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Original Paper

Geophysical Mapping by Electromagnetic Induction of Gold Occurrences in Birimian Formations of Liptako: Case of Sorbon Haoussa Sector (Souhwest Niger)

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Abstract

The survey zone corresponds to the Sirba greenstone belt, one of Liptako Birimian Formations (LBF) of Niger. Previous aeromagnetic and geochemical works reveal the significant gold occurrences. The present study integrates geophysical mapping of these occurrences by electromagnetic induction on field. A multi-frequencies system of 10 frequencies was used for depth and subsurface investigation of resistive anomalies. The interpretation of obtained results shown two types of resistive anomalies, corresponding to the conductive units: deep anomalies obtained with low frequencies and subsurface anomalies detected with high frequencies. The subsurface anomalies were detected around the 15 meters and the deep anomalies were recorded beyond 80 meters. All of the detected resistive anomalies are in a lenticulars shapes oriented N-S or E-W. The analysis of combined resistivity map from all frequencies shown three zones of resistive anomaly presenting a high potential in conductive metals: The first zone Z1 (most important), located in Eastern studied zone covering, covering a surface of 3.5 Km^2, the second zone Z2 is located in West and covers an area of 2.9 Km^2 and the third anomaly zone Z3 is located in South with a surface of 0.96 Km^2. On field, these conductive units correspond to auriferous quartz veins and/or highly altered manganese schists, exploited by using the artisanal mining wells, up to 20 meters in depth.

Keywords

electromagnetic induction, resistive anomaly zone, gold occurrences, Sirba Greenstone Belt, Liptako Birimian formations, Niger

1. Introduction

The studied area (Sorbon Haoussa) is located in northeastern part of the Sirba volcano-sedimentary belt, one of the three belts of Lower Proterozoic Birimian greenstone formations to the SW of Niger (Figure 1a). The two main geological units are the granitic batholite to the SE and the volcano-sedimentary formations to the NW. The survey area covered a surface of 21 Km^2 with the altitudes varying from 220 to 264 meters (Figures. 1b, c). This zone is well known for its significant gold mineralization, generally contained in graphitic and or manganous schists (Project NER/88/023, 1991; JICA, 1993; Colin Brown, 1998; Project PADEM, 1995; Claude Jobin et al., 2010). It has significant gold occurrences (JICA, 1993; PADEM Project, 1995; Claude Jobin et al., 2010), which are exploited by using artisanal mining pits, systematically implemented. Previous works are limited to airbone geophysic (Project NER/88/023, 1991) and geochemical (JICA, 1993; Project PADEM, 1995; SEMS Exploration Services Ltd. 2009; Claude Jobin et al., 2010) prospection. This study aims to determine the subsurface and depth spatial distribution of these occurrences. To achieve this objective, geophysical method by multi-frequency electromagnetic induction was adopted. These surveys specifically allowed the mapping of conductive (mineralized zones) and resistive (host rocks) units as well as the directions, thicknesses and depths of the anomalies.

