Applied Journal of Physical Science
Volume 3(1), pages 1-12, February 2021
Article Number: 46909F351
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2020.038
https://integrityresjournals.org/journal/AJPS

Full Length Research

Quantitative discovery and geophysical estimation of limestone deposits at Takowangwa area, Mokwa, North-Central Nigeria

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Received 29th December, 2020; Accepted 1st February, 2021

ABSTRACT: Takowangwa area in Mokwa, Niger State, North-Central Nigeria was probed using Electrical Resistivity (ER) and Induced Potential (IP) methods to discover possible limestone deposits. The probe was conducted at five profiles, within which 25 Vertical Electrical Soundings (VES) were carried out. The Terrameter SAS 4000 for which the maximum current electrode spacing AB/2 was 100 m and the Schlumberger array were adopted for the soundings. The results from the computer modelling software (IP2WIN) revealed the occurrence of limestone deposits in all the five probed profile locations. This was inferred from the exhibited low resistivity and chargeability values which characterised all the profiles in their first and second geoelectric layers. The characterised low resistivity and chargeability values ranged respectively from 43 to 155 Ωm and 1.12 to 155 msec, while the thickness range was from 20.69 to 86.53 m. These two geophysical approaches (Electrical Resistivity and Induced Polarization) showed a good degree of correlation in the resistivity and chargeability values of the limestone and their varying quantities. This research work estimated the occurrence of vast limestone deposits of the magnitude 2.0 x 10^6 t which can be of very much economic importance in domestic, mining and industrial purposes. More detailed integrated geological, geophysical studies and drillholes to cover the study area and even with further extension beyond the probed area for better understanding of the economic potential of the study area were recommended.

Keywords: Chargeability, geoelectric layer, limestone, resistivity.

INTRODUCTION

Limestone possessing a very high economic value and not found naturally everywhere other than in areas underlain by sedimentary rocks, makes it an important raw material to other areas in need of it and thus, would therefore attract the buyers and the relevant industrialists to any location naturally enriched with the mineral deposits. This would therefore, boost the economy of such locality. Limestone being a sedimentary rock is composed majorly of calcium carbonate ($CaCO_3$) in the form of the mineral calcite. It is usually characterized by occurring in grey, but it may also be white, yellow or brown. It is a soft rock and is easily scratched. It will effervesce readily in any common acid. It most commonly forms in clear, warm, shallow marine waters. It is usually an organic sedimentary rock that forms from the accumulation of shell, coral, algal, and faecal debris (William, 1997). It often has variable amounts of silica in it, as well as varying amounts of clay, silt, and sand (Bell, 1963).

Limestone has numerous uses to mankind; as a building material, glass making, an essential component of concrete (Portland cement), as aggregate for the base of roads, as white pigment or filler in products such as toothpaste or paints, as a chemical feedstock for the production of lime, as a soil conditioner in agricultural practices, and as a popular decorative like floor tiles. It is also used in medicines and cosmetics as its calcium contents are considered good for the health of a nursing mother if given in moderation. Animals can also largely benefit from having limestone in their diet so it is often added to their feed (Feedipedia- 2012-2020). In addition, powdered limestone is used in coal mines as a safety precaution because it absorbs pollutants, as well as being used on roofs to prevent or reduce weather or heat related roof damage (Mijinyawa et al., 2007). Also, the geological formations of limestone are most of the great petroleum reservoirs. It may be used for remineralizing and increasing the alkalinity of purified water to prevent pipe corrosion and to repair important nutrient tiers (Akhoondan and Sagüés, 2013). However, despite its numerous uses, it can be toxic to humans as it may cause respiratory tract irritation. Adverse symptoms may include respiratory tract irritation, and coughing. Prolonged inhalation may cause chronic health effects (Henry et al., 2017; Reynolds, 2003). That notwithstanding, limestone still maintain a better recognition due to its economic importance.

Mokwa local government is faced with low revenue derive, lack of small or medium scale industries, enriched with unexplored mineral deposits and unemployment among others. This research was therefore, aimed at discovering the possible limestone mineralized vein(s) to the tune of economic quantity within the study area, using geophysical investigation techniques which can go a long way in addressing such challenges.

The geophysical methods are very useful for limestone investigation because of the intrinsic heterogeneity of the medium (Vouillamoz et al., 2003; Van Schoor, 2002). The high contrast in resistivity values between carbonate rock, clayey and sandy materials favour the use of Electrical Resistivity (ER) and Induced Potential (IP) methods for determining the boundary between these earth materials (Zhou et al., 2000). In this survey, these ER and IP are the same method of different techniques employed in the investigated possible limestone deposits in Takowangwa. These same methods have been successfully used earlier to discover viable limestone deposit (1.9 x 10^9 t) up to economic value at Onigbedu, South-Western Nigeria (Oyedele et al., 2016).

The measurement procedure was the introduction of electrical current at the selected locality (Takowangwa area in Mokwa), whose objective is to highlight an image of the subsoil according to the section of ER. In order to confirm the location of the different contacts encountered, measurements in Induced Polarization (IP) were recorded. These ER and IP models gives detailed information on the targeted different heterogeneities existing within the prospected field. The choice of these ER and IP was based on the fact that they have been found to be the best among geophysical tools used in geological, mining prospecting, hydrological, and geotechnical investigations (Antonio et al., 2016). Resistivity and chargeability are well known geophysical parameters which are traditionally applied to limestone and other mineral explorations. The technique of their combination has promoted the use of geoelectric methods in landfill investigations (Ibrahim et al., 2019).

Therefore, the objective of this study is to probe Takowangwa area in Mokwa, Niger State, Nigeria using Electrical Resistivity (ER) and Induced Potential (IP) methods to discover possible limestone deposits.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study location (Takowangwa area) is located within the Mokwa local government of Niger State, Nigeria. The study area lies between longitudes 4°98'' and 5°04'' E, and latitudes 9°30'' and 9°44'' N (Figure 1). The area has considerable relief and thick vegetation typical of tropical rain forest setting with climate made up of two seasons – wet season (April to October) with precipitation ranging approximately from 1000 to 1,200 mm and dry season (November to March). Temperature in the area is uniformly high with a mean of 31°C while evaporation ranges between 4.2 and 8.1 mm. Relative humidity in the area is usually high and fluctuates between 70 to 80% in the rainy season but could fall below 40% in the dry season (Iroye, and Okunlola, 2019). Mokwa occupies a total land area of 4,338 km^2 with its population displaying an unprecedented dynamic progression from 98,234 in 1991 to 242,858 in 2006, with an estimated population escalation prediction of 341,200 by 2016 as at the last 2006 conducted population census by Nigeria Population Commission in 2010. The town is known for its traditional crafts production, especially the processing of hoes, cutlass, simple agricultural machineries and melon processing and marketing and some lot others. Mokwa has potential for industrial and other multipurpose domestic raw materials such as kaolin, clay, granite, limestone, silica sand, rice, yam, sorghum, millet, maize, mango, and sugarcane, etc. Mokwa has residents comprising of large tribes such as the Nupe, Yoruba, Hausa, Igbo, Gbagi and others. Its main land use is for agriculture and mostly commercial and residential buildings.

