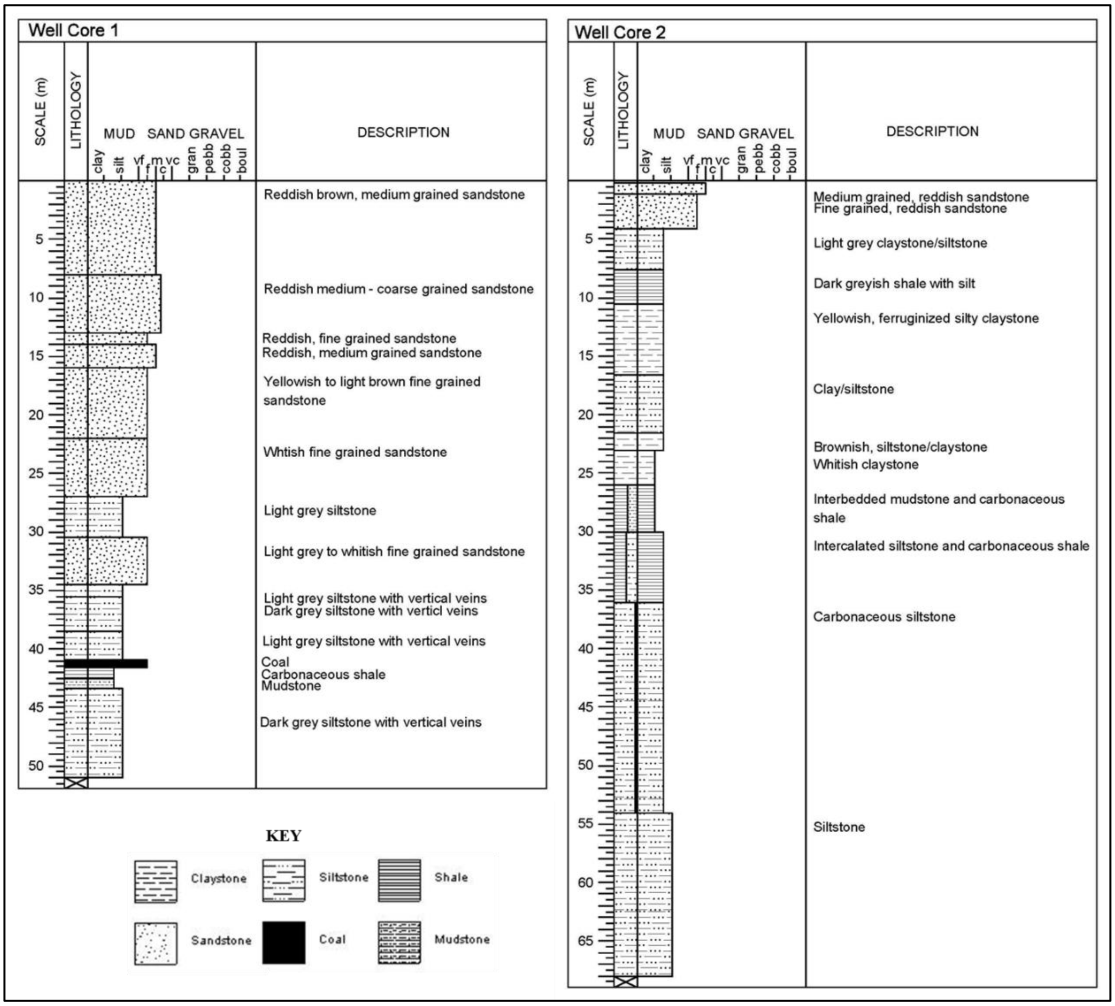

Fig. 6. Stratigraphic logs of well cores 1 and 2, showing the coal seam encountered at a depth of 41 m in Well 1, but not penetrated in Well 2

4.4. Interpretation from Double-Dipole Profiling

The apparent resistivity values obtained using the double-dipole electrode configuration were plotted as electrical resistivity tomographic (ERT) pseudo-sections to identify areas displaying anomalous patterns (Figs. 8-10). A prior knowledge of the local geology from the geological field mapping guided the interpretation of the data, as well as the planning of the survey. The resulting pseudo-sections show the measured apparent resistivity, the calculated apparent resistivity, and the resulting inverted true resistivity 2D sections. The goodness of fit criteria used to assess the accuracy of the calculated resistivity goodness fit is shown above the true resistivity sections. Finally, the surface elevation profiles were included to guide the understanding of the final model, accounting for variations in measurement geometry due to changing topography.