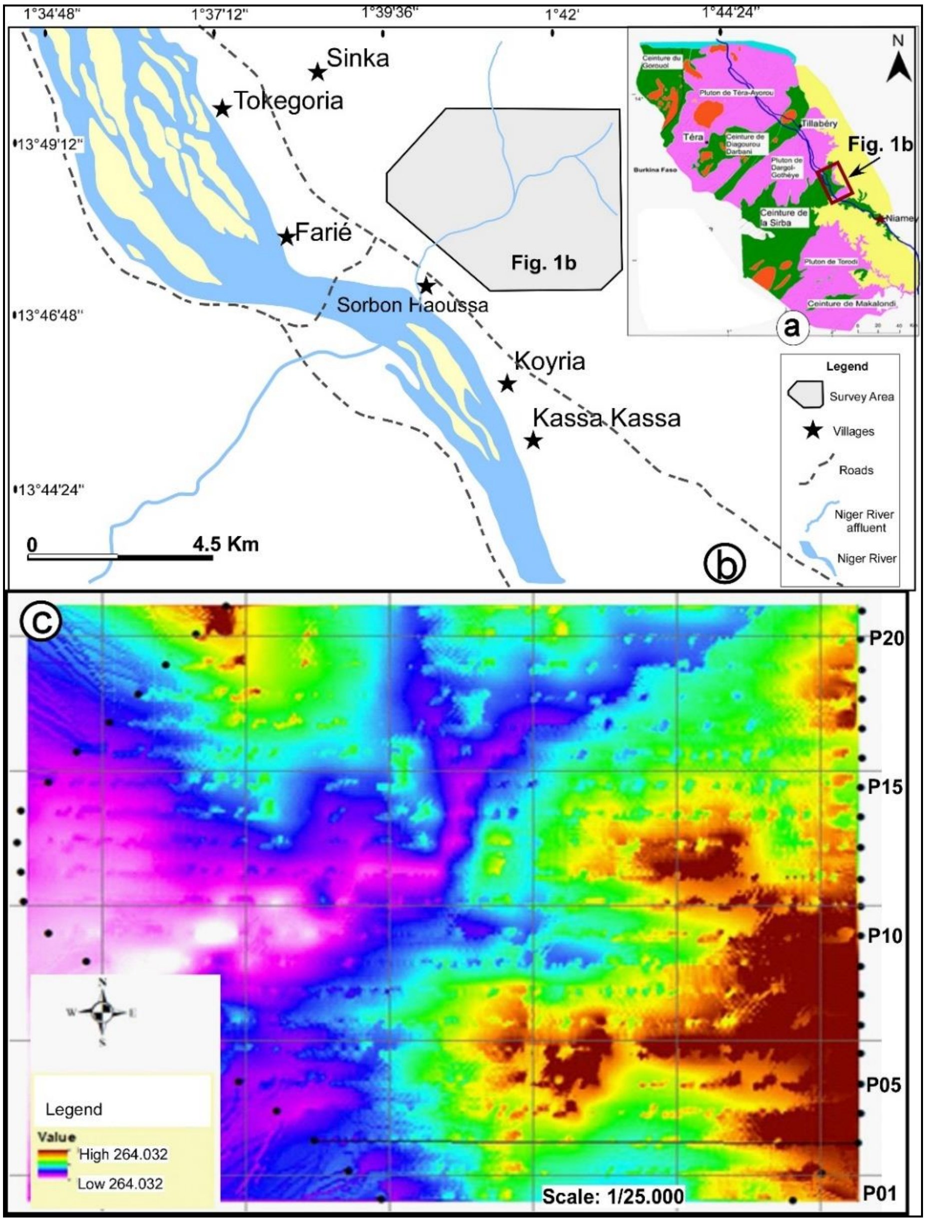

Figure 1. Locations of the Study Area within the Geological Map of Liptako Birimian Formations of Niger (a, b) (Machens, 1973; Dupuis et al., 1991; Abdou et al., 1998) (c): Topographic Map and E-W Electromagnetic Survey Grid

2. Method

Multi-frequency electromagnetic surveys allow to detect and map mainly the variations of conductive units in the subsurface (Acdi, 1973; Grauch et al., 2006) conductive veins and fractures. The survey grid used in the case of this study is consisted of 21 parallel lines with E-W direction (Figure 1c). The measurement stations are equidistant of 50 meters and are marked by stakes set up and surveyed with Differential Global Positioning System (DGPS). The PROMIS-10 system used in this work is a new multi-frequency electromagnetic induction technology that can send up to 10 frequencies up to 14 080 Hz, 28160 Hz and 56320 Hz for high frequencies. The other frequencies are 110 Hz, 220 Hz, 440 Hz, 880 Hz (low frequencies) and 1760 Hz, 3520 Hz, 7040 Hz (medium frequencies). In this system low frequencies are the most penetrative while high frequencies allow the investigation of the sub surface. In addition, the PROMIS-10 can record secondary magnetic fields along three axes X, Y and Z. The measurements are made profile by profile. At each measuring station, the system passes automatically from one frequency to another, which makes it possible to carry out a vertical survey (in depth). The subsoil is thus characterized horizontally and vertically along each profile, which allows to map the conductive anomaly in depth and in subsurface.

Geo-electric parameters such as resistivity, depth and thickness of each conductive level are also determined. The depth of investigation varies according to the transmission frequency, the resistivity of medium and transmitter-receiver distance. In general, it is equal to half of the transmitter-receiver distance but can reach 100 to 125% of this distance depending on the conductivity of the medium.

The principle (from the general viewpoint) is described as follows: When an electromagnetic wave penetrates the underground, it induces eddy currents in any conductive body (Faraday's Law of Induction) which then generates a disturbing magnetic field (Ampere's Law) of the primary magnetic field of the transmitter. The primary field Hp and the secondary field Hs are recorded at the receiver (Figure 2).

