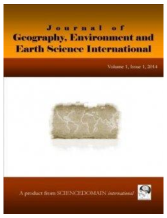

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Investigation of Graphite and Sulphide Minerals in Some Parts of Southern Umuahia Using Self Potential Anomalies

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Authors' contributions

This work was carried out in collaboration between both authors. Author ADE designed the study, managed the literature searches, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Both authors managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Self Potential, an electrical geophysical method is chiefly used in mineral prospecting. Vertical and lateral variations in the conductivity of earth materials produce variations in the potential distribution as measured on the surface thereby giving information of the sub-surface. A self-potential survey was carried out in the study area. Seven locations were considered. The profiles investigated had a total area of 2.34 km^2. A total of 315 self potential measurements were taken using the direct potential method with a 10m increase in the electrode spacing along each of the profiles. Obtained data show a negative anomaly of -2 mV to -600 mV and a positive anomaly of 5 mV to 277 mV distributed within the study area. It was observed that the potential anomalies are due to some conductive minerals like graphite and sulphide ore bodies. The Iso-potential contour map of the study area was made with an interval of 50mV which reveals the mineralogical trend of sulphide and graphite ore bodies. It was deduced that Nkwoebo, Umuoram and Egbeada regions of the study area would most likely have a graphite ore body while Umuchime, Amachara and Umuokwom will most likely have a sulphide ore body.

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Keywords: Self-potential; Ore; sulphide; anomaly.

1. INTRODUCTION

Self-potential or spontaneous potential (SP) is the naturally occurring potential of the earth resulting from geologic, geochemical and hydrological interactions which cause electrical potentials to exist in the earth in the vicinity of the measurement point [1]. These potentials are usually measured in millivolts relative to a survey base.

Spontaneous potential can be produced by mineralisation differences, electrochemical action, geothermal activity and bioelectric generation of vegetation. Charge separation in clay or other minerals due to the presence of semi-permeable interface impeding the diffusion of ions through the pore space of rocks or by the natural flow of conducting fluid through the rocks can also result to spontaneous potential. The controlling factor in all cases is underground water [2]. These potentials are associated with weathering of sulphide mineral bodies, variation in rock properties (mineral content) at geological contacts, the bioelectric activity of organic material, corrosion, thermal and pressure gradients in underground fluids, and other phenomena of similar nature [3].

The self-potential method has been frequently used in subsurface studies due to its sensitivities to variations in groundwater flow, chemistry or temperature [4]. SP method has been used in massive base metal exploration to detect the presence of massive ore bodies and has been extended to groundwater and geothermal investigations, environmental and engineering applications to; map seepage flow associated with dams, in geological mapping and in delineation of shear zones and near-surface faults [5]. SP observations can also be used to infer water table-table variations while some SP observations can yield an estimate of aquifer hydraulic properties [6]. SP has also been useful in characterising active volcanic areas. [7].

The SP method involves the measurement of the differences in natural ground potential between any two points on the ground surface which ranges from less than a millivolt to over ten volts [5]. The electric field is usually measured by high input impedance multimeter using non-polarisable electrodes [8]. The sign of the potential is an essential diagnostic factor in the interpretation of SP surveys results. However, the SP anomaly is highly dependent on the geology of the area thus providing a clue to the causative factor [9].

Chemical reactions which evolve as a result of the ore body being in contact with the solutions of varied composition give rise to different solution pressure contrast which in turn generates an electromotive force (e.m.f) which causes a flow of current in the ground [10].

1.1 Mechanism of Self Potential

Electrical potential is one of the properties of rocks and minerals. There are four principal mechanisms producing spontaneous potentials in the subsurface. They include; streaming or electrokinetic potential, liquid-junction or diffusion potential, Nernst or shale potential and mineralization potential or electrolytic contact [5].

While diffusion or liquid-junction potential is caused by the displacement of ionic solutions of different concentrations, that is the differences in mobilities of various ions in solutions of different concentrations, shale or Nernst potential occurs when similar conductors have a solution of different concentrations about them, that is there is no potential difference between two identical metal electrodes when immersed in a homogenous solution. The sum of the diffusion and Nernst potential gives rise to electrochemical or static self-potential [5].

