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Integrating Spontaneous Potential and Resistivity Methods in the Delineation of Pb–Zn Mineralized Veins in the Albian Shales in Enyigba-Abakaliki, Southern Benue Trough, Nigeria

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Abstract: The characters of the lead-Zinc (Pb-Zn) sulphide filled veins in response to the spontaneous potential (SP) and electrical resistivity methods of geophysics were evaluated in eight (8) different locations around some active Pb-Zn mines in Enyigba-Abakaliki area. Results of the survey indicate that the range of the SP values in the locations are (-67.4 – 10.26; -118 – 30.05; -109.50 – 21.00; -99.50 – 11.81; -78.50 – 14.78; -80.50 – 11.26; 10.77 – 42.01; -64.56 – 4.23) mV, while that of resistivity are (27.34 – 147.41; 22.63 – 160.29; 27.34 – 167.21; 61.92 – 151.81; 27.34 – 176.64; 49. 35 – 148.35; 77.00 – 180.72; 62.23 - 163.44) Ωm. The SP values of ≤ 50 mV and resistivity values of < 50 Ω were associated with structural veins hosting Pb-Zn sulphide ores in the area. Lower values suggest higher-quality deposits. The SP method displayed higher efficacy in delineating ore veins in this study. Hence, at points where the results of both surveys were not in agreement, the result of the SP survey was preferred.

Key words: Spontaneous potential · Lateral profiling · Enyigba · Abakaliki · Benue Trough · Lead-Zinc

INTRODUCTION

Solid mineral exists as a major alternative source of economic development to hydrocarbon in Nigeria. With the constant dwindling in the price of crude oil in recent times, solid mineral exploration is getting into focus as a means of wealth creation [1]. Deposits of Pb-Zn sulphide ores in Nigeria have been known for a long time covering an area of about 48, 000 km^2 [2]. Deposits are localized in Cretaceous sediments within the Benue Trough [3], in a variety of sedimentary host rocks ranging from shales in the Abakaliki area, carbonate in Arufu-Akwana and to sandstone in Zurak areas [4].

Since the discovery and mining of Pb-Zn deposits in Abakaliki area in the early 1900s, not much data exists on the geophysical survey of the area in terms of solid mineral exploration. Pb–Zn ore deposits remain amongst the most difficult to map using geophysical exploration methods [5]. The mineralogy, texture and shape of the ore are highly variable from place to place, even within a mining district [6, 7]. Attempts to investigate Metallic sulphide deposits in the area were made by [8, 9, 10]. However, while 10 evaluated the Pb-Zn sulphide veins in the Ishiagu area using a Very Low-Frequency electromagnetic method, 8 and 9 applied Spontaneous potential method alone in characterizing mineralized zones.

The Spontaneous Potential (SP) method has a wide range of applications in the exploration of solid minerals, particularly metallic sulphides [11; 12; 13, 9]. It is sometimes integrated with the resistivity method (14). The application of the electrical resistivity method in investigating Pb-Zn ore deposits is well known [5; 1]. Evrard *et al*. [5] observed resistivity range for the ores to be 5.00 – 80.00 Ωm, whereas [11, 14] identified very low SP anomalies to be associated with the presence of sulphide deposits at depth. Appreciating the relevance of integrated approach in subsurface investigations in recent times, this research, therefore, is intended to integrate electrical resistivity and spontaneous potential methods in delineating Pb-Zn sulphide ore-bearing veins in the study area.

