Full Length Research Paper

Characteristics of self-potential anomalies in Abakaliki Lower Benue trough of Nigeria

Chukwu GU

Department of Physics, Michael Okpara University of Agriculture, Umudike, P.M.B. 7267, Umuahia, Nigeria
Email: chukwug@yahoo.com; Phone: +2347034394600

Abstract

Abakaliki area occupies prominent place in the geological and geophysical history of Nigeria. This is because of the tectonic, evolutionary and structural developments associated with the zone. Abakaliki high has been noted for subsurface mineralization processes occasioned by naturally rich and well-endowed minerals in place. The Cretaceous sediments around Abakaliki (the oldest sediments in southeastern Nigeria) are folded and occur along the Benue Trough and Abakaliki Trough given rise to alternate anticlines and synclines. Self potential (SP) survey was carried out to investigate the characteristics of SP anomalies in these poorly bedded sandy shales of Abakaliki. Results show that mainly high negative SP values of magnitude between -600 mV and -800 mV were observed suggestive of lead-zinc mineralization. The overall potential anomaly characteristics in the area are not even, they vary from place to place both in magnitudes and in signs - positive and negative.

Keywords: Self potential anomaly, Abakaliki, shale, mineral, sediments, Benue Trough.

INTRODUCTION

Abakaliki is the state capital of Ebonyi State in SE Nigeria. Geologically, Abakaliki is known as uplift (Figure 1). This originated during the Coniacian when beds of rapidly changing lithofacies, including shales, limestones and an increasing amount of sandstone were deposited in southeastern Nigeria (Kogbe, 1976). The rapid facies change has been interpreted as being the first indication of the onset of the active tectonic phase of folding, faulting and uplifting which ended up in the Santonian.

The Santonian movements gave rise to the folding and uplifting of the northeast striking Abakaliki anticlinorium which in turn led to exposure and erosion of the Coniacian, Turonian and Albian formations (Murat, 1970; Short and Stauble, 1967). As a result of this uplift, two depressions were formed flanking the Abakaliki High. The depressions are the Anambra basin in the northwestern flank and the Afikpo syncline in the southeastern flank. The main foci of deposition during the Campanian to Palaeocene rest on these two depressions (Figure 2).

Owing to the geologic importance and relevance of this area in the geology of Nigeria with particular reference to the way and manner the rocks were formed, it is believed that there is accumulation of certain minerals within the crustal layer beneath. Hence, as a result of the contemporaneous, geothermal and tectonostratigraphic processes that resulted to the uplift system, mineralization process set in. It is

this mineralization process that causes characteristic spontaneous polarization potential anomalies within the subsurface (Chukwu, 1997; Chukwu et al., 2001).

SP anomaly survey, a geoelectrical method of exploration was applied to investigate the characteristics of the self-potential anomalies within the study area. These characteristics when established will be used to ascertain the mineral potentials, mineralogical trends as well as knowing the depositional characteristics of the area within the failed rift system of Abakaliki.

When two electrodes which are non-polarizable are inserted into the earth within a reasonable separation, a potential drop is observed between these two electrodes (Beck, 1981; Dobrin and Savit, 1988; Corwin and Hoover, 1978). This observation is mostly predominant if sulphide orebodies mainly those that contain pyrite (FeS_2) and pyrrhotite (FeS) are present. These two mineral bodies are well-known for producing the most consistent and strong SP anomalies (Beck, 1981).