Electrokinetic or streaming potential is caused by the flow of a liquid with electrical properties, passing through a porous medium with different electrical properties i.e. when there is a relative motion between the fluid and the rock matrix [11]. In a porous medium, the electric current density, linked to the ions within the fluid is coupled to the fluid flow to generate streaming potential [12,13]. Streaming potential occasionally gives rise to high potential anomalies associated with topography as used in the characterisation of active volcanic areas which results to a positive anomalous signal [14-16]. In most cases, the streaming potential associated with thermal driven fluid upflow was believed to be the primary cause of these positive anomalies [17]. The expression for Electrokinetic potential is as given in equation one [5].

$$E_k = \frac{\varepsilon \rho C_\varepsilon \Delta P}{4\pi\eta} \qquad (1)$$

Where

ε = Dielectric permittivity of pore fluid
ρ = Electrical resistivity of pore fluid
C_ε = Electrofiltration coupling coefficient
ΔP = Pressure difference and
η = Dynamic viscosity of pore fluid

1.2 Mineralization Potential

This is produced at the surface of a conductor with another medium. It is also called electrolytic contact. Mineralization potential is almost exclusively negative and exists largely in mineral zones containing sulphides, oxides, graphite and magnetite. Mineralization potential along with the static self-potential is among the basic causes of the large potentials associated with mineral zones. The large magnitude in potential of mineralized zones cannot only be attributed solely to the electrochemical potentials because the presence of metallic conductors in appreciable concentrations appears to be a necessary condition [18].

If two non-polarisable electrodes are inserted into the earth within a reasonable distance apart, a potential drop is observed between the two electrodes. This observation is mostly predominant if sulphide ore bodies 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 [19]. Large negative anomalies can also be observed over magnetite and graphite as shown in Table 1 [5]. Anomalies of -450mv or more negative are due to graphite but anomalies of -350 to -400 mv can occur in a variety of lithologic or mineralized conditions while sulphide ore bodies produce a range of up to 350mv between the most positive and most negative SP readings [18]. Other minerals producing fewer anomalies include chalcopyrite ($CuFeS_2$), calchocite (Cu_2S), and covellite (CuS). [20].

The negative SP anomaly observed due to an ore body can be explained thus; when the ore body saddles, the water table, a cathodic electrochemical half cell forms by the chemical reduction of the ions in the surrounding electrolyte, i.e. they gain electrons. Conversely, below the water table, an anodic electrochemical cell operates in which oxidation is dominant and ions loose electrons. The role of the massive ore body is to permit the flow of electrons from the lower half of the ore body to the upper half (i.e. a geo-battery). The net result of this process is that the upper surface becomes negatively charged hence the negative anomaly and the lower half becomes positively charged as shown in Fig. 1 [21].

The self potential method is qualitative and does not attempt to quantify the anomalous volume size owing to the unknown volumetric shapes, concentration/density of various masses and electrical properties of the sought causative media [18]. However, on combination of other geophysical methods like the gravity or magnetic method, thorough quantitative interpretations can be obtained. Nevertheless, when SP can give information about certain minerals.

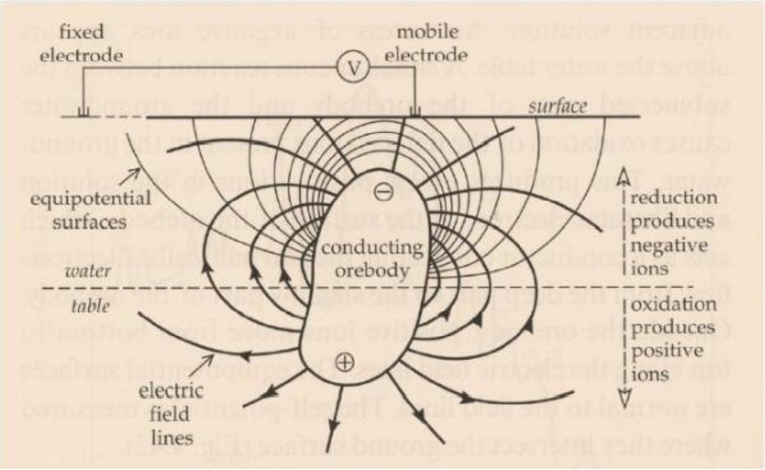


Fig. 1. A schematic model of the origin of the SP anomaly of an ore body [21]

Table 1. Types of SP anomalies and their geologic sources [5]

Source	Type of anomaly
Mineral potentials	
Sulphide ore bodies (Pyrite, chalcopyrite, pyrrhotite, sphalerite, galena)	Negative anomaly ≈ hundreds of mV
Graphite ore bodies	
Magnetite + other electronically conducting materials	
Coal	
Manganese	
Quartz veins	
Pegmatites	Positive ≈ tens of mV
Background potentials	
Fluid streaming, geochemical reactions, e.t.c	Positive +/- negative ≤ 100mV
Bioelectric (Plants, trees)	Negative ≤ 300mV or so
Groundwater movement	Positive or negative up to hundred of mV
Topography	Negative, up to 2V

1.3 Location and Geology of the Study Area

The study area covers the whole of Ohiya community and some parts of Amachara and Ossah all in South Eastern region of Nigeria. It lies between Latitude 05º 29' and 05º.33' North and Longitude 07º.26 and 07º.28' East which covers an area of about 15.7 km^2.

It is underlain by the Benin Formation which is the youngest rock-stratigraphic unit in the Niger Delta basin of Miocene to Recent age [22]. It is composed of continental deposits, including alluvial and upper coastal-plain deposits that are up to 2000 m thick mostly at the centre of the basin [23]. The Miocene to Recent Benin Formation is made up of sands which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of poorly cemented sands and clays. But generally, Benin Formation consists of shale/sand sediments with intercalation of thin clay beds [24,25].