Acceptability and reliability of any ER and IP data interpretation of an area may not be tenable without a good knowledge of the local geology of such area. This originated an enquiry into the earlier literatures on the geological mappings of the area. About half of the landmass of Niger State is underlain by the Basement Complex rocks while the remaining half is occupied by the Cretaceous Sedimentary rocks of the Bida Basin (Figure 2) (Amadi et al., 2012). The study area lies within the north-central part of the Nigerian Basement complex rock which is characterized by three lithofacies: the migmatite-gneiss complex, the low grade schist belt and the older granites (Amadi et al., 2012). The earlier geological mappings revealed that the area is underlain by granite and gneiss which in most locations are undifferentiated granite-gneiss-complex (Figure 3). The Bida Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south (Figure 2). It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded

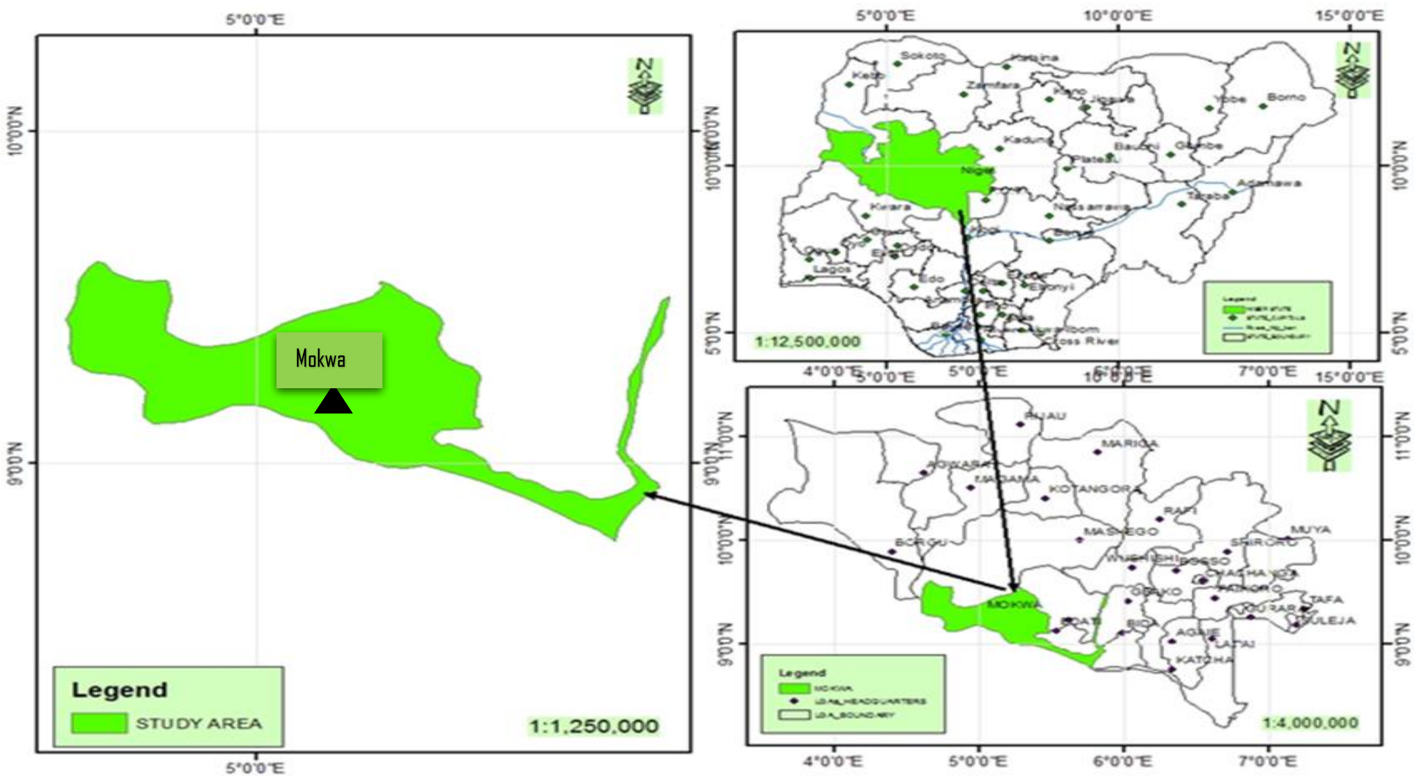


Figure 1. Map of the study area (Source: Amadi et al., 2012).

marine sediments (Amadi et al., 2012). The basin is a gentle down-warped shallow trough filled with Campanian-Maastrichtian marine to fluviatle strata believed to be more than 300 m thick (Opara et al., 2018). The basin might be regarded as north-western extension of Anambra basin, which is found in the southeast, both of which were major depocenters during the second major sedimentary cycle of southern Nigeria in the Upper Cretaceous time (Obaje et al., 2011). Often, experts working in the area have divided the basin geographically into northern and southern Bida basins probably due to rapid facies changes across the basins. The northern and southern Bida basins comprise of about 3 km thick Campanian to Maastrichtian continental to shallow marine sediments. The southern Bida Basin comprises of the basal Campanian Lokoja formation (mainly conglomerate and sandstone), Maastrichtian Patti formation (shale, claystone and sandstone) and the youngest Agbaja formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida formation (conglomerate, sandstone), Enagi formation (siltstone, claystone and sandstone) and Batati formation (Ironstone) (Abdulfatai et al., 2014).

METHODS AND INSTRUMENTATION

The vertical and lateral distribution of limestone deposits in Takowangwa area was probed using the ER and IP methods. The ABEM SAS Terrameter 4000 and its accessories was used for data capturing at maximum electrode (AB/2) spacing of 1 to 100 m. 25 Vertical Electrical Soundings (VES) were conducted using the Schlumberger electrode configuration across the five profiles covering a total area of about 20,000 square meter. The Schlumberger configuration was chosen out of several other electrode configurations for this research because it has a superior vertical resolution and depth penetration in this case are giving the same meaning as well as its ability to record higher quality data (especially IP data) than other configurations (Antonio et al., 2016). In addition, expanding the current electrodes A and B across a fixed point allows for the observation of apparent resistivity and chargeability values at that fixed point and also at increasing depths. Its signal to noise ratio improvement feature also fetches it another very important excelling score against others.