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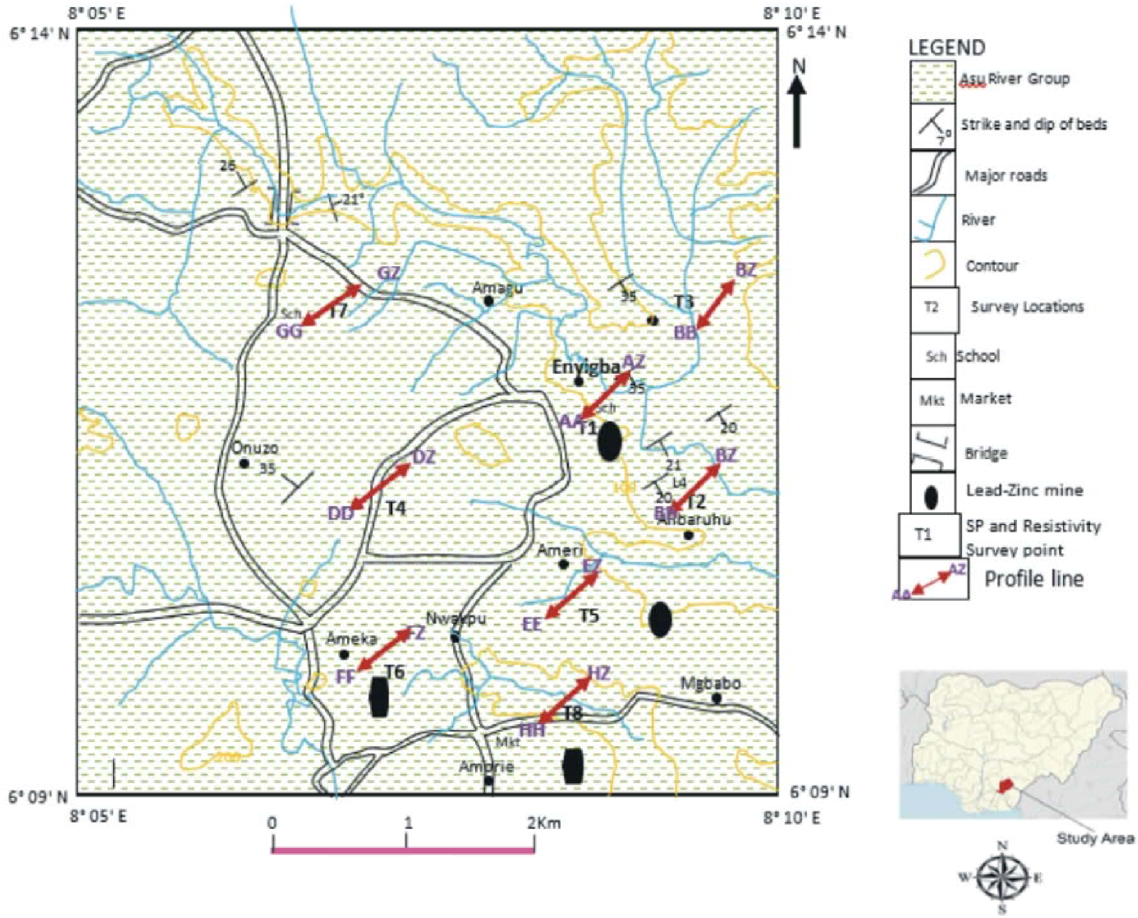

Fig. 1: Geological map of the study area indicating survey points and geographical location

Geologic Setting: The study area falls within the southern portion of the Benue Trough which is primarily underlain by sediments of Asu River Group, representing the Albian age (Fig. 1). The Asu River Group consists of alternating shales and siltstones with occurrences of fine-grained micaceous and feldspathic sandstones, mudstones and limestones [16]. This group has been sub-classified into the Abakaliki and Ebonyi Formations [17]. The Enyigba Pb-Zn field is part of the Abakaliki Formation. The entire Abakaliki area has been intruded by numerous magmatic rocks ranging from basic/intermediate igneous rocks [18] to pyroclastics in the Abakaliki area [19; 20]. The combined effect of tectonism and magmatism led to folding, fracturing and faulting of these rocks [21] there by creating a lot of veins capable of hosting the Pb-Zn ores. Earlier reports on Pb–Zn mineralization in the area include that of 3, 22, 23, 24, 25 and 26. These deposits occur in their ore forms as galena, sphalerite or combined, in tectonically generated veins within the shale members of the Asu River Group. Magmatic hydrothermal solutions have been suggested to have led their formation in the study area [27, 3, 28, 29]. The ores mostly occur as open space filling within en echelon, tensional, steeply dipping fracture system, commonly astride anticlinal axes [3] within the shales of Asu-River Group.