Petrographic analysis of Benin Formation indicates that the composition of the rocks is as follows: 95-99% quartz grains, 1-2.5% of Na+K-mica, 0 -1.0% of feldspar and 2-3% of dark coloured minerals [26]. Locally, the study area is made of mostly clays and alluvium deposits. There is an abundance of clay mineral, with evidence of shale and dark couloured minerals on the outcrop. The kaolin deposits are consolidated and are surrounded by sand, silt and clays [27].

It has a relative humidity of over 70% and it is characterized by high temperature of about 29ºC – 31ºC with an annual rainfall of about 4000mm per annum with two seasons – dry and wet seasons. Wet season starts from mid April to October and dry season from November to Mid April. It has double maxima rainfall peaks in July and September with a short dry season of about three weeks between the peaks locally known as “August Break” [27].

The area has an undulating pattern. It has high and low elevation and valleys. The elevation above sea level ranges from 107m to 131m. The location map of the study area is as shown in Fig. 2.

2. MATERIALS AND METHODS

A pair of non-polarizable electrodes, Ohmega 1000 Terrameter and two reels of wire were assembled in a field survey to get the self potential data. The direct potential method was used in generating the data. In this procedure, one of the electrodes is placed at a large distance far away from the base electrode. This electrode gives a reference potential against which the potential at each of the corners of a grid is measured. The base electrode is made to be stationary while the other is moved from point to point along a profile until the grid is completed.

Seven locations were investigated which covers the entire study area. Some of the locations which have a large area were subdivided into profiles and measurements were taken along the traverses. Table 2 shows the different locations and their coordinates. The length of the profiles ranges from 100 m to 200 m. Due to the topography of the study area, the longer profiles

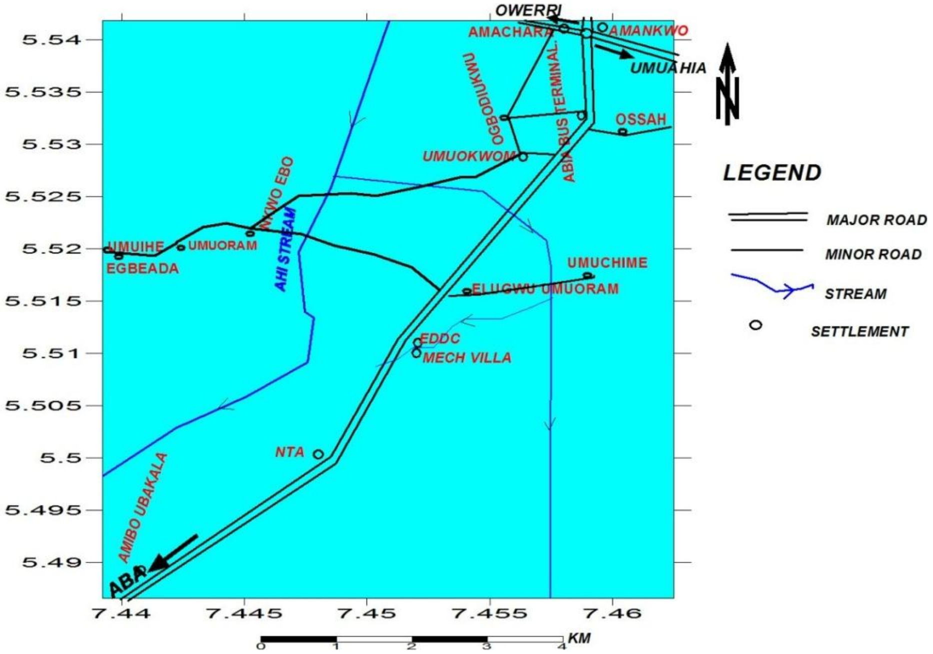


Fig. 2. Location map of the study area [27]

Table 2. Locations of the study area where measurements were taken location

Location	Coordinate		No of profiles
	Latitude (North)	Longitude (East)	
1	05^0.31.833 ' – 05^0.31.879 '	07^0. 27.649 ' – 07^0.27.750 '	1
2	05^0.31.630 ' – 5^0 31.669 '	07^0.27.394 ' – 07^0.27.422 '	1
3	05^0.32.436 ' – 05^0.32.469 '	07^0.27.133 ' – 07^0.27.173 '	1
4	05^0.30.502 '– 05^0.30.794 '	07^0.26.646 ' – 07^0.26.743 '	2
5	05^0.30.771 ' – 05^0.30.858 '	07^0.26.782 ' – 07^0.26.922 '	3
6	05^0.30.370 ' - 05^0.30.511 '	07^0.26.491 ' – 07^0.26.667 '	4
7	05^0.30.789 ' - 05^0.30.995 '	07^0.27.151 ' - 07^0.27.513 '	9

were obtained where there is a relatively even topography while some were shortened when it meets an undulating plain. The distance of separation between the two electrodes is increased by a distance of 10 m.