In the ER method, an artificial electrical current was injected into the ground through two current electrodes (A and B) and the potential difference generated across the two other potential electrodes (M and N) within the two current electrodes were measured (Antonio et al., 2016). The movement of the electrical current (measured in Ampere) via the electrodes A and B results in a potential difference (ΔV) (measured in Volts) across M and N, thus allowing the determination of the apparent resistivity by Terrameter using equation (1), and thereafter changing the Terrameter into IP mode enabled the determination and

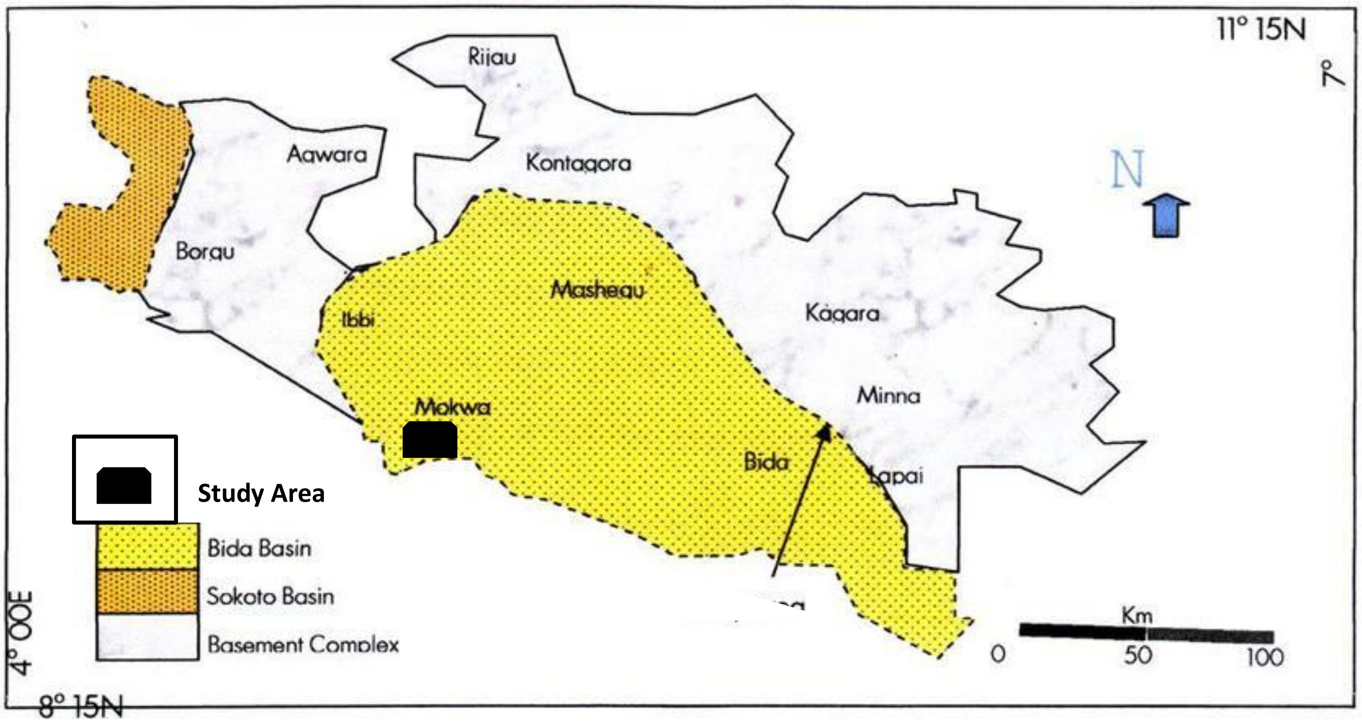


Figure 2. Geological Map of Niger State basement complex and sedimentary basins (Amadi et al., 2012).

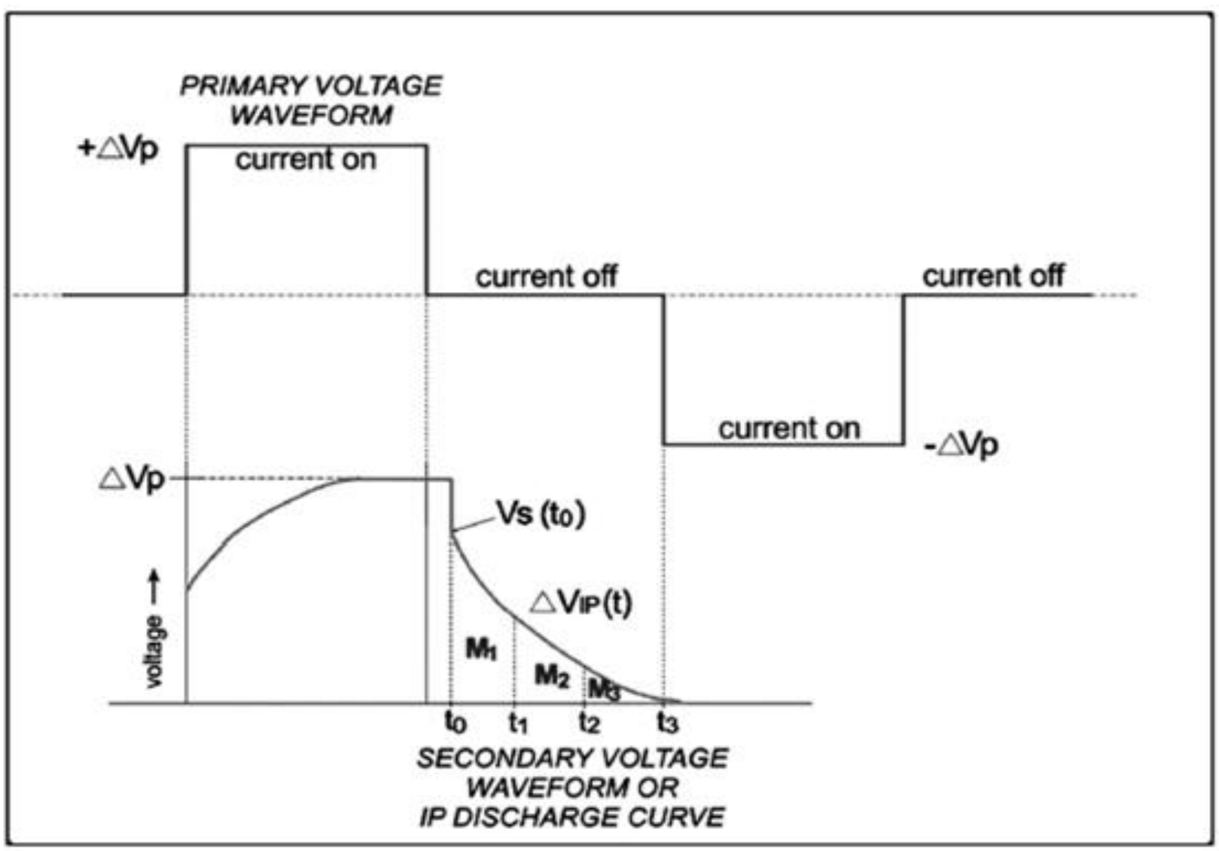


Figure 3. IP decay curve - Time domain (Antonio et al., 2016).