MATERIALS AND METHODS

Eight (8) traverses of both SP and resistivity surveys were concurrently carried out at eight different locations within the study area (Fig. 1). The choice of geophysical survey points was made at the reconnaissance stage. SP surveying was carried out using the Abem Terrameter SAS 1000 with its set of cable reels and a pair of non-polarizable electrodes, which are copper electrodes immersed in copper sulphate solution contained in a porous pot. A total field method was applied in taking readings along each traverse, with an intra-traverse spacing of 5 m. The choice of total field method was based on its advantages over the gradient method [30].

The resistivity surveying was carried out using Abem Terrameter SAS 1000, 2 pairs of steel electrodes and their associated cable reels. Field data were acquired by applying Wenner electrode configuration in lateral profiling [30] along each traverse using 5 m equal electrode spacing.

Coordinates of each measurement point were determined using Garmin-Extrex Global Positioning System. All raw data were recorded in the field data sheet, while processing and interpretation of the field data were done with the aid of Microsoft Excel spread sheet.

RESULTS

The results of the present work are as represented in Tables 1 and 2. From table 1, the range of the SP values in the locations are (-67.4 – 10.26; -118 – 30.05; -109.50 – 21.00; -99.50 – 11.81; -78.50 – 14.78; -80.50 – 11.26; 10.77 – 42.01; -64.56 – 4.23) mV. From Table 2, the range of values for the resistivity data are (27.34 – 147.41; 22.63 – 160.29; 27.34 – 167.21; 61.92 – 151.81; 27.34 – 176.64; 49. 35 – 148.35; 77.00 – 180.72; 62.23 - 163.44) Ωm respectively.

Table 1: Summarized Results from Self Potential (SP) Survey in the study area

S/N	Space (m)	SP1 (mV)	SP2 (mV)	SP3 (mV)	SP4 (mV)	SP5 (mV)	SP6 (mV)	SP7 (mV)	SP8 (mV)
1	5	6.18	-11.21	4.25	-4.79	-0.74	5.2	22.24	2.52
2	10	-5.68	-13.29	-6.74	-29.7	0.48	-13.47	23.31	-6.67
3	15	-14.35	-10.2	-7.31	7.14	0.56	-25.18	28.45	-17.32
4	20	-6.65	-23.22	-20.2	-0.12	-2.67	-40.8	25.23	-18.27
5	25	2.29	-88.21	-19.34	-88.35	-6.43	-38.13	24.56	-22.25
6	30	-17.48	-12.14	-18.75	-99.50	-78.5	-36.01	31.48	-64.56
7	35	-67.24	-7.14	-17.32	-5.2	-70.23	-20.52	35.24	-50.29
8	40	-9.84	-18.38	2.39	-62.1	-58.73	4.77	36.27	-28.93
9	45	-8.47	-18.02	1.23	-85.92	-20.45	-66.12	32.41	-28.12
10	50	-55.15	-19.62	-65.35	-95.2	-11.3	-80.50	24.21	-29.82
11	55	-44.79	-14.97	-64.25	-81	-2.54	-76.11	26.13	-19.25
12	60	-27.32	-5.46	-23.01	-65.03	-4.5	-2.5	31.32	-18.1
13	65	-17.44	-8.99	21.00	-10.5	-35.82	2.34	33.52	-7.13
14	70	-9.04	-22.26	-20.75	-12.2	-45.34	4.5	35.82	-6.39
15	75	-8.61	-8.72	-75.23	-12.12	-48.54	1.7	34.23	-14.27
16	80	-8.25	-14.35	-109.50	-10.12	-11.33	-79	31.91	-16.94
17	85	-40.24	-0.67	-34.2	-4.01	-3.54	-28.01	21.82	-30.27
18	90	-4.79	-3.55	-31.2	1.02	-1.67	-5.28	18.95	-30.27
19	95	10.26	30.05	-44.3	2.03	2.54	-2.35	18.11	-29.95
20	100	6.24	20.04	-56.95	4.03	11.5	-0.26	16.22	-28.31
21	105	-1.56	-118.00	-3.21	-0.1	-2.44	3.61	13.62	-26.11
22	110	-0.49	21.89	1.9	-2.05	-7.4	11.26	10.77	-21.22
23	115	3.64	11.17	-1.24	1.03	-9.33	-0.32	14.72	-20.78
24	120	1.05	16.78	-5.71	4.11	10.23	1.59	20.54	-14.52
25	125	4.1	27.47	-34.82	2.1	14.78	-4.59	21.42	-13.92
26	130	-0.25	-0.35	-37.72	5.12	-0.35	-6.35	19.02	-12.63
27	135	3.64	-1.71	-20.21	10.11	-3.64	-0.12	23.01	-10.25
28	140	4.02	-4.29	-10.14	2.02	-9.53	4.88	40.25	-8.25
29	145	5.05	-11.33	-0.25	4.31	4.11	3.15	16.21	-6.72
30	150	4.08	4.58	4.58	3.01	2.34	-1.24	28.46	-10.82
31	155	-0.25	2.63	2.32	-0.25	-1.23	-2.01	13.45	-11.27
32	160	-1.81	-1.73	1.73	1.25	-0.55	2.11	42.01	-0.25
33	165	3.28	4.2	4.32	3.62	1.67	5.29	30.21	1.23
34	170	4.16	4.16	0.17	4.21	2.27	11.02	28.43	4.23
35	175	2.31	3.5	0.19	4.28	1.34	2.72	35.23	3.57
36	180	-0.15	7.51	5.02	2.84	2.14	-0.28	16.13	1.23
37	185	1.01	10.81	6.03	3.22	-3.21	-1.25	25.87	-0.13
38	190	5.61	7.2	6.03	10.25	-1.25	-0.12	38.41	5.28
39	195	3.22	6.9	7.13	2.78	2.52	4.77	27.56	2.37
40	200	1.11	10.5	8.72	11.81	11.25	3.81	37.41	3.27