3. RESULTS, ANALYSES AND DISCUSSION

Results from the survey show that the self potential values are predominantly negative with some positive values. The table of potential values is as shown in Tables 3 to 7. The obtained SP values for each of the profiles were plotted against the offset distance to get the spectral signature as shown in Figs. 3-7.

The negative values reveal mineral zones which may contain sulphides, oxides, graphite magnetite and other electrically conducting minerals while the positive anomalies depict the presence of non-conductive minerals.

Locations one to three have conductive materials due to high negative anomalies recorded. This depicts the presence of sulphide ore bodies with minute non-conductive minerals which gave rise to the few positive anomalies. Similarly, location four has both negative and positive potential values with profile two having the highest positive potential anomaly of 83.77mV which implies that the conducting minerals can be detected more as you move from profile two to one.

In location five, profiles one and three have exclusive high negative potential anomalies whereas the second profile has low negative and positive anomaly. This indicates that the ore body is abundant along profiles one and three whereas the host rock and other non-conductive materials are likely to be concentrated along profile two.

Table 3. SP values of locations 1 – 3

Offset distance (m)	Potential (mV)		
	Location 1	Location 2	Location 3
0	-44.82	-31.03	-95.74
10	-67.14	-90.26	-149.00
20	-109.5	-50.10	-151.40
30	-146.4	-75.65	-178.90
40	-263.3	-84.17	-295.80
50	-240.9	-172.80	-351.70
60	-230.7	-163.60	-313.10
70	-192.1	-40.56	-334.40
80	-225.7	51.37	-336.50
90	-249	46.85	-443.20
100	9.394	40.56	-483.00
110	-338.5	_	_
120	-270.4	_	_
130	-282.6	_	_
140	-281.6	_	_
150	-297.8	_	_
160	-371	_	_
170	-305	_	_
180	-336.5	_	_
190	-233.8	_	_
200	-174.8	-	-

Location 6 has quite a unique feature as it has both the highest positive potential anomaly (251.1 mV) and the highest negative anomaly (-640.5 mV). It shows an intermittent trend as we move from profile one to four. Profiles one and three have exclusive negative anomalies; profile two almost has non-conductive values while profile four is almost exclusively conductive with a single positive anomaly at 120 m offset. This implies that, sulphide ore bodies are likely to be seen abundantly along profiles one, three and four alongside other non-conductive materials which will be more in profile two.

It can also be deduced that in location seven, the trend in potential values shows a transition from negative values to positive as we move from profile one to profile eight till it became predominantly positive in profile nine. This implies that the abundance of these conductive minerals tend to decrease as we move from profile one to profile nine. However, ore bodies seem to be more predominant along profiles five, six and seven because of the exclusive negative anomalies obtained.

Furthermore, the most active anomalies due to the sulphide ore bodies are obtained in profile six of location seven, profile three of location six and profile one of location five because they all have high negative potential anomalies of -500 mV and above.

The Iso-potential map of the study area was contoured with an interval of 50 mV which reveals major areas of the abundance of graphite and sulphide ore bodies as shown in figure 8. As stated earlier, graphite gives a strong negative anomaly of -450 mv or more while anomalies up to -350 mv are associated with sulphide ores. Therefore, from the iso-potential map, it can be deduced that graphite and sulphide ore bodies are more in the North-Western and South-Western areas of the study area. The mineralogical trend seem to extend from the South-Western region to the North-Western region while sulphide ore body and very minute quantity of graphite can be seen at the South-Eastern part of the study area.

Therefore Nkwoebo, Umuoram and Egbeada will most likely have a graphite ore body while Umuchime, Amachara and Umuokwom will most likely have a sulphide ore body. There is however little or no need to obtain information about depth since only shallow bodies are most likely to give rise to a spontaneous polarization potential. The maximum depth of sensitivity of SP method is approximately 60-100m depending on ore body and nature of overburden [5].

Table 4. SP values of location 4

Offset distance (m)	Potential (mV)	
	Profile 1	Profile 2
0	30.32	83.77
10	-84.38	2.129
20	-102.4	-96.34
30	-207.4	14.5
40	-363.9	-64.7
50	-216.5	-103.4
60	-209.4	-150.1
70	-274.5	-99.18
80	-197.2	-126.7
90	-266.3	-129.8
100	-268.4	20.08