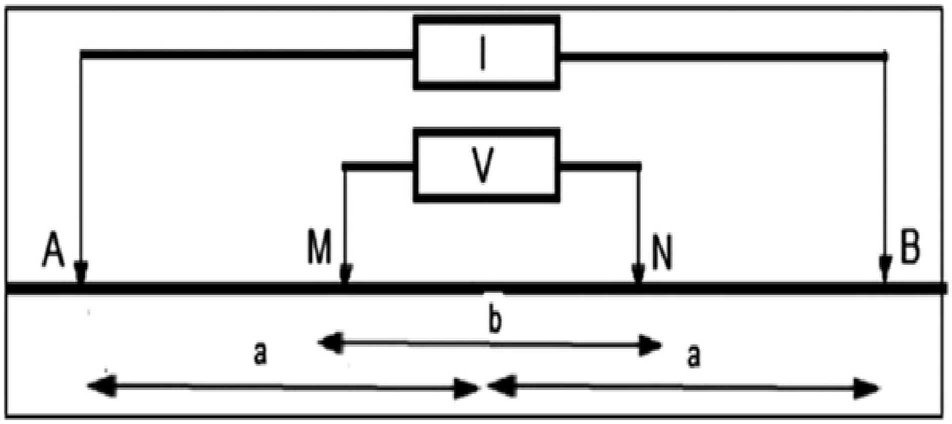


Figure 4. Arrangement in the field - VES Schlumberger array (Antonio et al., 2016).

recording of chargeability measured (Equation 3).

$$\rho_a = K\frac{\Delta V}{I}(ohm.m) \quad (1)$$

In the same process, the chargeability determination in the concept of IP was stimulated also by injecting electric current into ground for a giving time through same current electrodes and then switched off after which a delayed response to voltage in natural materials (Telford et al., 1990) was observed. As electrical current flow through the current electrodes A and B on the surface, a primary potential difference ΔV_p is established. It has been shown that (ΔV_p) varies with time and acquires the shape of a curve (Equation 2) (Telford et al., 1990).

$$\Delta VI_P = f(t). \quad (2)$$

This curve connects the steady-state asymptote ΔV_p with the zero asymptote after switching off the current. The concept of this method is based on the amplitude of a ΔVI_P (t) value and is related to the geological feature's greater or lesser capacity to polarize (Figure 3).

The decay curve can be studied as a whole or just sampled at some intervals of time (Telford et al., 1990). The chargeability recorded in time domain is expressed in milliseconds (ms), it is a measured area under the decay curve normalized by primary voltage V_p, using equation 3 (Telford et al., 1990).

$$M = \frac{1}{V_P}\int_{t1}^{t2} \Delta V_{IP}(t)dtmV / V^{2} \quad (3)$$

The concept of IP is usually attributed to either of the two factors; Electrode Polarization (EP) and Membrane Polarization (MP). In this particular situation, MP was what prevailed occurring in rocks with a low metal element contents. The variations in the clay contents within different layers of soil and bedrock were responsible for the various IP responses and therefore facilitated the delineation of those layers of interest (limestone deposits). The discovery of these different subsurface layers of interest was achieved through the interpretations of the identified variations in resistivity and IP values obtained as well as their correlations with the previous standard established subsurface geological features' parameters. During the VES field procedure, a successive resistivity and chargeability measurements were made with the same type of configuration (Figure 4).

RESULTS AND DISCUSSIONS

This research work showed Some level of accuracy in results obtained and economic convenience of ER and IP as also revealed in the works of Badmus and Olatinsu (2009) and Ehinola et al. (2012). The results of the VES soundings at each of the five profiles (apparent resistivity values) obtained from the field were plotted against half the current electrode spacing (AB/2) using computer iteration techniques to obtain modelled parameters for quantitative interpretation. The pseudo-sections and chargeability cross-section obtained from the computer software (IP2WIN) samples of which were presented in (Figure 5), was employed in interpretation of both the VES and the IP response. Three geoelectric layers with limestone deposits areas with depth variations and thickness were revealed within the profiles probed and summarised (Table 1).

Profile 1 reveals the presence of limestone litho-face mainly across VES points 4 and 5 as exhibited by low resistivity and chargeability values across the first and second geoelectric layers (Figure 6). The resistivity ranges from 77 to 257 Ωm with its corresponding chargeability ranged from 2.01 to 6.68 msec. The depth ranged between 3.12 and 28.99 m over a thickness of 25.87 m as shown in Table 1. The second profile also reveals the presence of limestone deposits at VES points 1, 2, 3 and 5 as

Table 1. Apparent Resistivity ranges with thickness, depth values and possible limestone deposits locations across profiles 1 – 5 at Takowangwa area, Mokwa.

Profiles	Layers	Resistivity range (Ωm)	Chargeability range (msec.)	Profile anomaly depth range (meter)	Anomaly thickness (meter)	Possible rock Interpretation
1	1 2 3	77 – 96 78.5 – 257 425 – 1504	2.01 – 2.49 2.04 – 6.68 11.05 – 39.10	3.12 – 28.99	25.87	Clay, Limestone, Sandstone
2	1 2 3	22.89 – 125 143 – 215.6 1282 – 1816	0.60 – 3.25 3.72 – 5.59 33.33 – 47.23	3.21 – 24.69	21.48	Clay, Limestone, Sandstone
3	1 2 3	65 – 185.3 155 – 237.9 1107 – 2012	1.69 – 4.82 4.03 – 6.19 28.78 – 52.31	3.56 – 50.23	48.67	Clay, Limestone, Sandstone
4	1 2 3	43 – 131 76 – 121 908 – 2012	1.12 – 3.41 2.00 – 3.12 23.61 – 52.31	4.81 – 25.50	20.69	Clay, Limestone, Sandstone
5	1 2 3	85 – 157 105 – 197 1451 – 1592	2.21 – 4.08 2.73 – 5.12 37.73 – 41.39	5.04 – 91.57	86.53	Clay, Limestone, Sandstone