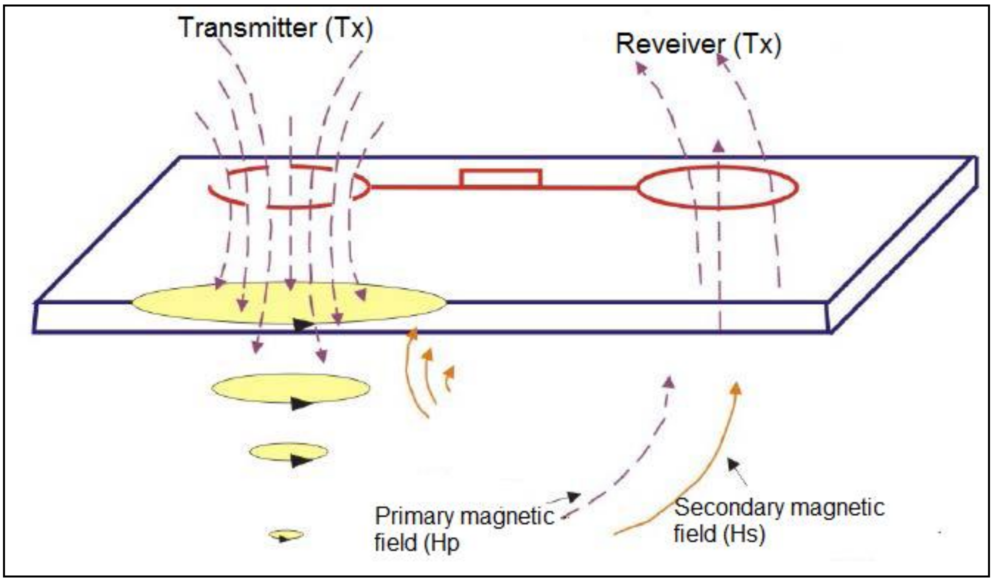

Figure 2. Electromagnetic Induction Device with Transmitting (Transmitter Tx) and Receiving (Receiver Rx) Loops Showing the Process of Penetration of Electromagnetic Field into the Underground and the Generation of Electric Currents and Recorded Secondary Magnetic Fields

3. Result

3.1 Results of Electromagnetic Survey

The results of the electromagnetic survey are distributed as follows (Appendix 1): Total number 21 profiles carried out oriented East-West, spaced of 200 meters. Total length of the profiles: 101.000 m and 2037 drilling points spaced of 50 meters. The data obtained allowed on the one hand to determine the geo-electrical parameters, in particular the resistivity, the thickness and depth of the anomaly (Appendix 2) and on the other hand to map the resistive anomaly zones (low, medium and high frequencies) corresponding to the conducting levels.

3.2 Analysis and Interpretation of Resistive Anomaly

3.1.1 Anomaly Maps for Low Frequencies

The resistivity anomaly maps, low frequencies (110 Hz, 220 Hz, 440 Hz; D), 880 Hz; Figure 3 shows a spatial variation in the electrical resistivity data. They highlight the existence of an E-W conductive structure located on profile 12. This structure is highlighted by the 110 and 220 Hz frequencies (Figure 3 a, b) which are the most penetrative. A resistivity anomaly appears also in the eastern part of survey zone, marked by very low resistivity values revealing the high conductive units with varying depths. The presence of shallower resistive units that can be un-mineralized quartz veins (resistivity between 300 and 500 Ohm.m) can be observed.

The resistivity anomaly map, from all low frequencies (Figure 4) shows that the high conductivity units have a lenticular shape (green, blue and red color) contained in a resistive unit (host rock). These conductive lenses show a N-S alignment in the East of the zone, which can be considered as a zone having a highly potential in conductive metals (gold anomaly). The scattered high resistive lenses are observed in the center and in South of the zone, forming a cluster oriented E-W (Figure 4). On field, the conductive lenses correspond to quartz veins and/or highly altered manganese schists, operated by using the mining wells up to 20 meters in depth (Figure 5).