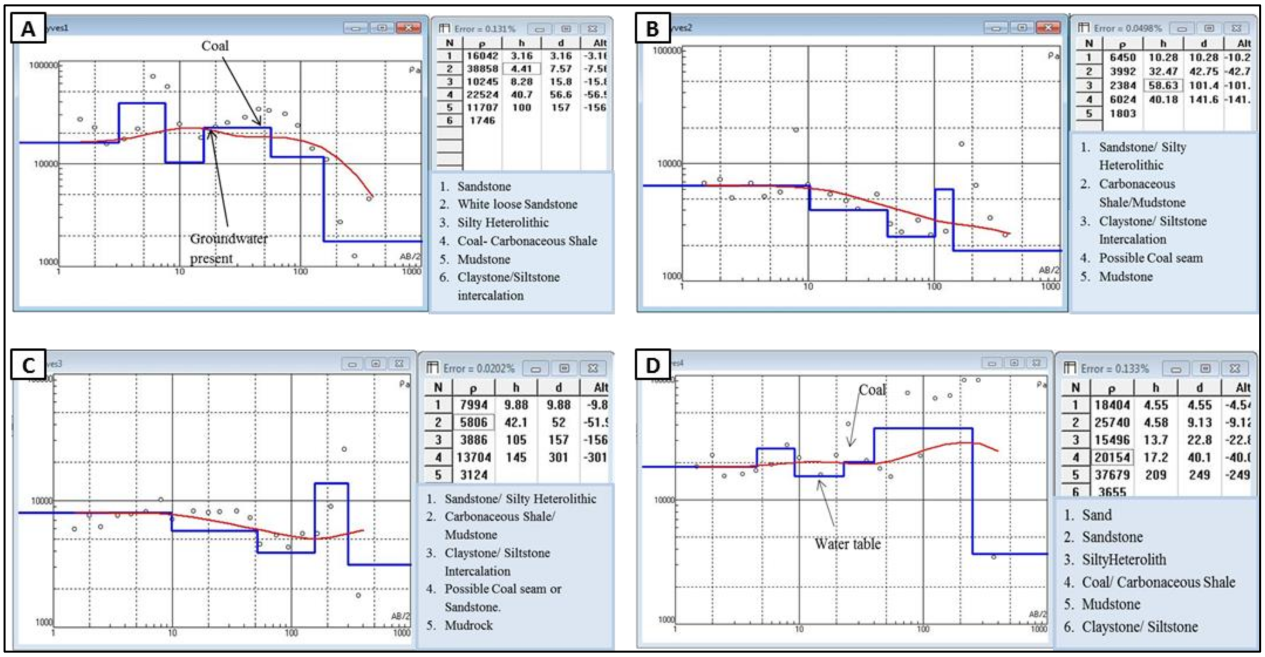

Fig. 7. Sounding curves for all four VES stations showing geo-electric sections interpreted using information from well core data. (A) VES 1; (B) VES 2; (C) VES 3; (D) VES 4