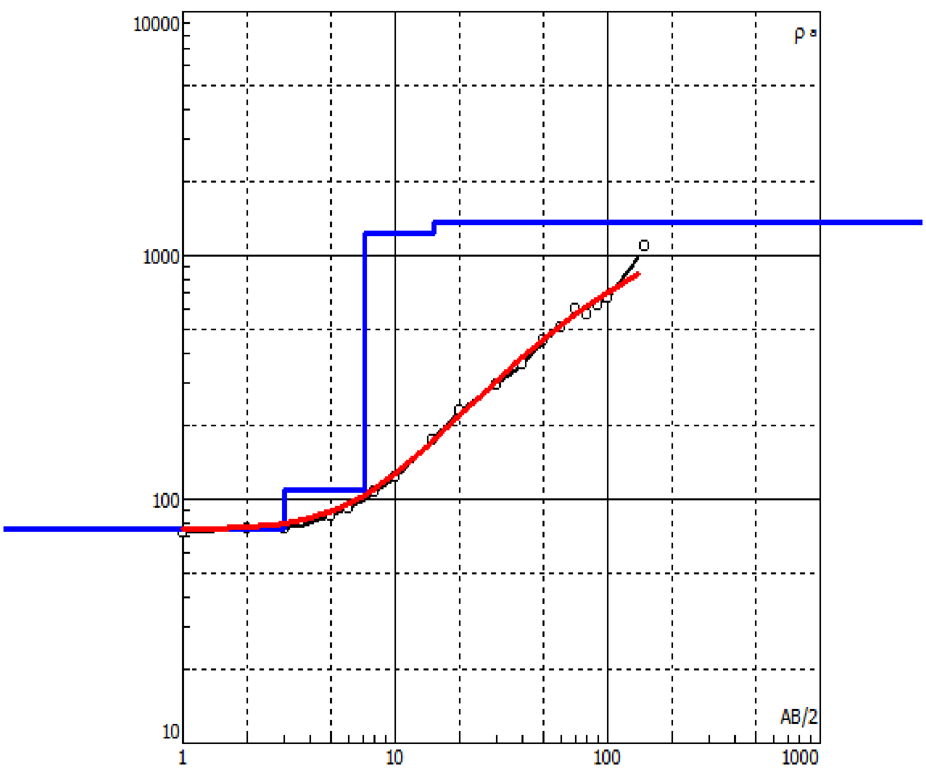


Figure 5. Computer modelling for some selected sounded stations (VES points).

debited from the low resistivity and chargeability values across the first and second geoelectric layers (Figure 7). The resistivity ranges from 22.89 to 215.60 Ωm with its corresponding chargeability ranged from 0.60 to 5.59 msec.

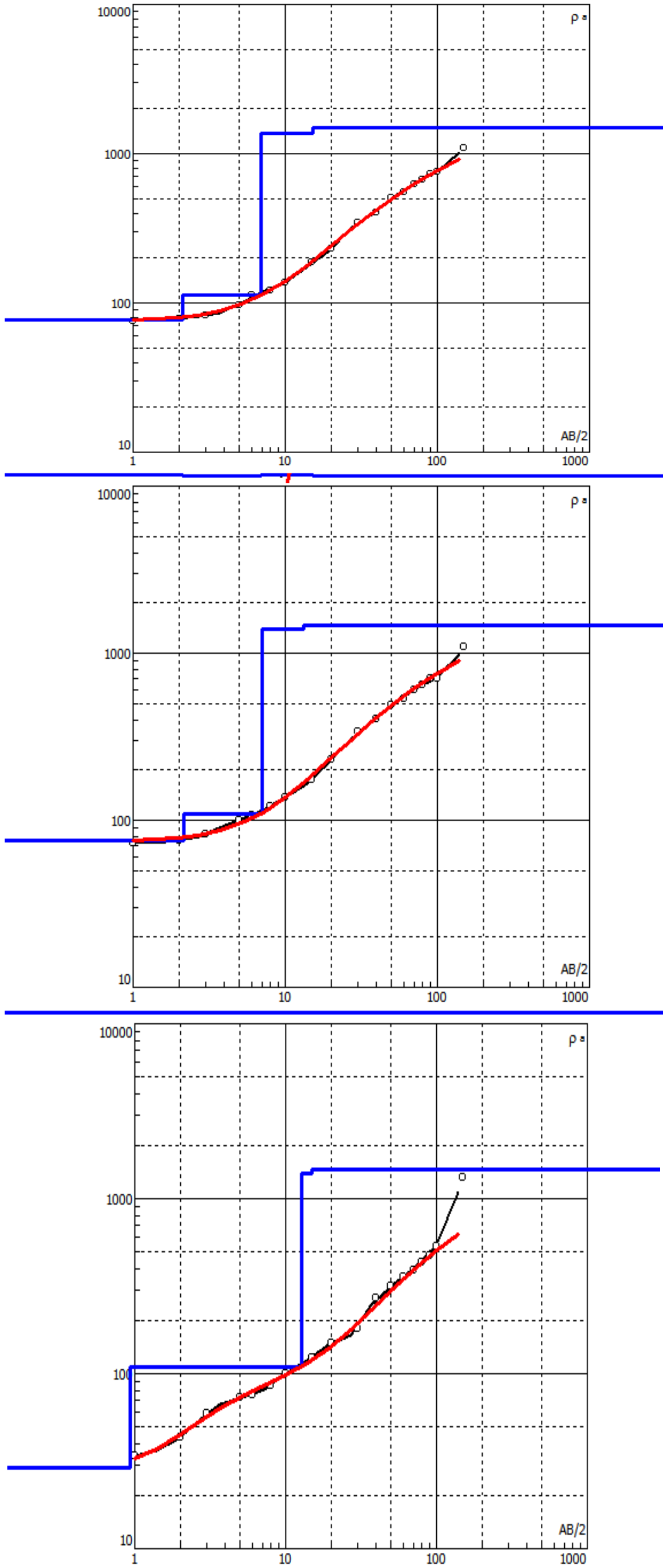
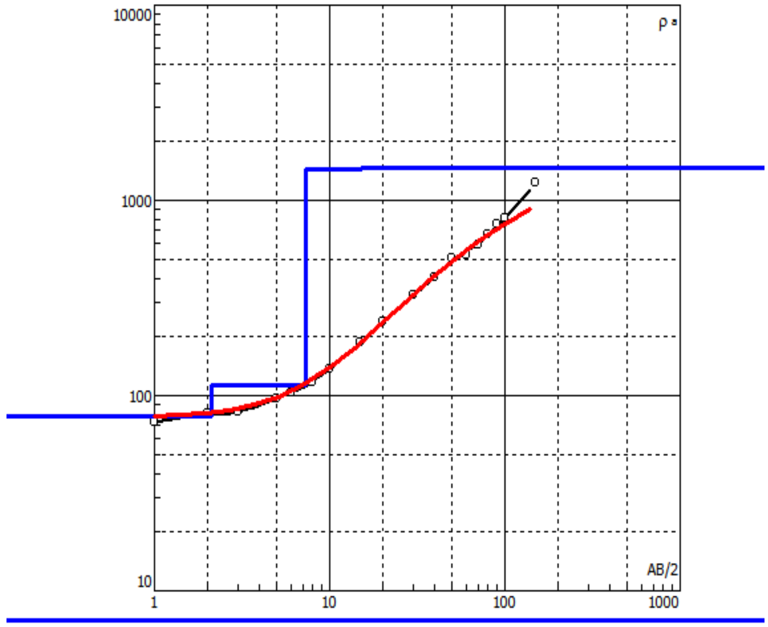


Figure 5. Contd.