Maximum values　　Minimum values

Table 2: Summarized Result of electrical resistivity Survey in the study area

S/N	Space (m)	$\ell a_1(\Omega m)$	$\ell a_2(\Omega m)$	$\ell a_3(\Omega m)$	$\ell a_4(\Omega m)$	$\ell a_5(\Omega m)$	$\ell a_6(\Omega m)$	$\ell a_7(\Omega m)$	$\ell a_8(\Omega m)$
1	5	147.41	124.15	157.78	133.89	176.64	145.21	160.92	109.06
2	10	100.58	119.43	108.43	63.8	142.06	132.32	156.52	79.2
3	15	67.57	82.03	72.29	121.63	115.3	135.46	168.46	73.86
4	20	64.43	36.14	61.29	133.58	82.35	121.63	164.06	69.46
5	25	104.35	56.2	79.52	116.92	69.77	66.63	160.29	65.06
6	30	79.2	122.58	100.89	61.92	27.34	111.89	132.95	62.23
7	35	27.34	119.43	113.46	70.4	98.06	116.92	110.63	88.95
8	40	67.26	113.78	88.63	72.6	101.2	132.32	104.66	69.46
9	45	70.09	132.01	72.6	80.46	115.3	121.63	100.89	72.92
10	50	47.77	123.21	61.29	109.06	132.95	79.2	110.32	98.69
11	55	57.52	107.18	45.57	151.81	110.63	49.35	134.21	100.89
12	60	79.2	100.89	69.46	132.63	104.03	61.29	143.95	120.38
13	65	82.66	97.43	77.43	145.21	68.83	51.86	135.78	76.06
14	70	110.63	79.2	88.95	131.06	66.32	90.2	148.66	96.49
15	75	66.32	100.89	55.32	101.2	49.35	67.89	160.61	99.95
16	80	72.92	117.86	27.34	86.12	80.78	61.92	163.75	101.2
17	85	104.35	114.86	45.57	98.38	84.23	74.49	167.21	72.6
18	90	76.29	69.46	72.92	90.2	87.06	90.52	177.89	68.52
19	95	39.29	60.35	108.43	82.66	110.63	107.49	163.75	74.49
20	100	82.66	25.46	50.92	83.92	101.2	112.21	159.04	66.32
21	105	92.72	22.63	77.32	72.6	80.78	132.32	155.58	101.2
22	110	120.38	67.26	72.92	80.46	76.69	137.66	132.95	119.75
23	115	132.01	61.29	108.43	113.78	102.78	138.29	125.09	113.78
24	120	99.07	83.92	69.46	69.77	132.63	143.64	120.06	101.2
25	125	88.95	123.21	61.6	80.78	157.46	136.09	111.58	93.35
26	130	130.75	107.8	79.52	82.66	164.69	148.35	87.38	88.95
27	135	79.52	82.66	80.46	111.89	100.89	123.52	77.00	88.63
28	140	42.43	101.2	108.43	132.32	99.00	113.78	121.63	102.78
29	145	76.06	121.63	76.37	135.78	97.12	117.23	159.35	120.06
30	150	142.38	92.72	80.46	100.89	132.32	121.63	134.78	112.21
31	155	77	108.43	85.8	78.89	131.69	112.52	135.78	102.46
32	160	70.01	105.29	69.46	76.67	129.49	101.52	161.24	90.2
33	165	151.81	102.15	65.69	69.77	132.63	107.49	93.66	93.66
34	170	98.69	76.69	79.2	111.89	104.66	121.63	113.78	110.63
35	175	101.2	82.66	104.35	116.92	107.49	103.4	120.06	101.52
36	180	120.69	108.43	101.83	122.89	129.81	145.52	134.21	132.63
37	185	148.35	69.46	121.63	134.21	135.78	132.32	129.81	135.78
38	190	78.58	125.09	75.75	107.8	143.32	135.78	135.78	132.32
39	195	98.38	132.01	139.86	142.06	156.21	131.69	161.55	135.46
40	200	142.06	160.29	167.21	135.78	168.15	132	180.72	163.44