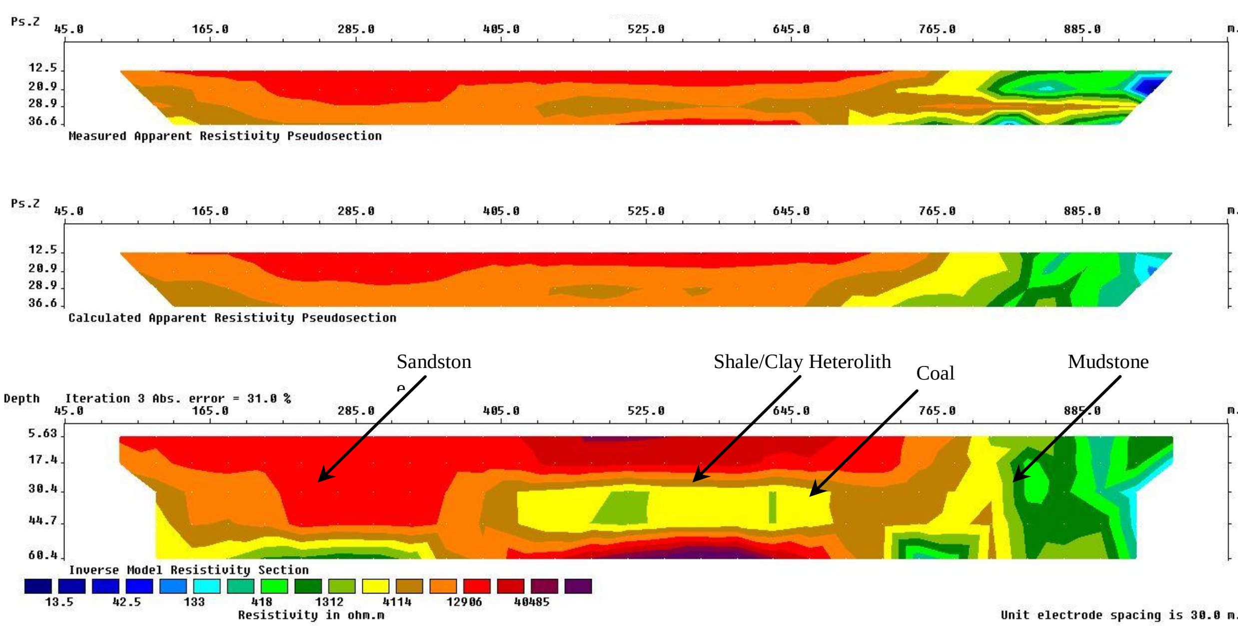

Fig. 8. SW-NE resistivity section using double-dipole configuration along profile 1 parallel to seam strike. Top – measured apparent resistivity plot; Centre – calculated apparent resistivity plot; Bottom – inverted true resistivity plot

In profile 1, high resistivity values were recorded at the top layer of the section up to the 735 m point, ranging from a depth of 20 m to 44.7 m and is interpreted as loose sand and sandstone (Fig. 8). Average resistivity recorded in these layers is 26,000 ohm-m. It is underlain by the silty heteroliths, with a thickness of 25 m in the southwest and diminishing considerably to less than 5 m in the northeast. An average resistivity of 10,708 ohm-m was recorded for this layer. Underlying the heteroliths is the coal/carbonaceous shale sequence with a total thickness of about 2 m. This zone is laden with water and the coal acts as an impermeable layer for the accumulation of groundwater- which seeps out as the Iyi Coal Spring. The resistivity of the coal seam which is known to be much higher than shale is masked by the shale and also the groundwater; and therefore a relatively lower average resistivity of 8510 ohm-m was recorded. This sequence is also notable at a greater depth in the northeast. Low resistivity values ranging from 133 ohm-m to 1312 ohm-m, was interpreted as a mud-stone/shale sequence at the base of the pseudo-section.