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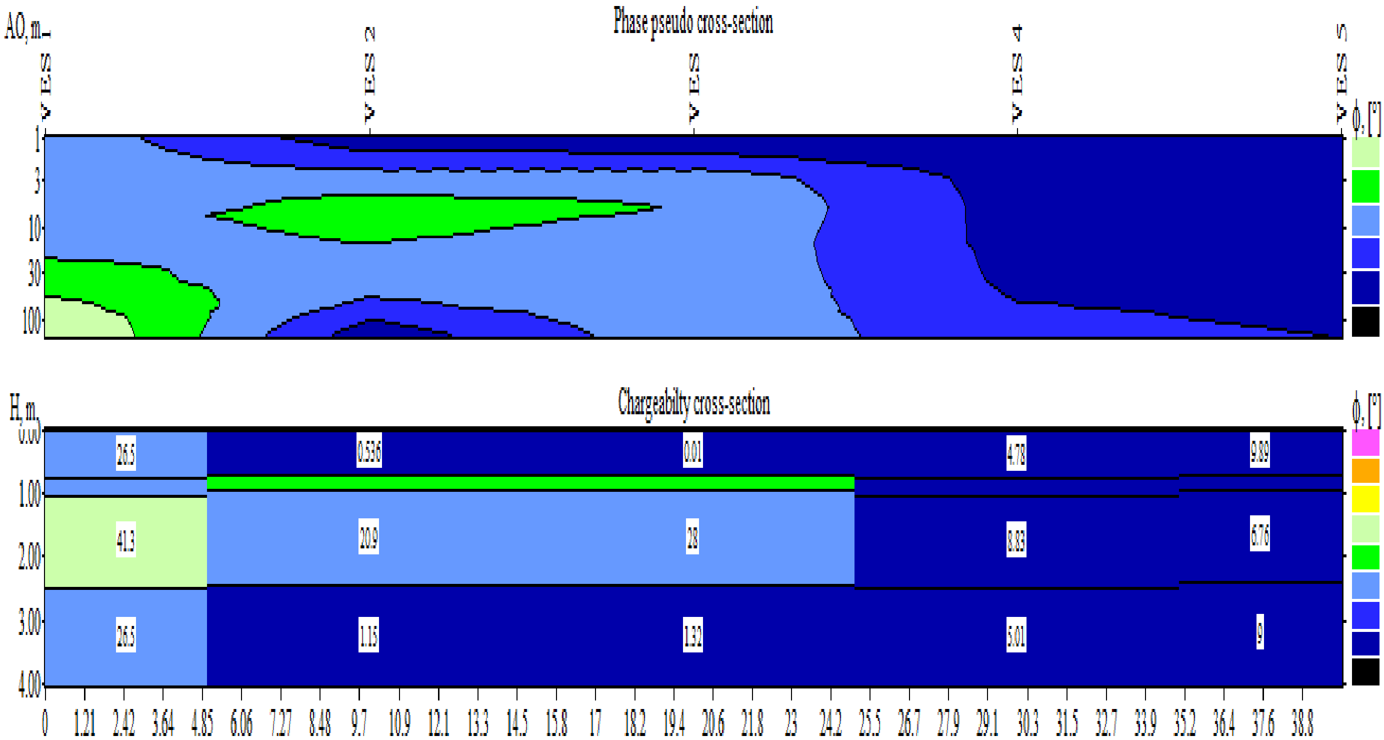

Figure 6. Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 1 at Takowangwa area, Mokwa.

The depth ranged between 3.21 and 24.69 m over a thickness of 21.48 m (Table 1).

Profile 3 also revealed the existence of limestone deposits across VES points 1, 4 and 5 as also characterised by low resistivity and chargeability values across the first and second geoelectric layers (Figure 8). The resistivity ranges

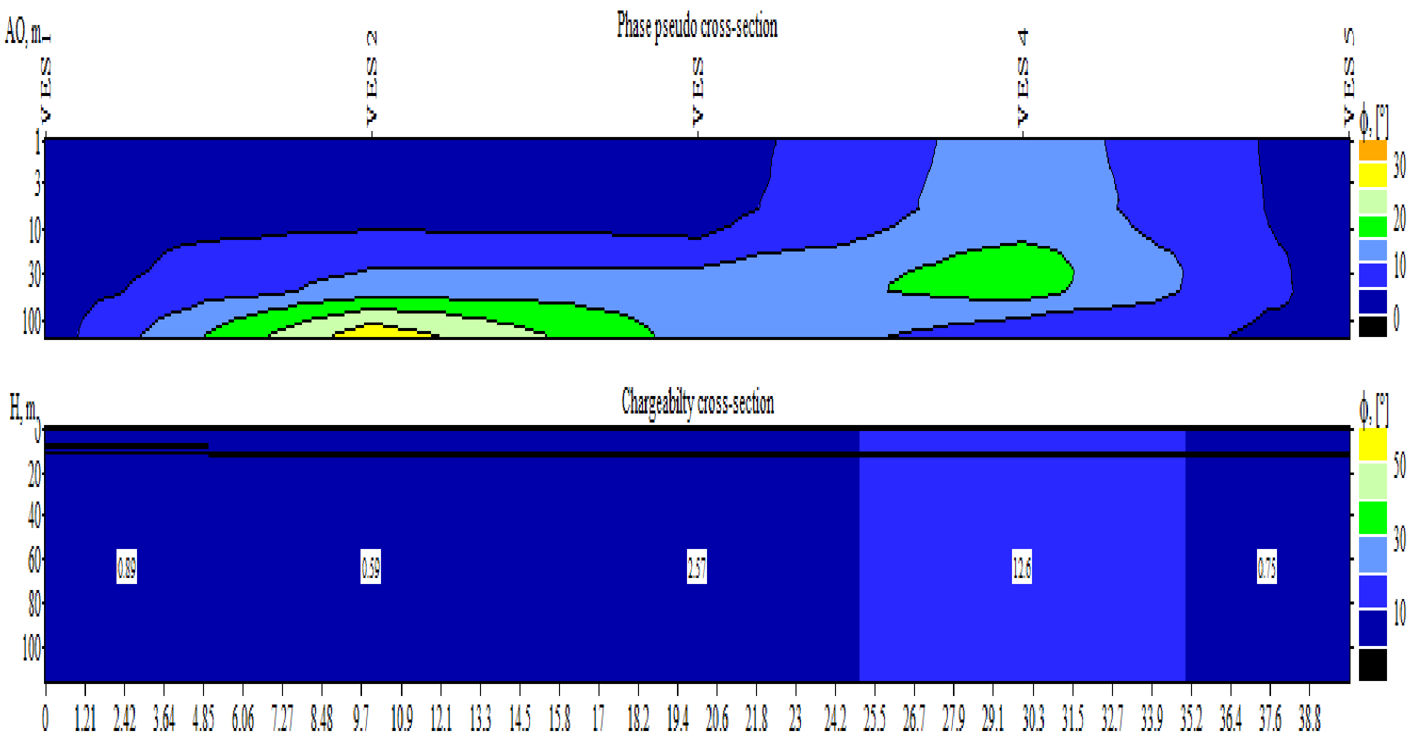

Figure 7. Phase pseudo cross-section and chargeability cross-section at VES points 1-5 along profile 2 at Takowangwa area, Mokwa.