Other minerals producing fewer anomalies include chalcopyrite ($CuFeS_2$), calchocite (Cu_2S), covellite (CuS) and graphite (C). Magnetite ore and anthracite coal also produce some potential drop. SP anomaly is highly dependent on the geology of the mapping area and hence, the geology of a particular location usually
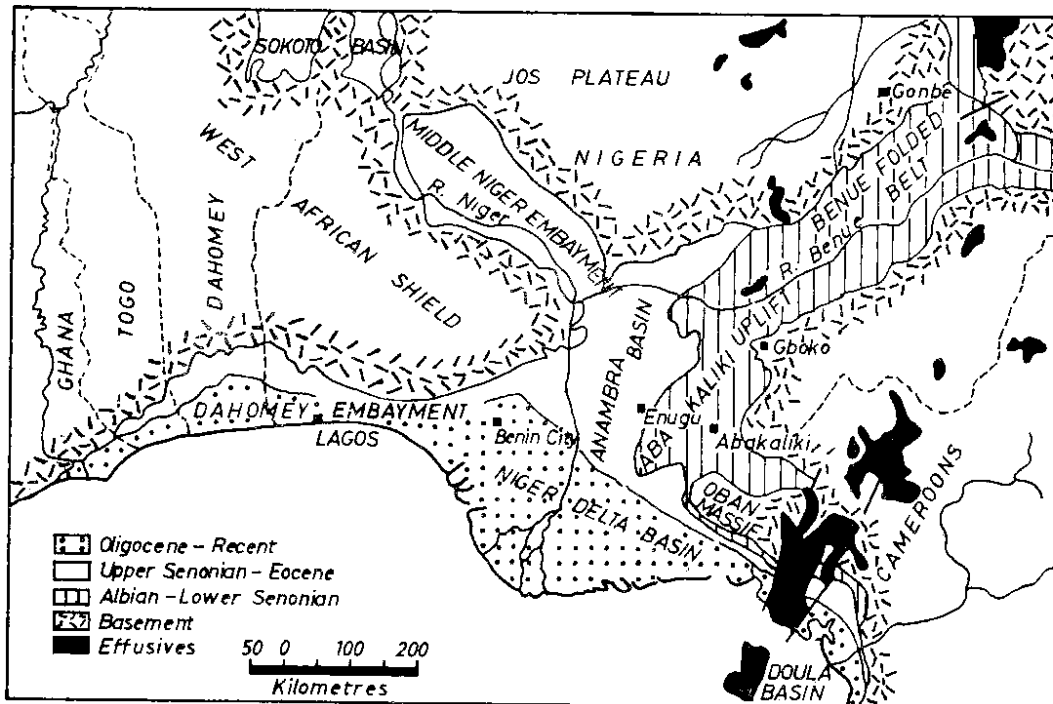
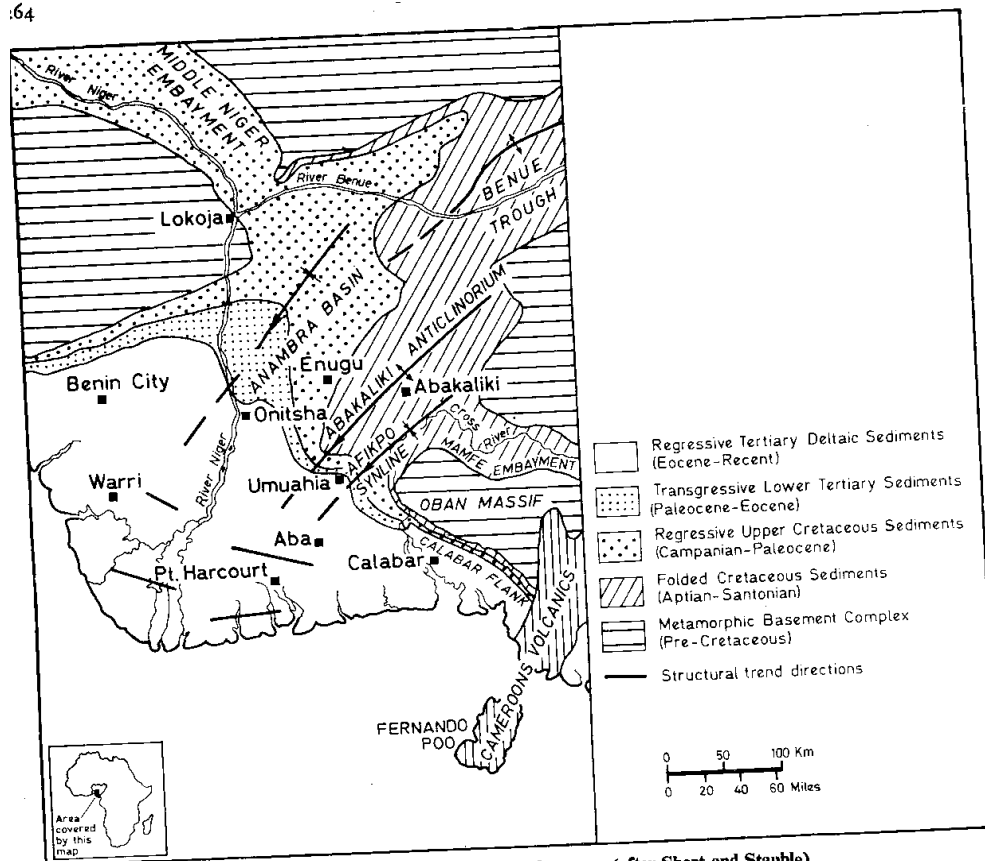**Figure 1.**Geological sketch map of southern Nigeria

Figure 2. Structural units of southern Nigeria with Benue Trough/Abakaliki Anticlinorium
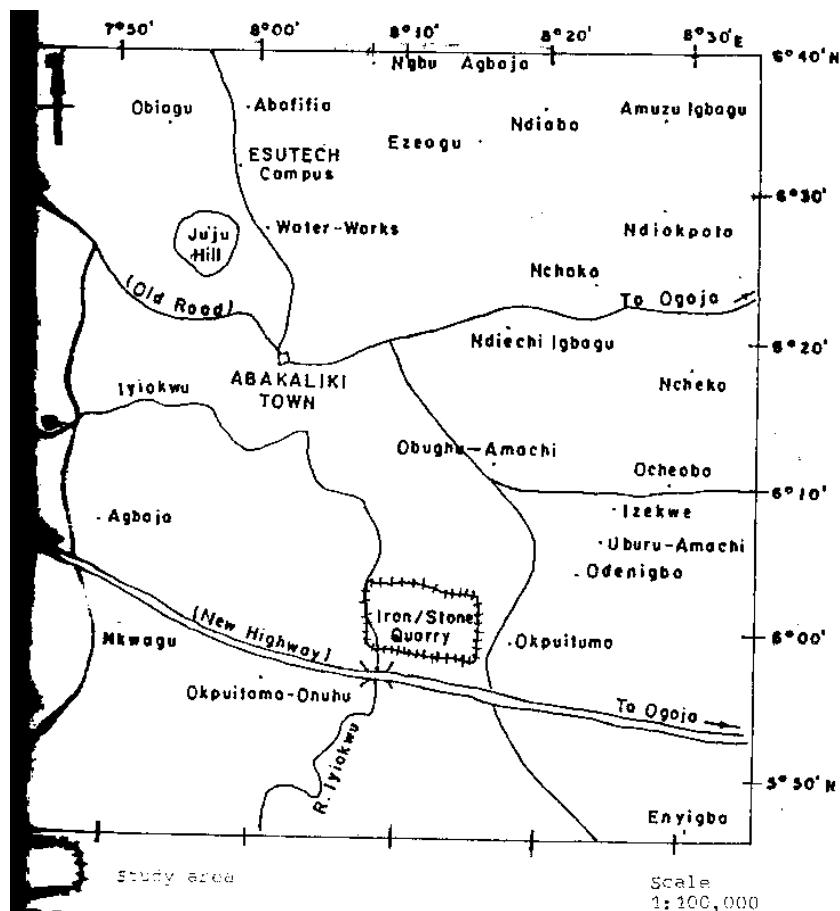
Figure 3. Location of the study area