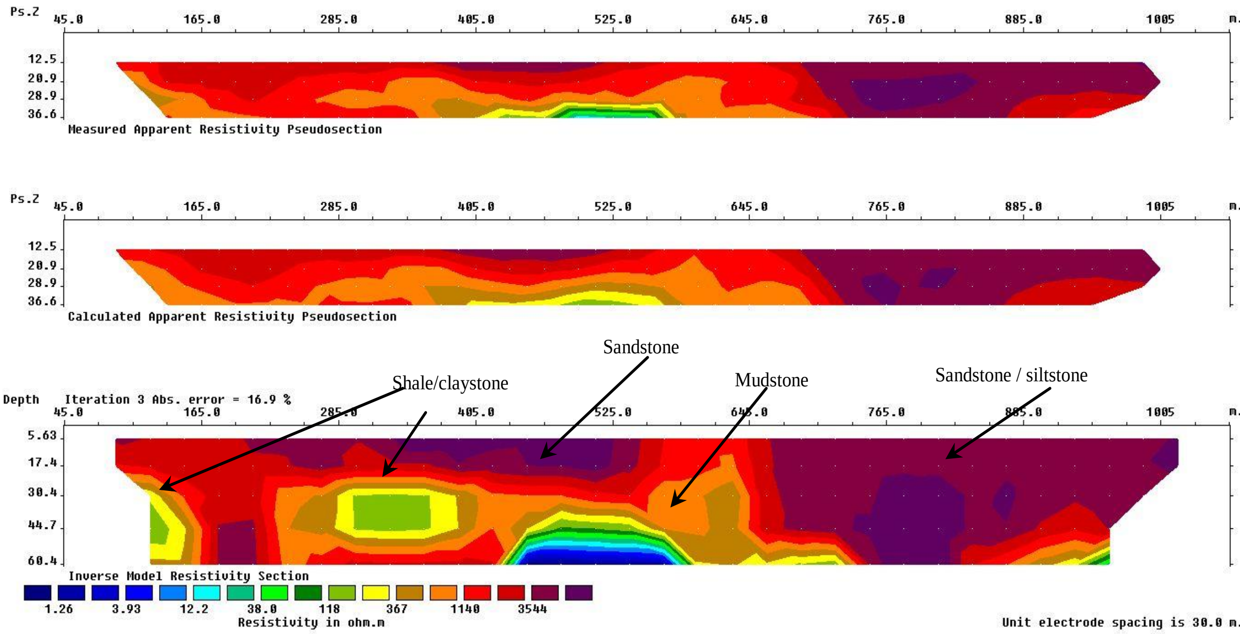

Fig. 9. SW-NE resistivity section using double-dipole configuration along profile 2 parallel to seam strike. Top – measured apparent resistivity plot; Centre – calculated apparent resistivity plot; Bottom – inverted true resistivity plot