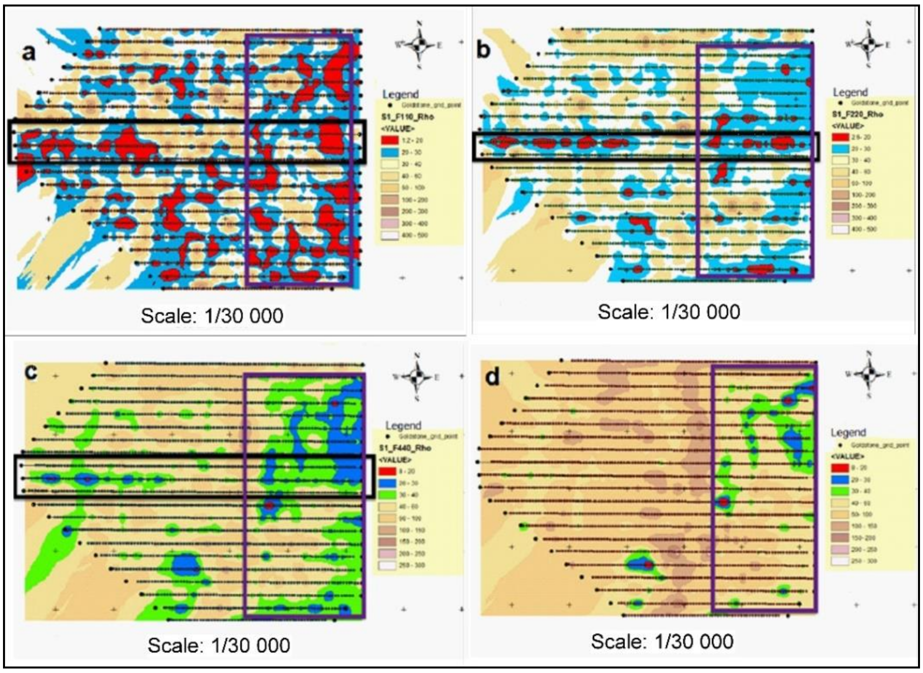

Figure 3. Resistivity Anomaly Maps for Low Frequencies: a) 110 Hz), b) 220 Hz, C) 440 Hz; D), d) 880 Hz

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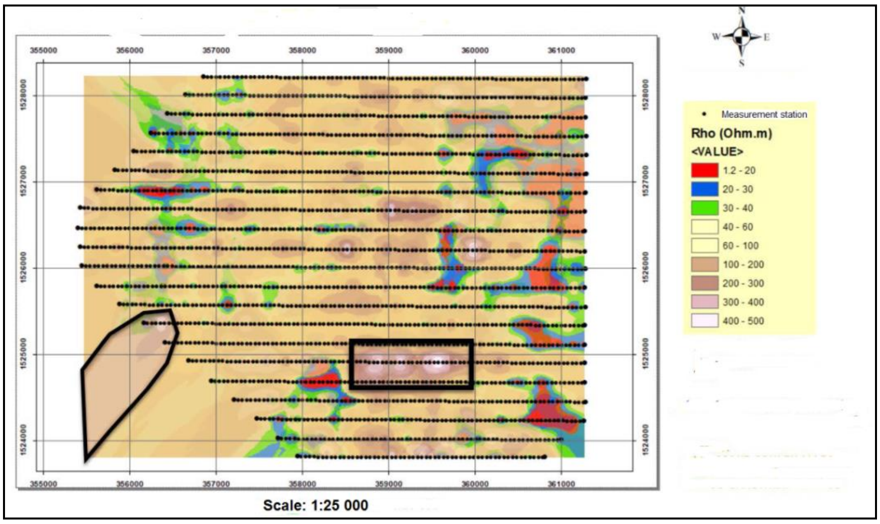

Figure 4. Combined Resistivity Anomaly Map for All Low Frequencies, Showing the Spread High Conductive Units in Lenticular Shapes (Green, Blue and Red Color). Other Colors Represent Resistivity Units (Host Rocks)

Figure 5. Photographs of Host Rock Outcrops for Gold Showings and Artisanal Mining Pits, Showing the Gold Bearing Outcrops

3.1.2 Anomaly Maps for Medium Frequencies

Medium frequencies are less penetrative than low ones. Analysis of the resistivity anomaly maps for the mid-frequencies (Figure 6) confirms the existence of three anomalous zones oriented N-S highlighted by the low frequencies (Figure 6 a). In addition, the 3520 Hz and 7040 Hz frequency maps (Figure 6 b and c) show the highly resistive levels, oriented N-S that can correspond to mineralized quartz veins.