provides clue to the causative factor of the SP anomaly observed (Chukwu, 2001).

The location of the survey area is within Latitude $5^0\,55^{'}$ – $6^0\,05'$N and Longitude $8^0\,06' - 8^0\,18'$E (Figure 3) which is in the southeastern part of Nigeria (GSN, 1955). Abakaliki area is underlain by rocks of Lower Cretaceous age forming one of the sedimentary basins in Nigeria.

MATERIALS AND METHODS

Measuring Instruments

The instrument for acquiring field data comprises of two non-polarizable electrodes, two reels of long insulted cables and a very sensitive high input impedance d.c. (centre-zero) millivoltmeter of range -5000 mV and +5000 mV. This meter is used so that both negative and positive SP values would be measured alike without necessarily reversing the terminals. These components are shown in Figure 4. The total circuit impedance due to all the components was 180 ohms when measured with an Avometer.

Field Procedure

There are two fundamental field procedures that are applied for SP measurements. These are direct potential measurement method and potential gradient method.

i)　　Direct potential measurement: In the direct potential measurement procedure, SP data are acquired using the instrument in Figure 4. One electrode is fixed at a point on the ground surface while the other electrode is moved from point to point within the region. This could be done either along a profile or within a grid (Figure 5). The separation between the two electrodes keeps varying.

ii)　　Potential gradient method: Here (Figure 6) the two electrodes separated by a constant distance are moved together along line of traverse (leap frog method). The potential drop at each station is measured and the gradient at such a point determined. Normally, the potential gradient at any point is given as in equation (1).

Potential Gradient,

$$V = \frac{\Delta V}{X} \quad . . \quad (1)$$

Where V is potential in mV and X is electrode separation (30m).
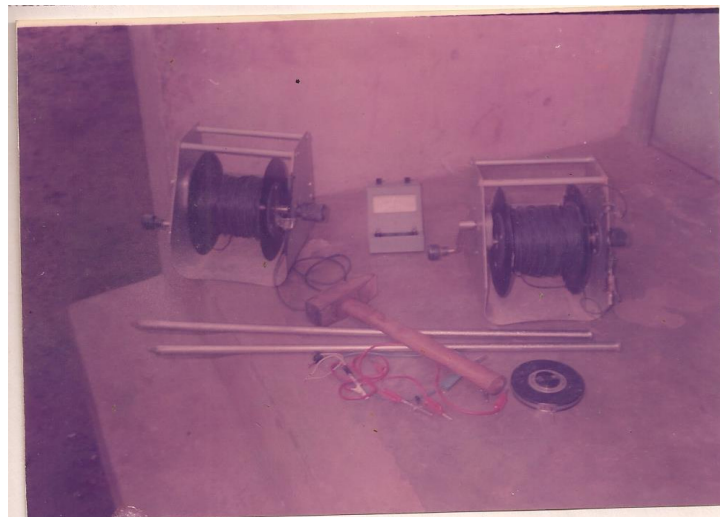
Figure 4. Measuring equipment used
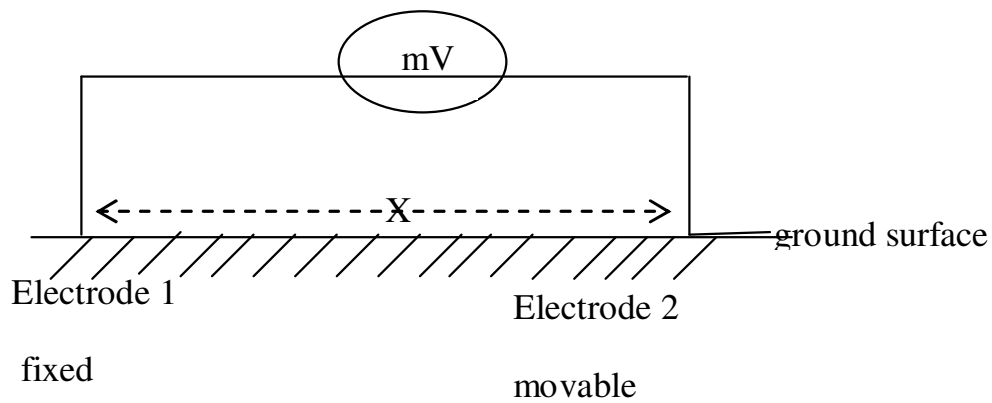
Figure 5. Direct potential measurement layout
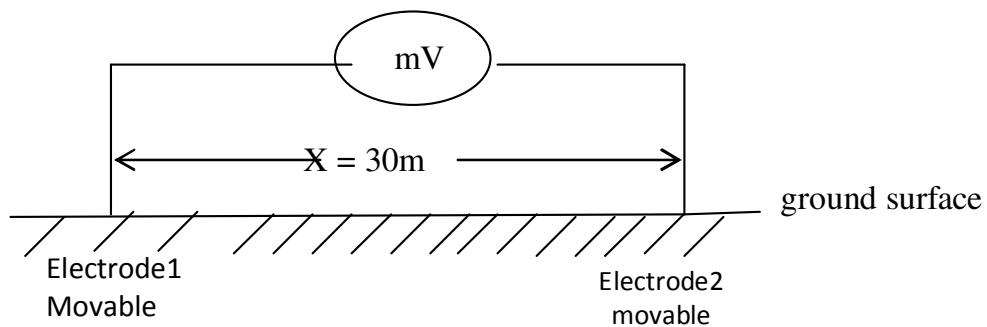
Figure 6. Potential gradient mapping layout (Leap frog method)