Table 5. SP values of location 5

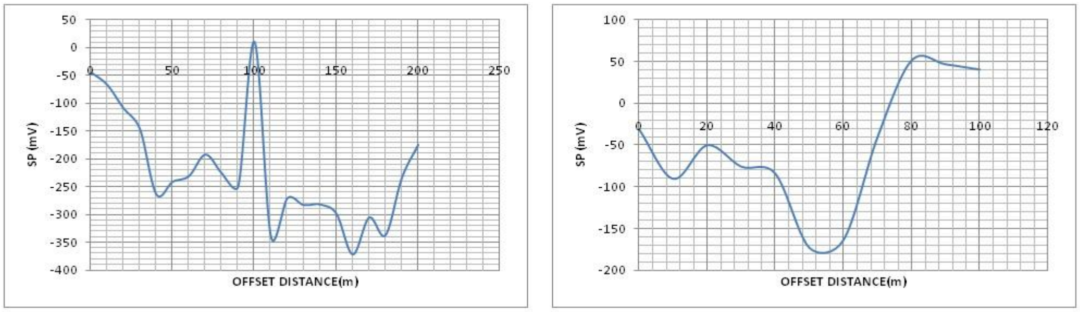
Offset distance (m)	**Potential (mv)**		
	Profile 1	**Profile 2**	**Profile 3**
0	-4.097	12.47	-72.81
10	-144	-45.03	-86.81
20	-185	21.9	-196.2
30	-222.6	-21.6	-416.8
40	-118.6	-28.7	-326.3
50	-186	-11.66	-247
60	-249	-83.57	-311.1
70	-352.7	-139.9	-283.6
80	-514.4	-118.6	-282.6
90	-373.1	-74.03	-473.7
100	-441.2	-168.7	-467.6

Table 6. SP values of location 6

Offset distance (m)	**Potential (mv)**			
	Profile 1	**Profile 2**	**Profile 3**	**Profile 4**
0	-286.7	-19.77	-112.5	-184
10	-341.6	224	-76.67	-199.2
20	-490	251.1	-69.97	-216.5
30	-297.8	188	-107.5	-289.7
40	-510.3	176.9	-114.6	-259.2
50	-569.3	54.56	-63.89	-342.6
60	-522.5	19.57	-74.44	-244
70	-494.1	131.8	-118.6	-266.3
80	-363.9	3.083	-286	-237.9
90	-416.8	-108.5	-640.5	-180.9
100	-437.1	105.4	-239.9	-175.8
110	-449.3	_	_	-256.2
120	-516.4	_	_	277.5
130	-504.2	_	_	_
140	-379.2	_	_	_
150	-416.8	-	-	-

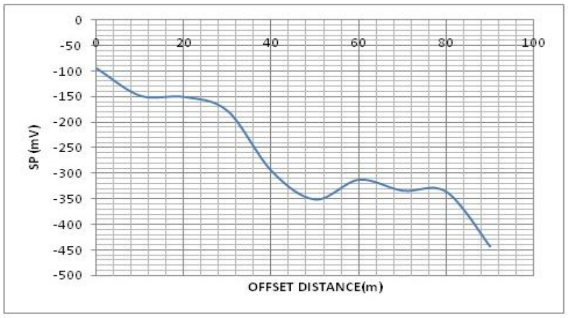
Table 7. SP values of location 7 offset distance (m)

	Potential (mv)								
	Profile 1	**Profile 2**	**Profile3**	**Profile4**	**Profile5**	**Profile6**	**Profile7**	**Profile8**	**Profile9**
0	-2.018	1.125	-67.54	21.09	-187	-89.85	-62.06	72.61	198
10	5.375	-80.52	-90.87	73.02	-232.8	-263.3	-113.5	170.8	187
20	-90.87	-63.28	-76.67	87.22	-220.6	-382.2	-180.9	119.6	148
30	-34.98	-100	-96.55	71.8	-293.8	-414.8	120.6	93.5	87.62
40	-45.43	-102.4	-121.7	160.2	-252.1	-306	120.6	85.39	69.16
50	-67.95	-52.73	-90.66	106.4	-288.7	-420.9	51.31	87.01	165.7
60	-92.69	-138.9	-53.75	108.5	-229.7	-390.4	-32.68	114.6	180.9
70	-195.2	-74.64	-88.03	104.4	-109.5	-368	67.74	-117.6	36
80	-196.2	-108.5	-41.37	-65.31	-10.44	-218.5	-71.39	-125.7	168.7
90	-220.6	-198.2	-46.65	-151.1	-47.46	-352.7	-106.4	-88.64	155.5
100	-86.4	-178.9	-96.75	-79.51	54.15	-406.6	-28.9	57.2	145.3
110	-106.4	-194.1	-53.95	-14.09	-222.6	-366	-123.7	-12.27	165.7
120	-166.7	76.87	-77.68	-134.8	-93.1	-37.2	-236.8	51.52	_
130	-84.98	-128.8	-65.92	-27.78	-16.12	-445.3	-176.9	-33.36	_
140	-122.7	-170.8	-75.25	-26.67	-64.9	-467.6	-139.9	152.1	_
150	-262.3	-152.5	-34.17	-44.21	-13.38	-443.2	-389.3	-3.904	_
160	-336.5	-154.1	-32.55	49.89	-112.5	-488	-296.8	_	_
170	_	-114.6	-58.82	79.9	-300.9	-492	_	_	_
180	_	-36.71	8.985	50.91	-223.6	-573.4	_	_	_
190	_	-108.5	6.916	39.55	-	-392.4	_	_	_
200	-	-201.3	17.03	101.4	-	-323	-	-	-