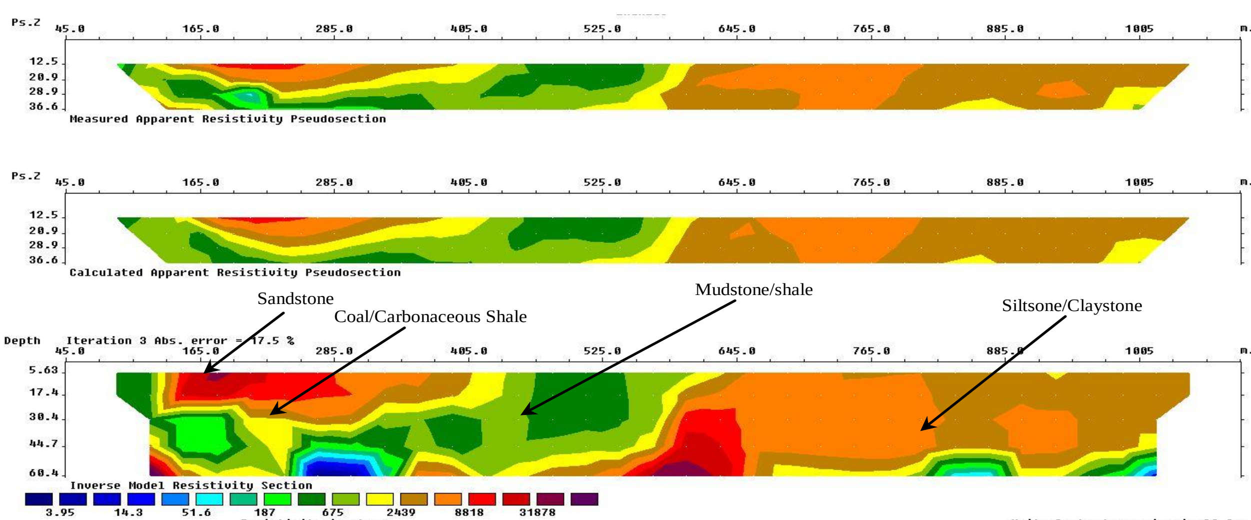

Fig. 10. NW-SE resistivity section using double-dipole configuration along profile 1 parallel to seam dip direction. Top – measured apparent resistivity plot; Centre – calculated apparent resistivity plot; Bottom – inverted true resistivity plot

Profile 2 shows a huge drop in the range of resistivity values, southwards into the less resistive Mamu Formation (Fig. 9). The most resistive units, interpreted as fine silty sandstone/siltstone, exist at higher elevations and at the northeast end of the profile, with resistivity values ranging from 3544 ohm-m to about 14,000 ohm-m. Its thickness is about 17.4 m at the center of the profile. Underlying this unit is siltstone/claystone intercalation with associated resistivity ranging from 750 ohm-m to 2342 ohm-m. The thickness of this layer is about 20 m to the southeast of the pseudo-section. On the western flank of the profile, shales laden with the shallow groundwater, reflects a lower resistivity ranging from 118 ohm-m to 765 ohm-.m. Thicknesses of the shale beds are the same as in profile 1.

Profile 3 runs northwest - southeast direction perpendicular to profiles 1 and 2 (Fig. 10). The higher elevated northwest flank shows vertical heterogeneity than the southeast which is filled with the siltstone/ claystone beds. In the northwestern part of the profile, the high resistive loose sand of the Ajali Formation was encountered. Underlying the sandstone beds is the siltstone/claystone heteroliths with resistivity ranging from 2439 ohm-m to 8818 ohm-m. Underlying the heteroliths is the coal/shale/mudstone sequence, which terminates at the foot of the higher elevated Ajali Formation. The thickness of this sequence reaches more than 20 m with the overlying coal only about 0.6 m thick.

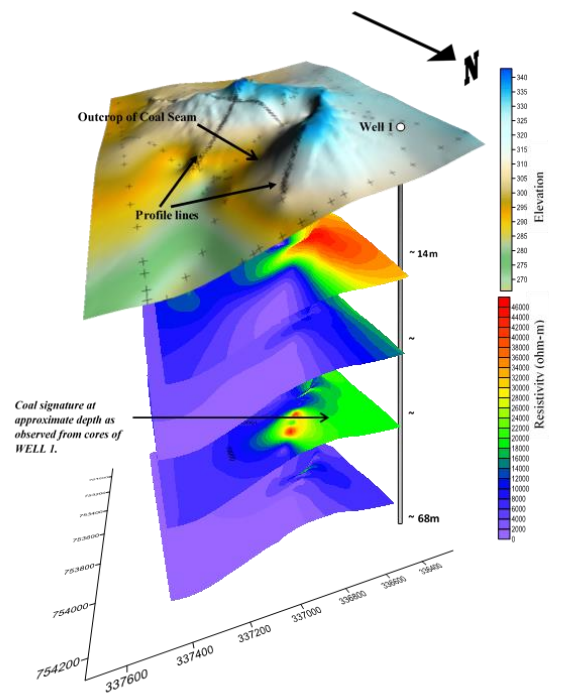

Fig. 11. Resistivity depth slice maps, stacked with 3-D relief map, for n= 1,2,3,4 modeled from all three double dipole profiles. *Note: the vertical intervals are not to scale*