SP Data Acquisition

From direct potential method, SP anomaly data were obtained through direct measurements in the field grid shown in Figure 7. There is a progressive increase by twenty (20) metres all through the measurements and there are five main locations within the grid from where all measurements started going clockwise. Fifteen readings are taken in a profile making a total of sixty measurements in a location. At times readings from a
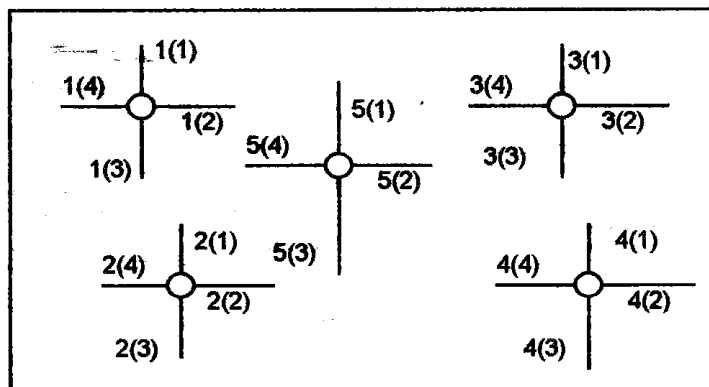
Figure 7. Measuring grid (not to scale)

Table 1. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-1200	
2	40	-1900	
3	60	-1000	
4	80	-700	
5	100	-1200	
6	120	-1300	
7	140	-1700	
8	160	-600	
9	180	-600	
10	200	-1000	
11	220	-1200	
12	240	-1300	
13	260	-1100	
14	280	-1200	
15	300	-1200	

particular location could over-lap into another location. Some of the SP field data recorded is shown in Tables 1-10.

Another set of SP anomaly data was obtained using potential gradient method otherwise called "Leap frog" method along the Enugu-Abakaliki highway (about 2.6 km) heading towards Ogoja in Cross-River State. This method involved a constant electrode-electrode separation of thirty (30) metres all along and then the potential gradients in millivolts per 30 metres computed using equation (1). The potential gradient data are shown in Table 11.

DATA ANALYSES, INTERPRETATION AND RESULT

Contouring and profiling

With the SP anomaly data in Tables 1-10; contouring was done over the mapped area, constructing an iso-potential contour map with contour interval of 100 mV. Three line sections AA´, BB´ and CC´ were taken across the iso-potential contour map (Figure 8).

Points A and C are in the southwestern part of the study area while point B is in southeastern part. The choice of these line profiles is considered by the presence of the major negative closures (-600 mV and -700 mV) located along profile AA´ whose centres are about 880 metres apart (Figure 9).

These anomalies generally trend in the direction N-60-E approximately with the southwestern anomaly having a larger lateral extent than the north-central anomaly. Two smaller anomalies of equal magnitude (-500 mV) are located at the north-western and north-eastern portions of the area of study. They are located along profiles BB´ and CC´. The north-eastern anomaly trends, north-south while, the north-western anomaly is approximately east-west in orientation.

Table 2. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-100	
2	40	-600	
3	60	-900	
4	80	-500	
5	100	-600	
6	120	-300	
7	140	-200	
8	160	-200	
9	180	-100	
10	200	-100	
11	220	-100	
12	240	-100	
13	260	-100	
14	280	-100	
15	300	-100	

Table 3.SP Field Data

	X (m)	ΔV (mv)	Remark
1	20	-200	
2	40	-400	
3	60	-300	
4	80	-500	
5	100	-500	
6	120	-300	
7	140	-100	
8	160	-400	
9	180	-200	
10	200	-500	
11	220	-300	
12	240	-500	
13	260	-400	
14	280	-400	
15	300	-400	

Table 4. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-100	
2	40	-300	
3	60	-500	
4	80	-200	
5	100	-500	
6	120	-100	
7	140	-100	
8	160	-200	
9	180	-100	
10	200	-0	
11	220	-100	
12	240	-100	
13	260	-100	
14	280	-100	
15	300	-100	

Table 5. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-600	
2	40	-500	
3	60	-700	
4	80	-600	Gentle slope
5	100	-400	
6	120	-4200	
7	140	-5000	
8	160	-4300	Spring
9	180	-4000	
10	200	-4000	
11	220	-3100	
12	240	-3000	Steepy slope
13	260	-2300	
14	280	-2300	
15	300	-2300	