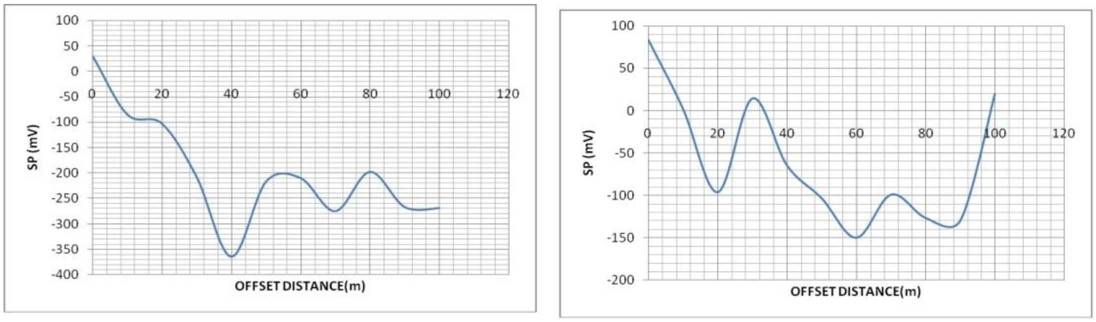
Location 1

Location 2



Location 3

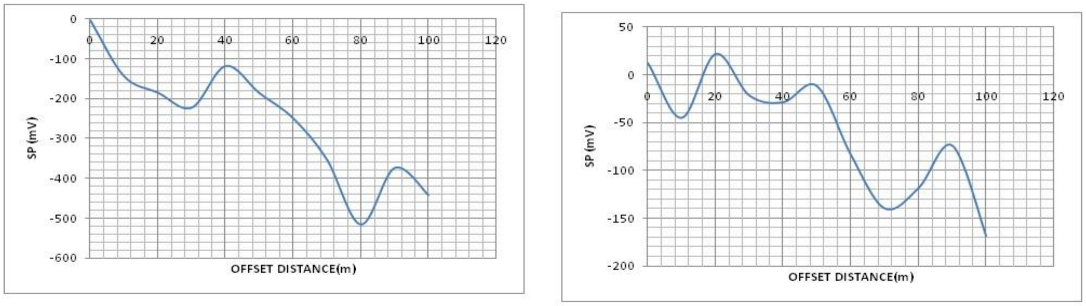
Fig. 3. Spectral signatures of locations 1 – 3