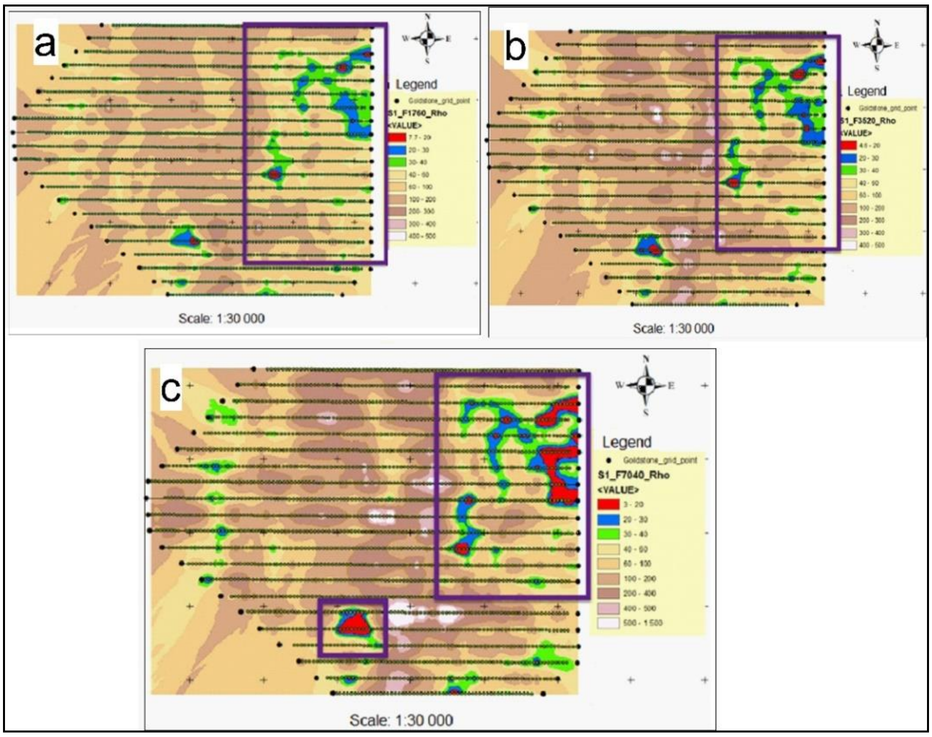

Figure 6. Resistive Anomaly Maps for Medium Frequencies: a) 1760 Hz), b) 3520 Hz, c) 7040 Hz

3.1.3 Anomaly Maps for High Frequencies

The high frequencies are the least penetrative and their depth of investigation varies from 1 to 10 meters for subsurface conductive units. The 14080 and 28060 Hz high frequency maps (Figure 7a, b) show the presence of subsurface conductive units in East, West and South. Whereas the 56320 Hz frequency map (Figure 7c), more superficial, shows resistive levels in South specifically on the first 6 profiles, in extreme North and West. These resistive levels could be the acidic intrusive units (granodiorite/granite) and un-mineralized quartz veins (Claude Jobin et al., 2010). The abundance of resistive units in 56320 Hz frequency map (Figure 7c) reveals the high meteoric alteration of host rocks on the surface. In the field, the conductive units (gold mineralization) are either associated with alluvium from meteoric alteration of manganese schists, or generally associated with highly altered quartz veins with low sulphide content. They are identified in the artisanal mining pits of gold.

The resistivity map from all frequencies (Figure 8) shows the spatial distribution of high mineral potential anomalies in the study area. Three resistivity anomaly zones with a high potential in conductive metals can be referenced Z1, Z2 and Z3 (Figure 8):

The first zone Z1 (most important), located in East of the area has a N-S trend and covers an area about 3.5 Km2;

The second zone Z2 is located in West with a N-S direction and covers an area of 2.9 Km2;

The third anomaly zone Z3 is located in South with a surface of 0.96 Km2, oriented N-S.