Table 6. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-1100	
2	40	-800	
3	60	-600	
4	80	-400	
5	100	-500	
6	120	-800	
7	140	-3600	
8	160	-2400	
9	180	-2000	
10	200	-0	Depression
11	220	-1400	
12	240	-1600	
13	260	-2100	
14	280	-2100	
15	300	-2000	

Table 7. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-1200	
2	40	-900	
3	60	-800	
4	80	-600	
5	100	-500	
6	120	-800	
7	140	-900	
8	160	-600	
9	180	-600	
10	200	-600	
11	220	-400	
12	240	-400	
13	260	-100	
14	280	----	Man-made
15	300	----	Lake

Table 8. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-200	
2	40	-200	
3	60	-300	
4	80	-400	
5	100	-400	
6	120	-500	
7	140	-500	
8	160	-600	
9	180	-600	
10	200	-600	
11	220	-700	
12	240	-700	
13	260	-700	
14	280	-700	
15	300	-700	

Table 9. Self-Potetial Field Data

	X (m)	ΔV (mv)	Remark
1	20	-100	
2	40	-0	
3	60	-100	
4	80	-200	
5	100	-200	
6	120	-200	
7	140	-300	
8	160	-300	
9	180	-200	
10	200	-200	
11	220	-200	
12	240	-300	
13	260	-200	
14	280	-300	
15	300	----	

Table 10. Self-Potential Field Data

	X (m)	ΔV (mv)	Remark
1	20	-400	
2	40	-300	
3	60	-300	
4	80	-300	
5	100	-300	
6	120	-200	
7	140	-300	
8	160	-200	
9	180	-200	
10	200	-200	
11	220	-300	
12	240	-300	
13	260	-300	
14	280	-300	
15	300	-300	

Table 11. Potential Gradient Data

	Distance X (m)	V (mv)	V/X (mv/30m)	Remark
1	30	-100	3.3	
2	60	+100	+3.3	
3	90	+100	+3.3	
4	120	0	0.0	
5	150	-200	-6.7	
6	180	----	River	Slope
7	210	-200	-6.7	
8	240	-100	-3.3	
9	270	-100	-3.3	
10	300	-300	-10.0	River Iyiokwu-swift and turbulent motion.
11	330	+200	+6.7	Rocky banks and river bed apparently
12	360	-200	-6.7	resting on crystalline basement.
13	390	+100	+3.3	
14	420	-100	-3.3	
15	450	-100	-3.3	Slope
16	480	+200	+6.7.	
17	510	+100	+3.3	Gentle
18	540	+100	+3.3	
19	570	+100.	+3.3.	
20	600	+100	+3.3	
21	630	-100.	-3.3	Fissil shale depicted by road
22	660	-100	-3.3.	construction marks
23	690	-100.	-3.3	
24	720	+200	+6.7.	
25	750	+100.	+3.3	
26	780	+300	+10.0.	
27	810	-100.	-3.3	
28	840	-200.	-6.7.	
29	870	+100	+3.3	
30	900	+200.	+6.7.	
31	930	+200	+6.7	Culvet
32	960	+400	+13.3.	
33	990	+800	+26.7.	
34	1020	-200.	-6.7.	
35	1050	-500	-16.7.	
36	1080	-1300	-43.3.	
37	1110	-600.	-20.0.	
38	1140	+600	+20.0	
39	1170	+1800	+60.0	
40	1200	-760	+58.5	
41	1230	+1700	+56.7	
42	1260	+700	+23.3	
43	1290	+400	+13.3	
44	1320	+1000	+3.3	
45	1350	+200	+6.7	
46	1380	+100	+3.3	
47	1410	-100	-3.3	
48	1440	-200	-6.7	
49	1470	+100	+3.3	
50	1500	+200	+6.7	
51	1530	+300	+10.0	
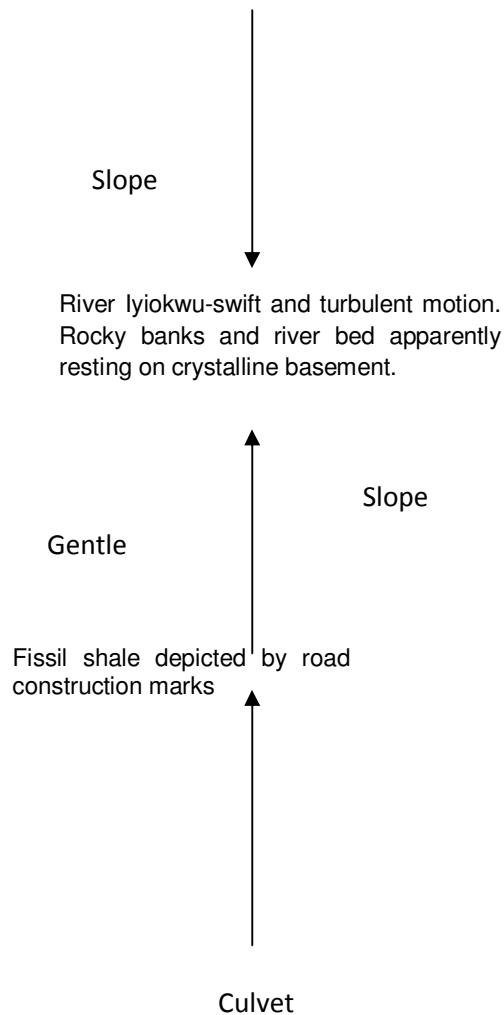
Table 11. Continuation