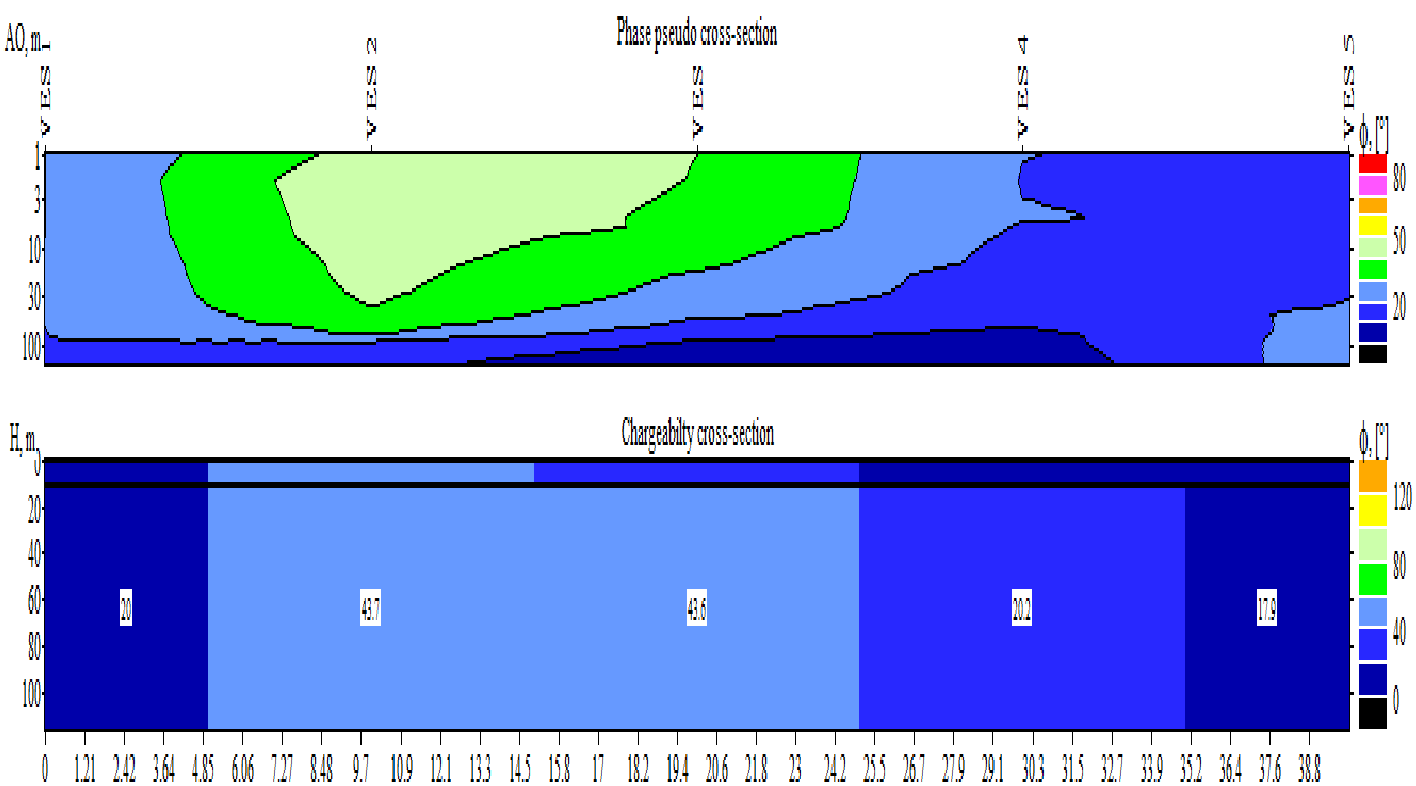

Figure 8. Phase pseudo cross-section and chargeability cross-section at VES points 1-5 along profile 3 at Takowangwa area, Mokwa.

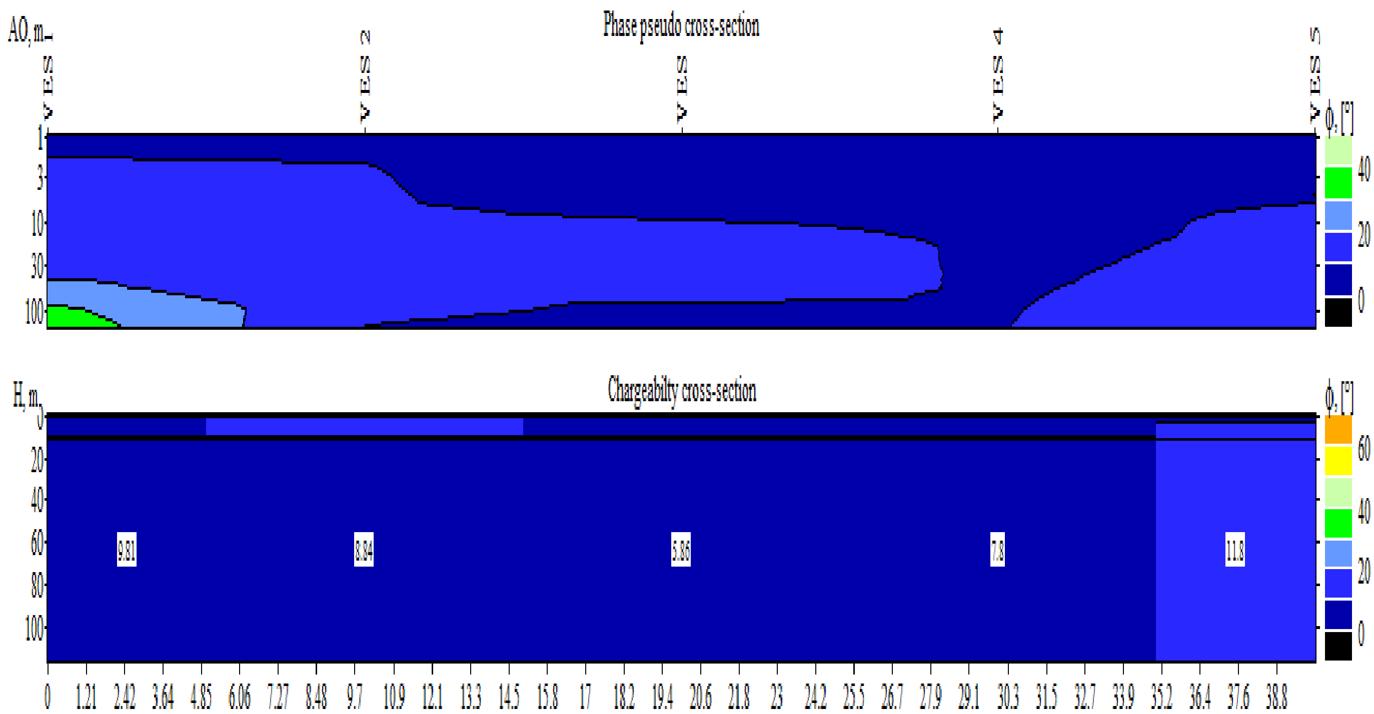

Figure 9. Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 4 at Takowangwa area, Mokwa.