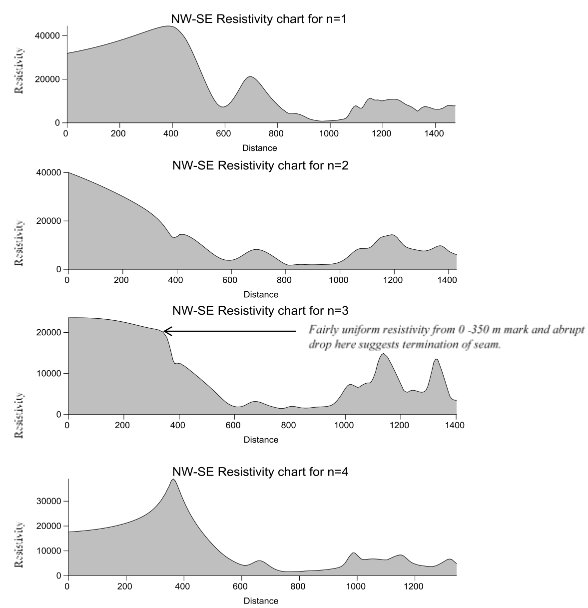

Fig. 12: NW-SE profiles across resistivity slice maps showing relatively even resistivity at the western end of n=3 slice map

To further understand the distribution of resistivity with depth across the three profiles, resistivity slice maps for n = 1, 2, 3, 4 data points, corresponding to depths 17.4 m, 30.4 m, 44.7 m, 60.4 m, respectively, were plotted and stacked (Fig. 11). High resistivity at the northwest corner of n = 1 depth slice indicates the topmost layer- the Ajali Formation, while eastards less resistive siltstone/ claystone of the Mamu Formation dominates the top layer of the area. At n = 2 depth slice, the silty heteroliths is shown beneath the sandstone beds as a less resisive layer and even less resistive towards the southeast where claystone, shale and mudtone abound. At n = 3 depth slice, green coloration at the northwest corner shows a zone of relatively high resistivity attributed to the coal bed. The coal bed signature ranges in resistivity from 14,000 ohm-m to 20,000 ohm-m. At n = 4 depth slice, low resistivity values correspond to shale/mudstone units.

Profile graphs showing NW-SE trending changes in resistivity across the various surfaces was also plotted (Fig. 12). The resistivity profile for n =3 reveals sharp drop in resistivity after a uniform resistivity range had been maintained for 350 m along the profile. This is in contrast to the irregularity in resistivity values along the other profiles and suggests the termination of the relatively high resistive seam along this profile.

4.5. Estimation of the Inventory Coal

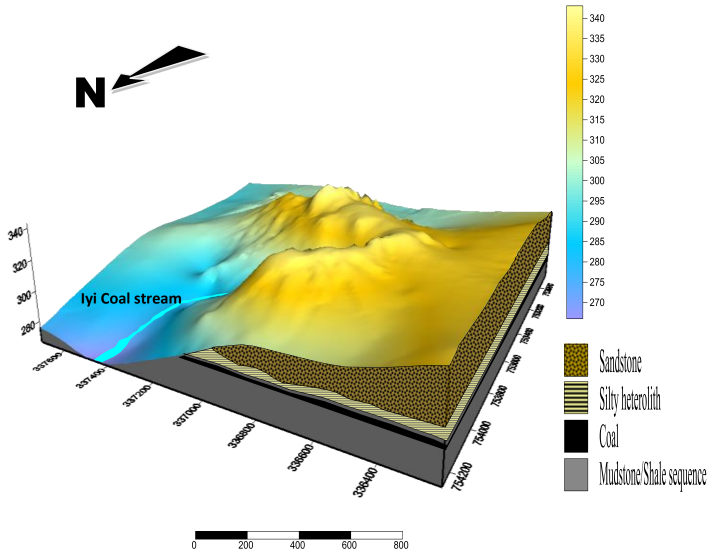

Fig. 13. 3-D model showing a conceptual representation of the subsurface at the NW part of the study area where the coal seam is believed to underlie

The findings from geologic mapping, core information, geo-electric sounding and profiling results was used to develop a conceptual geologic model for the area studied (Fig. 13). Inventory Coal refers to an estimate of in situ coal that does not satisfy reasonnable prospects test, and may include coal that currently has low prospecively due to natural or cultural features that preclude mining [20].