52	1560	+200	+6.7
53	1590	0	0.0
54	1620	-100	-3.3
55	1650	0	0.0
56	1680	+100	+3.3
57	1710	+200	+6.7
58	1740	+100	+3.3
59	1770	+100	+3.3
60	1800	+150	+5.0
61	1830	+150	+5.07
62	1860	-100	-3.3
63	1890	+100	+3.3
64	1920	-200	-6.7
65	1950	+100	+3.3
66	1980	0	0.0
67	2010	-100	0 3.3
68	2040	-100	-3.3.
69	2070	+100	+3.3
70	2100	-100	-3.3.
71	2130	0	0.0
72	2160	-200	-6.7.
73	2190	+200	+6.7
74	2220	-100	-3.3.
75	2250	0	0.0
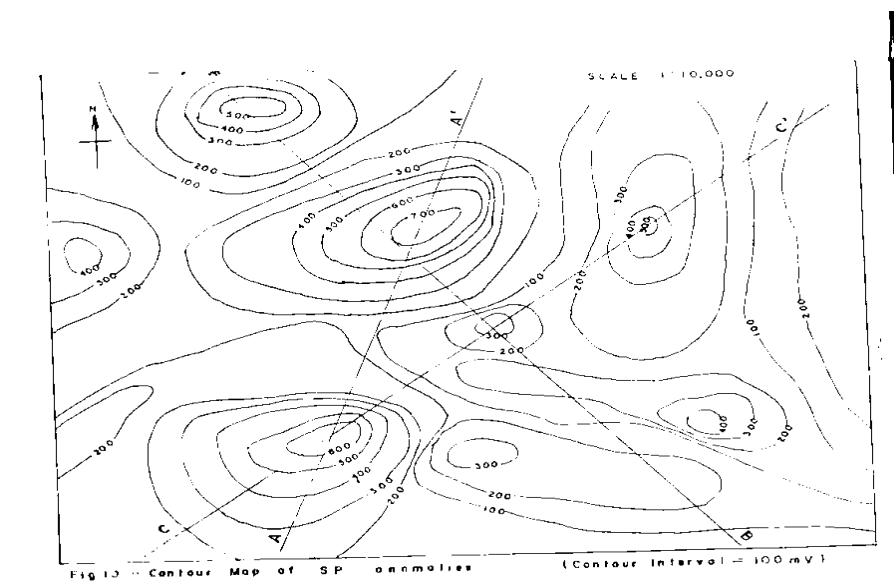
Figure 8. Contour map of SP anomalies

Interpretation

It is easy to observe that the spontaneous potential anomalies in the area are not evenly distributed. There are zones of high negative potentials. The central and southwestern flanks of the study area represent the high value closures while NW, NE and SE portions depict the lows.
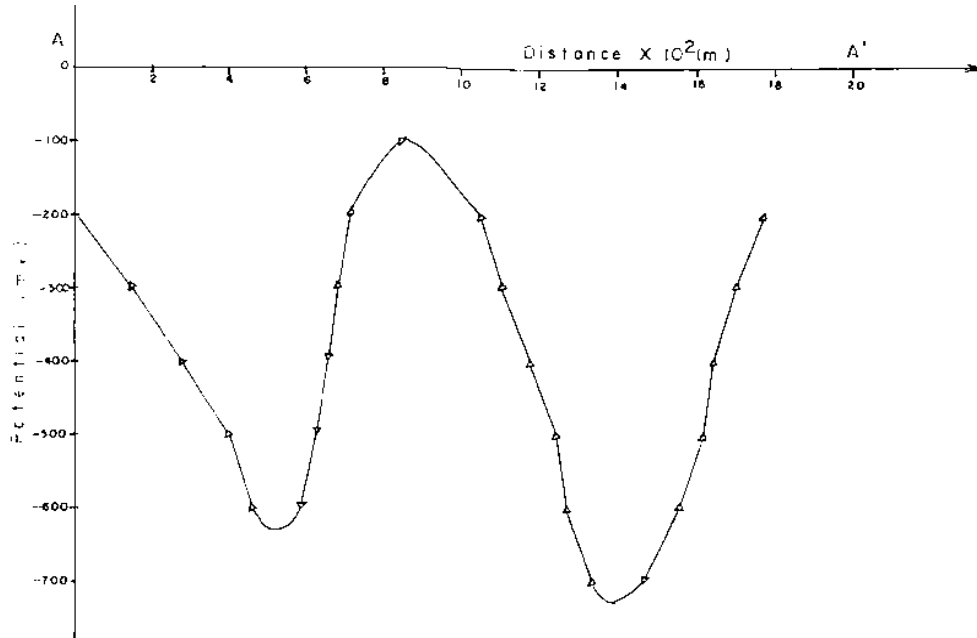
Figure 9.SP profile AA'
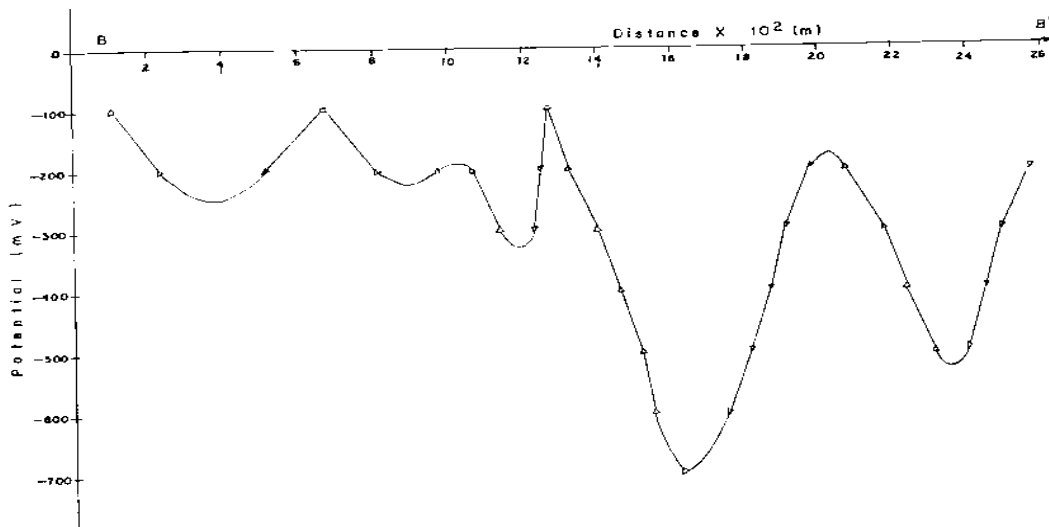
Figure 10.SP profile BB'