Profile 1

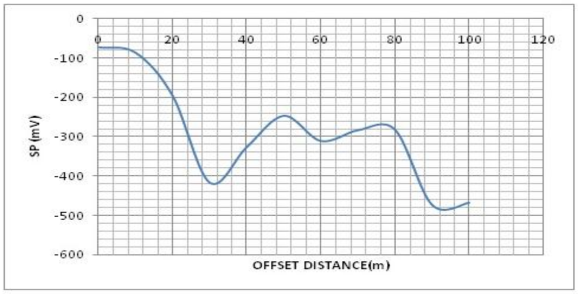
Profile 2

Fig. 4. Spectral signatures of locations 4



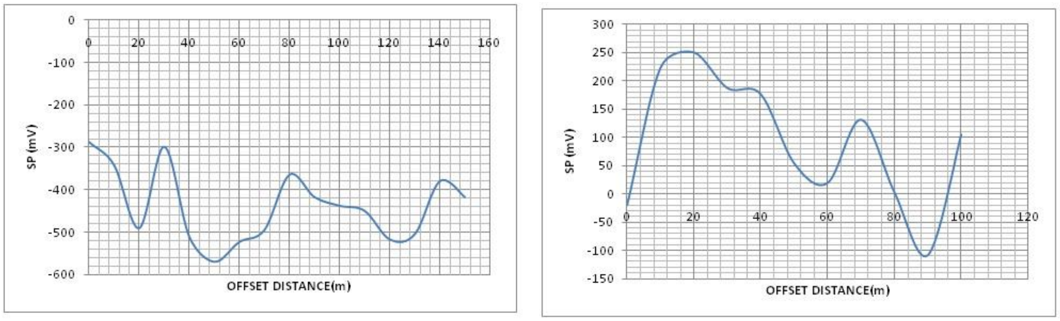
Profile 1

Profile 2



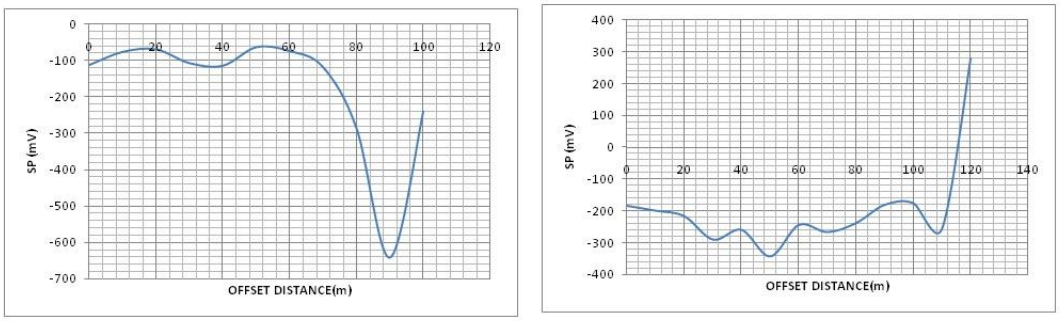
Profile 3

Fig. 5. Spectral signatures of locations 5



Profile 1

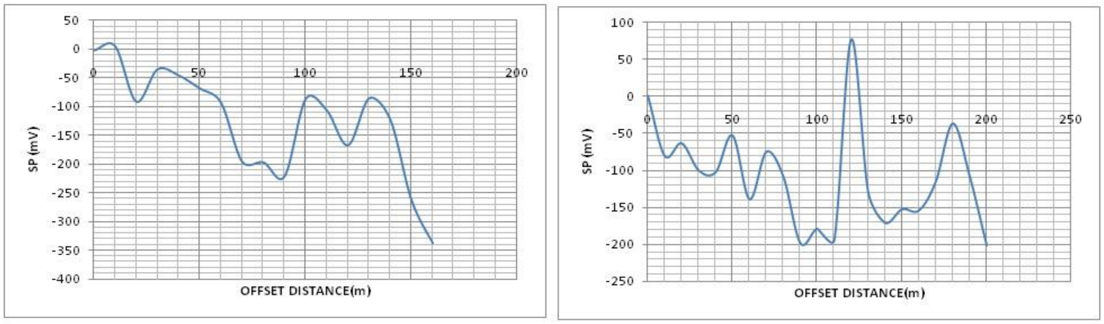
Profile 2



Profile 3

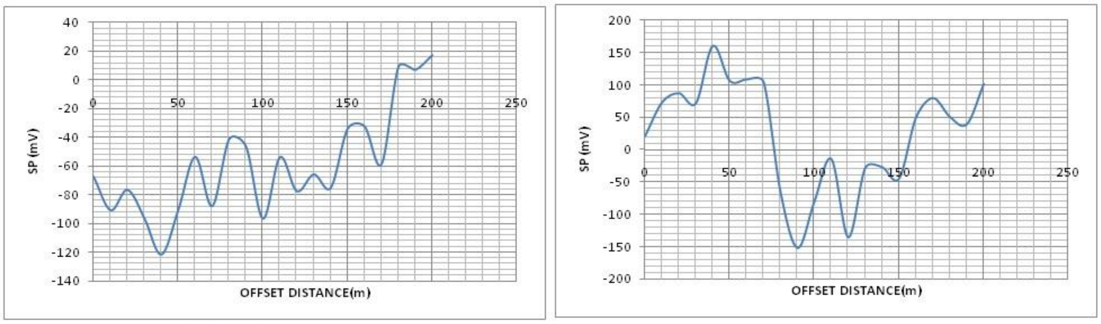
Profile 4

Fig. 6. Spectral signatures of locations 6



Profile 1

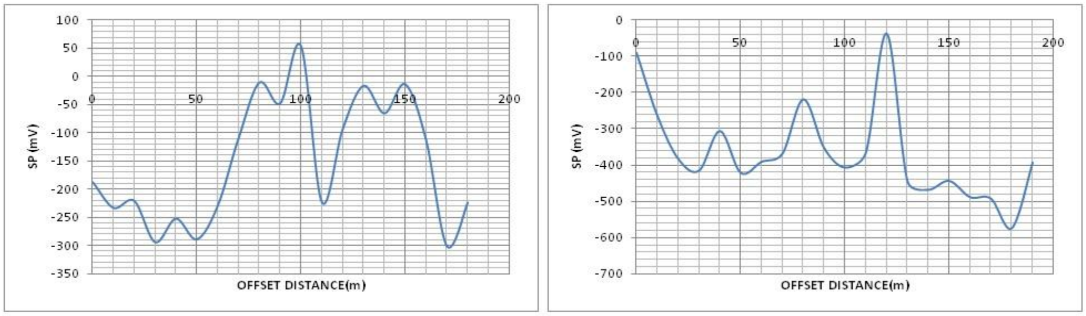
Profile 2



Profile 3

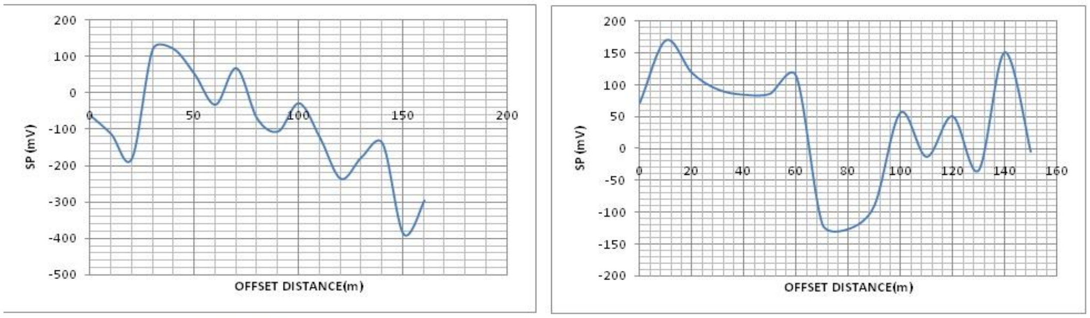
Profile 4

Fig. 7a. Spectral signatures of locations 7



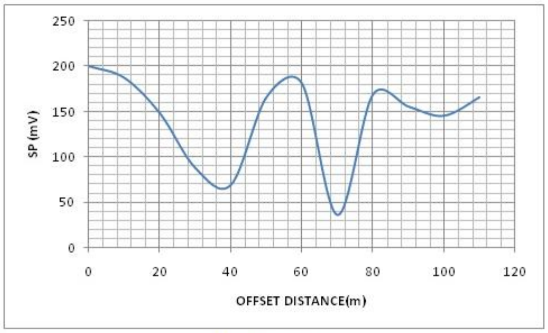
Profile 5

Profile 6



Profile 7

Profile 8



Profile 9

Fig. 7b. Spectral signatures of locations 7

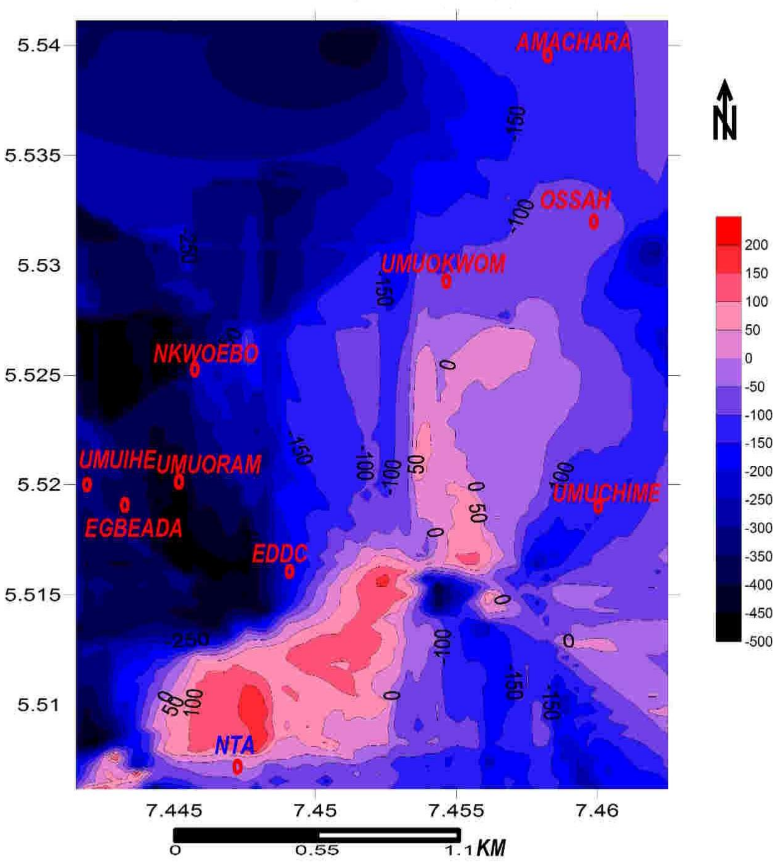


Fig. 8. ISO-potential contour map of the study area

4. CONCLUSION

This work investigates the self-potential anomalies of some of the southern parts of Umuahia. The self-potential technique involves measurement at the surface of electrical potential developed in the earth by the electrochemical action between the minerals and solutions which they are in contact. There is no impressed or external field in play. Ore bodies through mineralisation process grow and exist in the underlain subsurface. The SP anomaly of the study area is predominantly negative with varying magnitudes ranging from -2 mV to -600 mV. Positive SP anomalies were also seen from 5mv to 277 mV. The negative SP anomalies are due to the presence of mineral containing sulphides and graphite. The abundance of the conducting minerals is in locations three, four, five and seven. Such communities as Umuchime, Amachara and Umuokwom are likely to have sulphide ore bodies as indicated by the potential anomalies measured while Nkwoebo, Umuoram and Egbeada all in Ohiya will have a graphite ore body.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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