Maximum values   Minimum values

While the very low values of the two geophysical methods suggest potential occurrence of Pb-Zn sulphide filled veins, high values suggest areas away from possible deposits.

DISCUSSION

A correlation of the plots of SP and Resistivity data in profile 1 (Fig. 2) identified two (2) Pb-Zn veins which are separated by a thin wall of the host rock. Their SP values are < -50 mV, while their resistivity values are < 50 Ωm. A correlation of the two data sets for profile 2 (Fig. 3) also identified two sulphide filled veins which are situated approximately 70 m apart, with their SP and resistivity readings being < -50 mV and < 50 Ωm respectively. A correlation of both plots along profile 3 (Fig. 4) indicates two possible veins juxtaposed to each other. The plots of both data along profile 4 (Fig. 5) suggests the presence of a sulphide vein which is relatively wide when compared with others previously identified. The plots of both data sets along profile 5 (Fig. 6) revealed the presence of two sulphide veins with a thin separation. The plots of both readings from profiles 6 (Fig. 7) and 7 (Fig. 8) respectively identified the

Fig. 2: SP and Resistivity plots of Profile 1

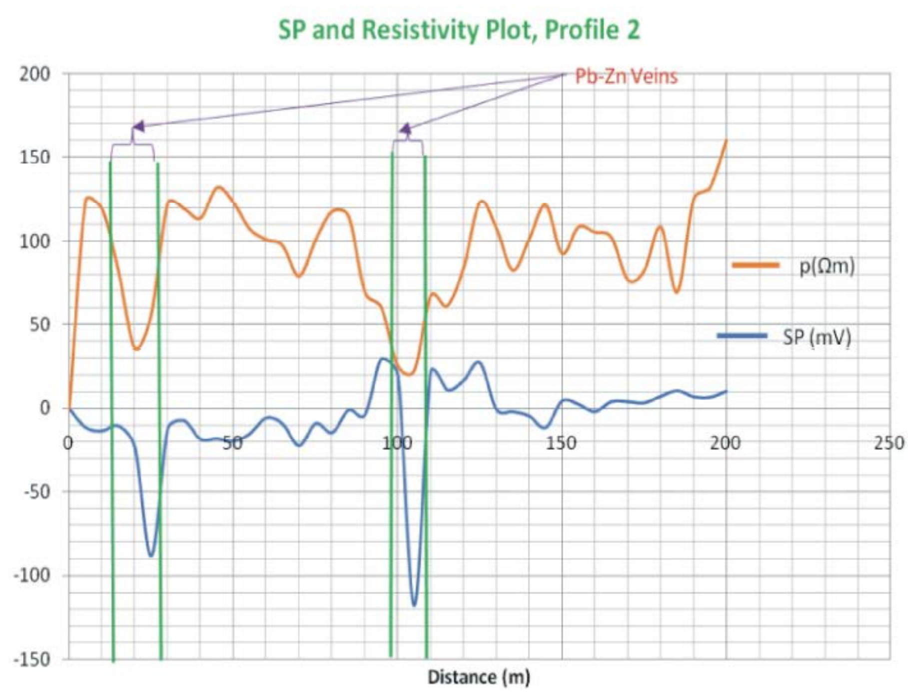

Fig. 3: SP and Resistivity plots of Profile 2

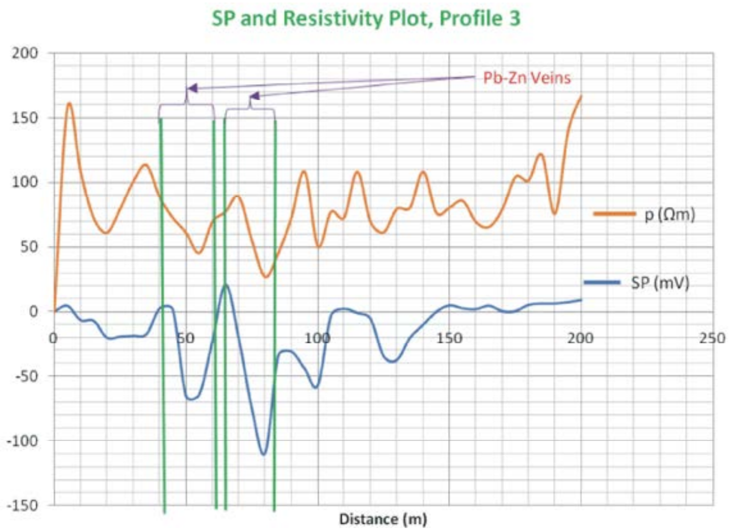

Fig. 4: SP and Resistivity plots of Profile 3

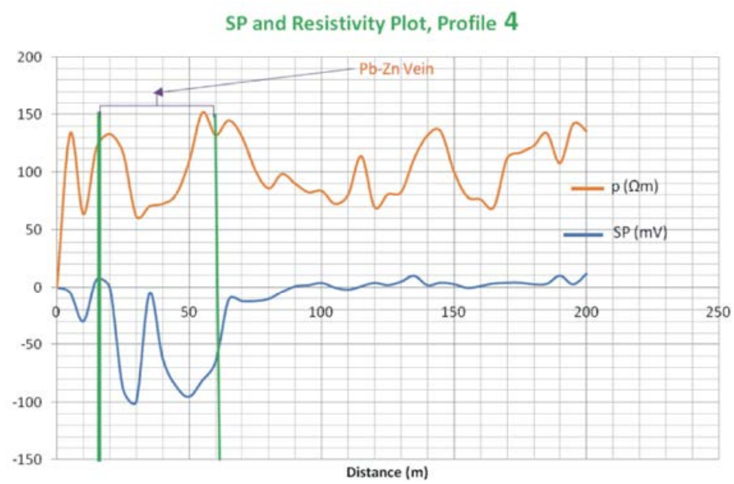

Fig. 5: SP and Resistivity plots of Profile 4

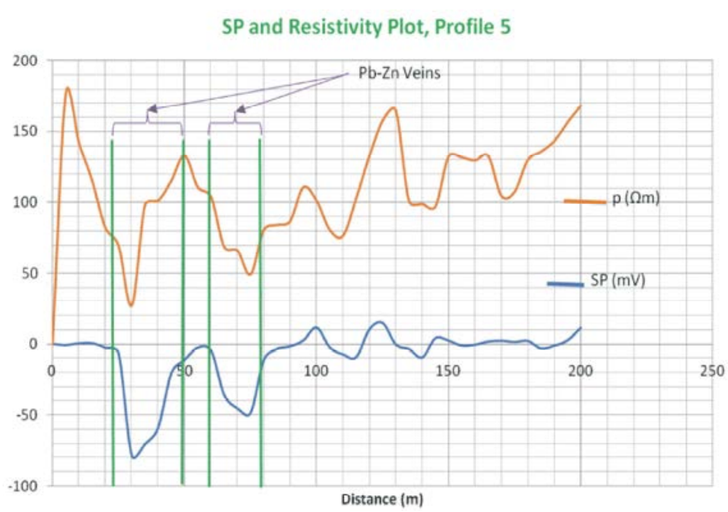

Fig. 6: SP and Resistivity plots of Profile 5

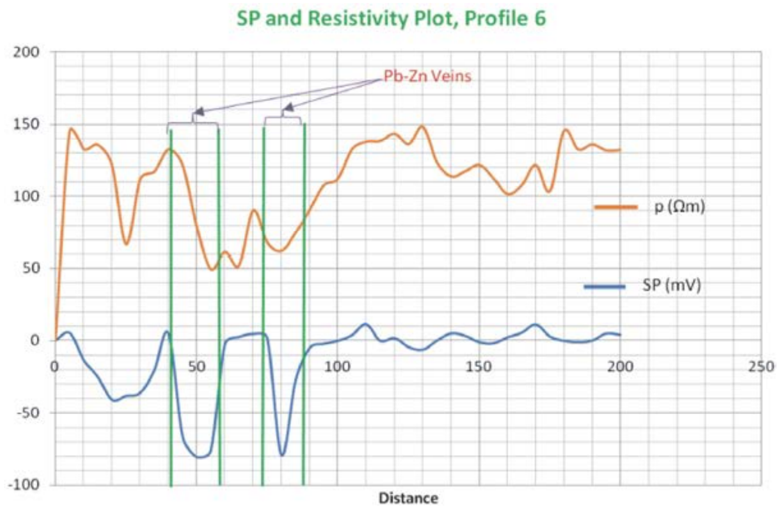

Fig. 7: SP and Resistivity plots of Profile 6

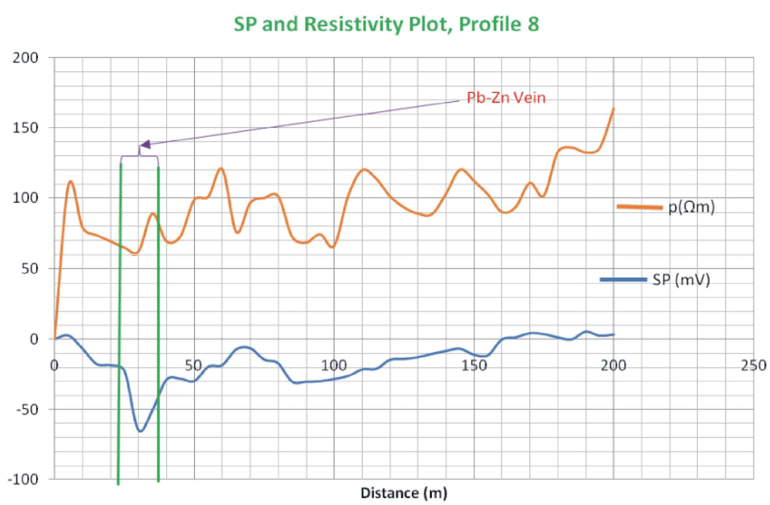

Fig. 8: SP and Resistivity plots of Profile 8

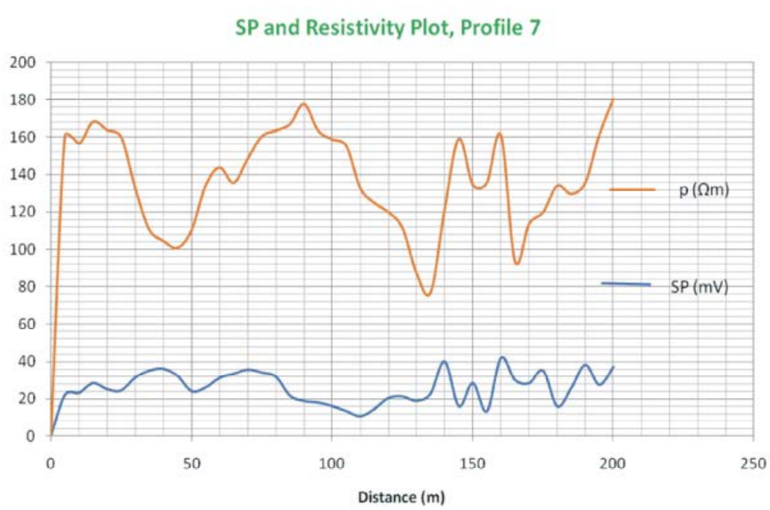

Fig. 9: SP and Resistivity plots of Profile 7

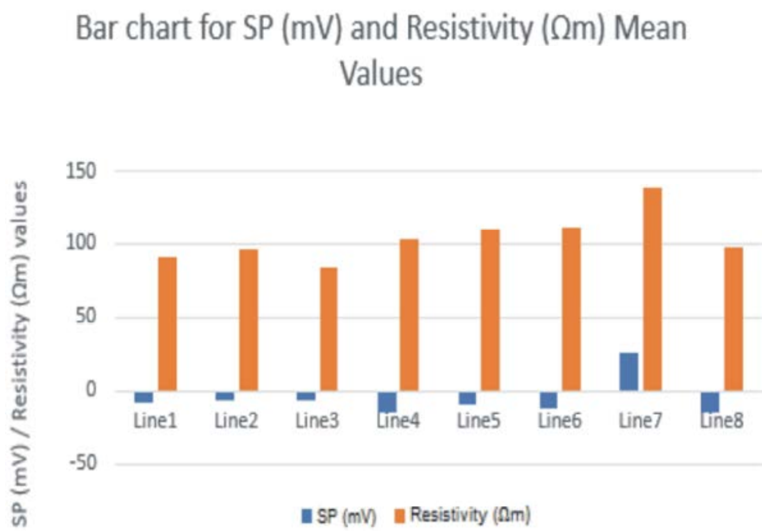

Fig. 10: Mean values of SP and Resistivity plots along the 8 profiles