In this study, Inventory Coal was estimated based primarily on Points of Observation (PO), such as the outcrop at the Iyi Coal Spring and the Well 1 core data, and supplemented by Supportive Data (SD), such as the geo-electric data acquired. The SD were used with PO to improve confidence in seam continuity.

Critical variables, such as the thickness of the overburden relative to the seam, the seam thickness and the quality, which is undetermined, are physical and chemical properties of seam that may potentially limit reasonable prospects for eventual economic extraction [20].

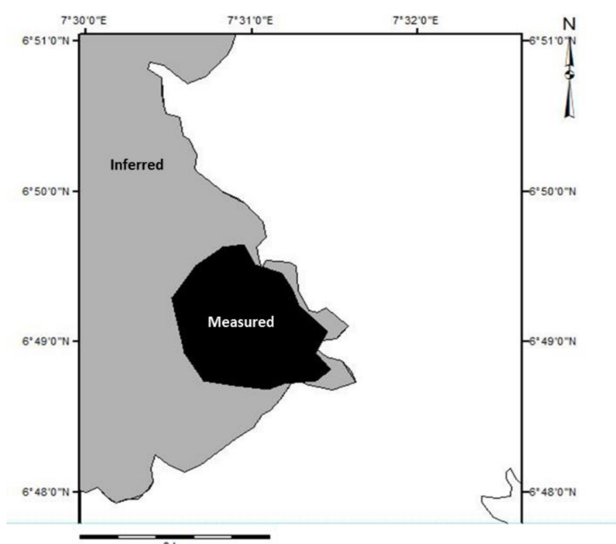

Fig. 14. Map of Inventory Coal showing areas underlain by the measured and inferred coal reserve

The thickness of the overburden from Well 1 and relevant geo-sections ranges from 28 to 41 m, and thicknesses of up to 100 m is expected at other elevated points and farther NW. The seam area was extrapolated from the different PO and SD points and profiles within the study area. Using TatukGIS Viewer, the seam area, was estimated to be about 10,380 m^2. The thickness, in turn, is 0.6 m as measured from the PO, and the density is given as 1.4 t/m^3. The formula to estimate the coal seam quantity is given by:

$$coal\ seam\ estimate\ in\ tonnes] = thickness\ (m) * seam\ area\ (m^2) * in\ situ\ coal\ density\ (\frac{t}{m^3})$$

Hence the estimated tonnage was calculated as 8,719 tonnes. This estimated value is classified as "inferred estimate" (Fig. 14). The seam is believed to extend further northwest and possibly links up with the Ezimo coal seam, which is being mined. The area in black (Fig. 14) shows the "measured estimate" with about 2,100 tonnes of coal. This study excludes other deeper Maastrichtian coal sequences in the Mamu Formation as noted in previous studies.

5. Conclusion

The geology of the study area consists of the three formations: the Ajali, Mamu and Nkporo Shale Formations. The seam studied is a part of the uppermost part of the Maastrichtian Mamu Formation, underlying only parts of the study area and overlain by the Ajali Formation at the NW end. Outcrop data and core data from two wells were the point of observation data, while electrical resistivity sounding using the Schlumberger array and profiling using the double-dipole array were used to delineate the coal seam. The coal seam is characterized by high resistivity values ranging from 4114 – 12,986 ohm-m with thickness of 0.6 m. The depth to the seam from the interpretation of the sounding curves is not uniform, but ranges from depths of about 30 – 41 m, which may be attributed to the elevation at the surface.

Estimation of available Inventory Coal was attempted and classified into "inferred" and "measured". The estimated reserve tonnage is 8,719 tonnes computed for an area of 10,380 m^2. 2,100 tonnes was calculated as the measured (proven) estimate. This estimated tonnage, although, relatively small, may be economically viable and can be harnessed by individuals and local investors for domestic purposes or generation of electric power for Eha-Alumona/Orba environs.

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