Profile AA´ over the ore body suggests that the body is a massive structure close to the surface (see Figure 9). It is believed to be an iron sulphide ore body which extends vertically across the water-table 33 metres beneath the surface, on the average. By geometrical modeling it appears to assume the shape of a near-trapezium. A graphical plot of SP versus distance along this same profile (Figure 9) indicates that the SP values are as high as -700 mV.

In like manner, the potential profile along BB´ in Figure 11 show that the SP values here are more than -600 mV.

Figure 11 is the profile along CC´.

Under idealized field conditions, it is possible to obtain some information about the size of the ore body, there is little or no need obtaining information about depth since only shallow bodies are likely to give rise to a spontaneous polarization potential. The estimate of the ore body causing the major anomalies (i.e. SP values greater than -500 millivolt) has an approximate lateral extent of 700 m, 1000 m and 600 m in the east-west direction and also 600 m, 600 m and 450m in the north-south direction respectively. Figure 12 confirms this
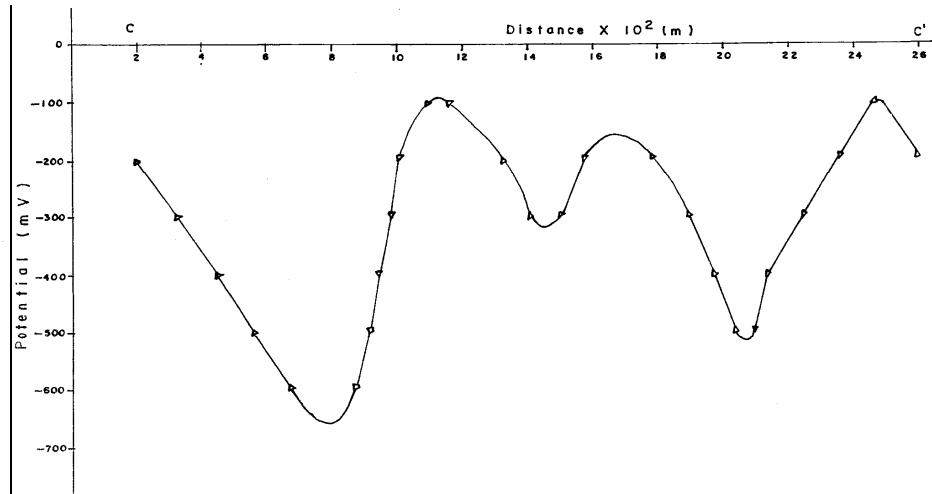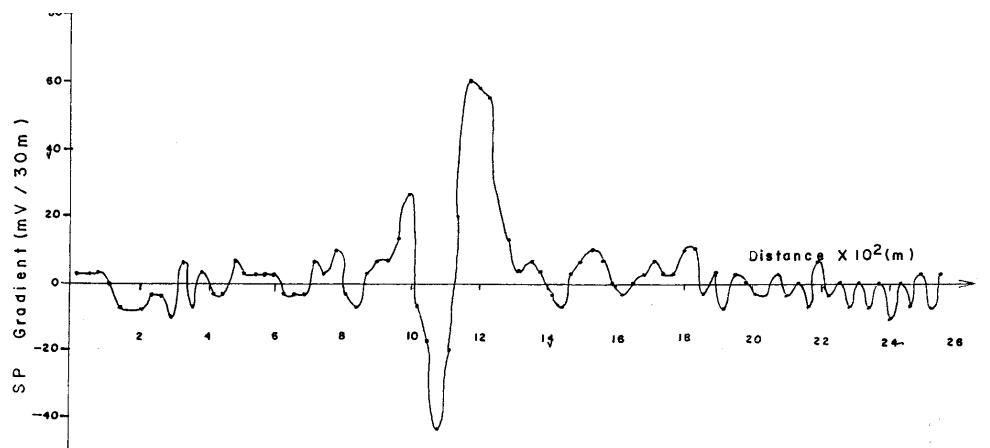
Figure 11.SP profile CC'

Figure 12. Plot of Self-Potential gradient Values

assertion about the sulphide mass (Chukwu, 2001).