presence of two (2) and one (1) sulphide veins in the areas respectively. The plot of both geophysical data along profile 7 (Fig. 9) indicates that the survey did not intersect any sulphide vein. A correlation of the mean values of both methods across the eight profiles (Fig. 10) suggests profile 3 as the most prolific of the eight profiles. The narrow nature of the lodes and their discontinuation along each traverse supports the view that they are vein fillers.

All the Pb-Zn deposits identified in the study area had SP values of ≤ -50 mV. The lower the value of the SP reading, the higher the accuracy of the survey and the higher the quality of the ore. The width of the negative anomaly curve suggests the horizontal thickness of the ore veins. The result of the resistivity survey did not correlate well with those of SP at some locations (Figs. 2, 7 and 8). However, at points where they are quite correlatable, it could be observed that the resistivity values for the ore filled veins are < 50 Ωm. At points of poor correlation, the SP data was relied upon for interpretation, which paid off. This suggests that the SP method is more reliable than a one-dimensional (1D) lateral resistivity profiling method in detecting fractures filled with Pb-Zn ores in sedimentary terrains.

CONCLUSION

The spontaneous potential and resistivity methods were integrated to delineate Pb-Zn ore veins in the study area. The result of this work provides information on the response of the ore veins to the two (2) simple but basic geophysical approaches to survey for solid minerals. In the absence of some more advanced cum sophisticated equipment, qualitative exploration of these deposits could continue with the available ones. This work has further emphasized the relevance of the application of an integrated approach in the exploration of solid minerals.

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