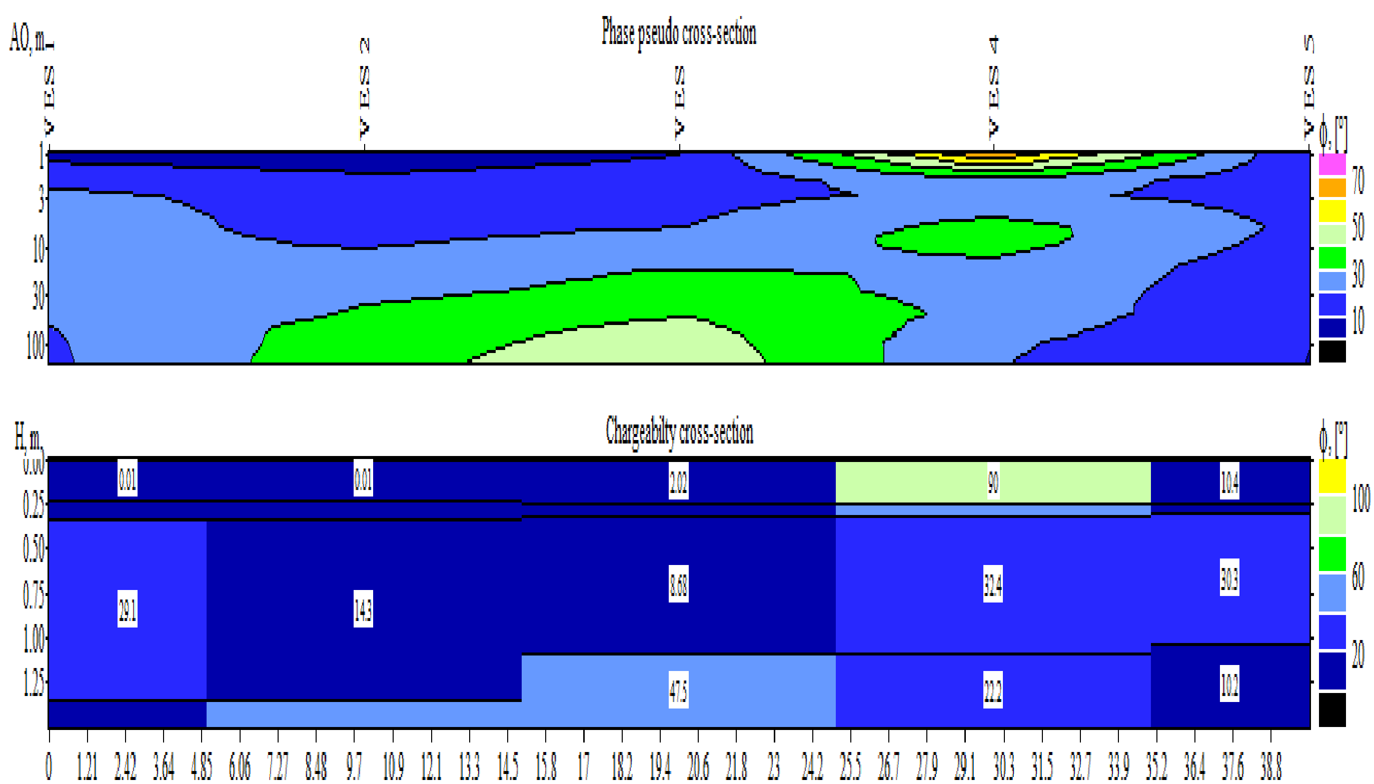

Figure 10. Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 5 at Takowangwa area, Mokwa.

from 65 to 237.90 Ωm with its corresponding chargeability ranged from 1.69 to 6.19 msec. The depth ranged between 3.56 and 50.23 m over a thickness of 48.67 m (Table 1). The discovery in Profile 4 was also the occurrence of limestone deposits across VES points 2, 3, 4 and 5 as occasioned by the low resistivity and chargeability values across the first and second geoelectric layers too (Figure 9). The resistivity ranges from 43 to 121 Ωm with its corresponding chargeability ranged from 1.12 to 3.12 msec. The depth range was between 4.81 and 25.50 m over a thickness of 20.69 m (Table 1).

The largest amount of limestone deposits with thickness of up to 86.53 m was discovered in Profile 5 across VES points 1, 2, 3 and 5 (Figure 10). This was also inferred from the delineated low resistivity and chargeability values displayed across the first and second geoelectric layers within the profile. The resistivity ranges from 85 to 197 Ωm with its corresponding chargeability ranged from 2.21 to 5.12 msec. with a depth ranged from 5.04 to 91.57 m (Table 1).

Limestone reserve estimation (LRE)

The limestone deposit reserve estimation for the probed location in Takowangwa area of Mokwa for which the dimension was 100 m by 200 m, covering an area of 20,000 m^2 was determined using equation 4 (Oyedele et al., 2016). The average thickness of limestone deposits was estimated at 40.65 m and limestone density is 2.5 g/m^3 (Telford et al., 1990).

$$\text{LRE} = \text{Area x Thickness x Density} \quad (4)$$

20,000 m^2 x 40.65 m x 2.5 $g/m^3 \approx 2.0 \times 10^6$ t.

Conclusions and Recommendations

This research work has revealed that Takowangwa area exhibited occurrences of limestone deposits of much economical interest which dominated all the five profiles probed. The highest measured width of veins carrying limestones deposits thickness of about 86.53 m was encountered in a depth range between 5.04 and 91.57 m at Profile 5 across VES points 1, 2, 3 and 5. This occurrence of vast limestone deposits over an area which is characterized by flat topography with plain land covers can be of very much economic importance in mining and industrial purposes for the communities within the area and beyond. The geophysical surveyed area was just about 20,000 m^2 only, for which this huge amount of limestone deposits (2.0×10^6 t) was estimated with a clear indication of the possibility of its limestone richness extension even beyond the study area. This study thus established that the probed area (Takowangwa area) is rich in limestone deposits which could be economically exploited. Therefore, in order to have enough and accurate prediction in terms of its qualitative and quantitative economic aspects, an integrated geological and geophysical studies as well as well drilling of borehole (s) is recommended.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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