RESULTS

The result of the investigation indicates that the predominant orebodies in this area of research are pyrite (FeS_2) and pyrrhotite (FeS) because these are the two minerals that have characteristic high negative SP anomalies. Their SP anomaly values are as high as -600 mV because of their high iron content. The study area contains huge amount of ferrogenized sandstone even in commercial quantity. The sandstone assumes its nature as a result of our tropical condition (Ozoemena, 1991; personal communication at the mining site). Owing to oxidation process, the ferrous ions (Fe^{2+}) change color from brown to ferric ions (Fe^{3+}) which gives rise to the reddish coloration we observe.

There are proven evidence of weathering in the rock. Large negative SP anomalies are indicative of mineralization and this is suggestive that orebodies exist therein in the subsurface. Though most of the SP anomalies are negative, SP anomaly within the vicinity is not uniformly distributed. With regards to the mineralogical trend, as long as the natural geological conditions prevail, minerals will continue to grow following mineralization, i.e. mineralogical trend is high. Also, other minerals (e.g. brine, barytes, limestone) have been associated with this area. For the depositional behavior of the area, Abakaliki in the lower Benue valley, the stratigraphical sequence in this valley; sedimentation appears to have started during the Middle Albian (Lower Cretaceous) and ended about the Maestrichian. The middle Albian sedimentation was responsible for the deposition of very thick marine, dark, grey shales, siltstone and subordinate limestones. The shales, in

most cases lay uncomformably on the Basement Complex (Reyment, 1965; Offodile, 1976). The zone is endowed with a lot of mineral deposits.

CONCLUSION

This work has been carefully and painstakingly carried out to investigate the characteristics of spontaneous potential or self-potential anomalies in Abakaliki area, Ebonyi State of Nigeria. Based on the laws governing SP method, self-potential technique involves measurement, on the ground surface, of electric potentials developed in the earth subsurface by electrochemical action between minerals and solutions with which they are in contact. This is quite natural as no external field is involved. Ore bodies (mainly sulphide) through mineralization process grow and exist in the underlain subsurface. The high negative SP anomalies are indicative of the fact that pyrite is the primary sulphide body therein.

On the average, the potential drop for the ore ranges from -0.6 to -0.8 volt revealing that it is an area of high negative SP values. The SP anomaly characteristics were negative but of varying magnitudes. The mineralogical trend is high provided the favorable geologic conditions are sustained. Normally, commercial ore does not ordinarily occupy the whole volume of a deposit; the ore is in most cases surrounded by mineral of poor grades, sometimes fading into the country rock. Non-even distribution of SP anomalies lends credence that there are possible ore-shoots in the area. These ore-shoots, undoubtedly, represent those points where high negative SP anomalies were recorded.

REFERENCES

Beck AE (1981). Physical principle of exploration methods. Macmillan Press, London pp. 31-41.

Chukwu GU (1997). SP anomalies around Abakaliki area of southern Nigeria. M.Sc dissertation (unpublished), University of Port-Harcourt, Port-Harcourt.

Chukwu GU (2001). Preliminary study of lateral extent of sulphide orebody within Abakaliki area of southeast Nigeria. Nig. J. Earth Sci. 1(1): 21-26.

Chukwu GU, Ekine AS, Ebeniro JO (2008). SP anomalies around Abakaliki anticlinorium of SE Nigeria, Pacific J. Sci. Technol. 9(2): 561-566.

Corwin RF, Hoover DB (1978). The self potential method in geothermal exploration. Geophysics 44: 226-245.

De Witte L (1948). A new method of interpretation of self-potential field data. Geophysics, 13:600-608.

Dobrin MB, Savit CH (1988). Introduction to geophysical prospecting 4th Edition. McGraw-Hill Book Coy Japan

Farrington JL (1952). A preliminary description of the Nigerian Lead/zinc field. Economic Geology 47: 583-608.

Geological Survey of Nigeria (GSN) (1955). Geological map of Ogoja, Benue and Abakaliki Provinces

Grant FS, West GF (1965). Interpretation theory in Applied Geophysics. McGraw-Hill Book Company, New York

Kogbe CA (1976).The Cretaceous and Paleogene sediments of southern Nigeria, Geology of Nigeria, Elizabethan Publishing Company, Lagos.

Murat RC (1992). Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. Africa geology. University of Ibadan Press pp. 635-641

Offodile ME (1976). A review of the Geology of the Cretaceous of the Benue valley. Geology of Nigeria, Elizabethan Publishing Co. Lagos

Pedersen LE (1991). Relations between potential fields and some equivalent sources. Geophysics, 56: 961-971.

Reyment RA (1965). Aspects of the Geology of Nigeria – Ibadan University Press, pp. 12-23.

Scheidegger AE (1976). Foundation of Geophysics. Elsevier Scientific Coy. Amsterdam.

Short KC, Stauble AJ (1967). Outline of Geology of Niger Delta, AAPG Bulletin 51: 645-656.

Stacey FD (1977). Physics of the Earth John Wiley and Sons, New York.

Uzuakpunwa AB (1974). The Abakaliki pyroclastics Eastern Nigeria: New age and tectonic implications. Geological map III.