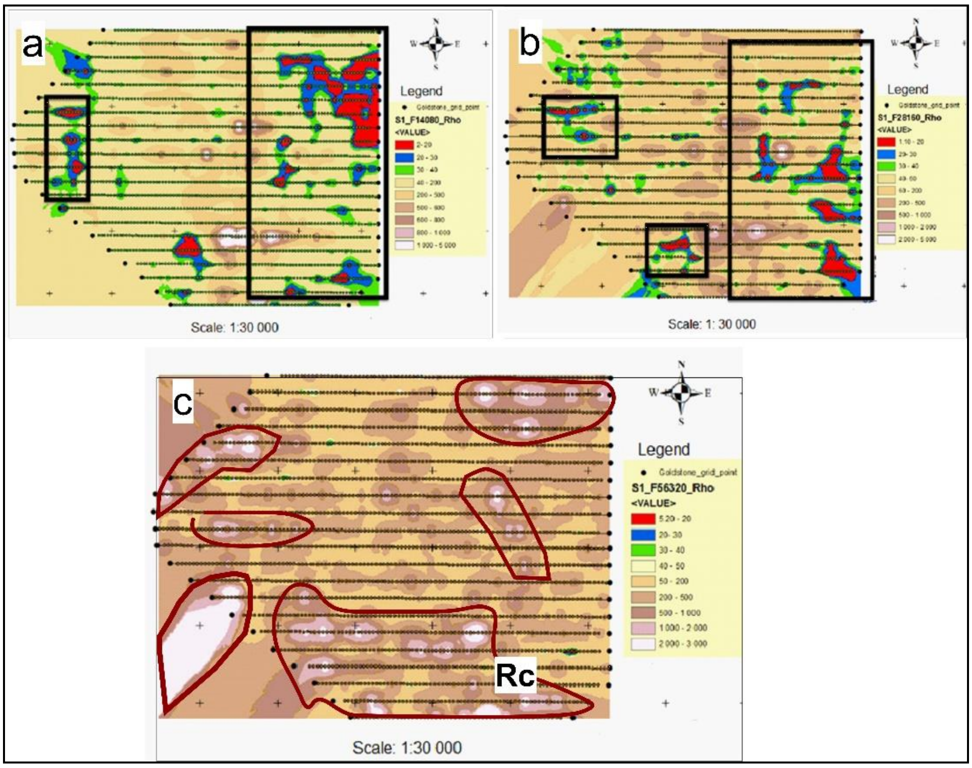

Figure 7. Resistive Anomaly Maps for High Frequencies: a) 14080 Hz, b) 28060 Hz, and c) 56320 Hz. Rc: Resistivity Contour

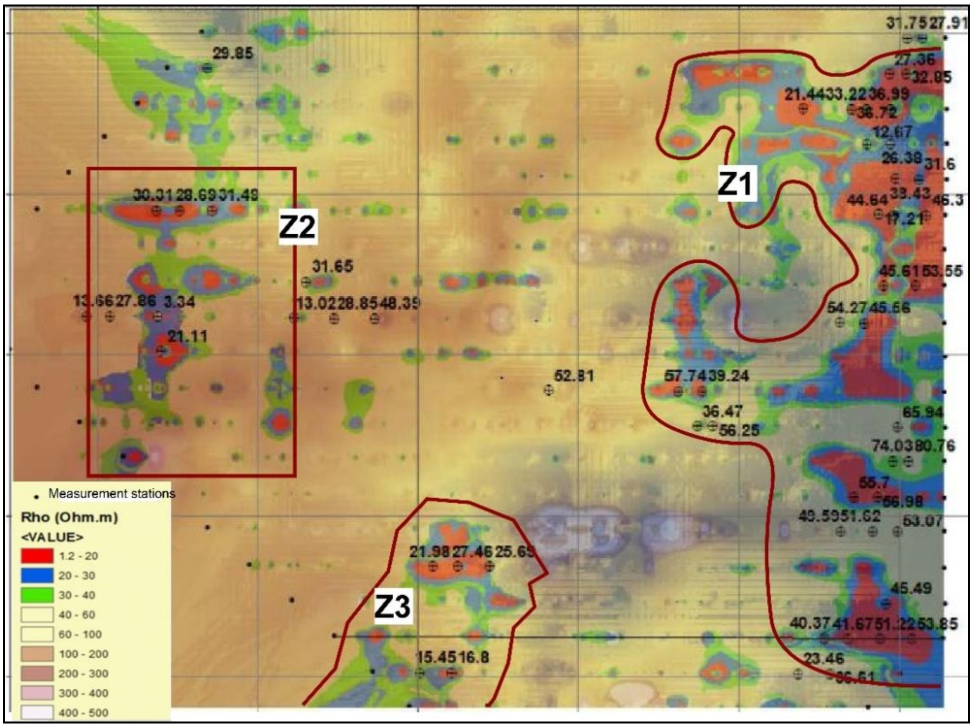

Figure 8. Spatial Distribution Map of High Potential Zones in Conductive Minerals from All Frequencies Showing the Location of Drill Points and Associated Anomaly Depths

3.3 Analysis of Geo-Electric Data

Geo-electrical parameters (resistivity values, anomaly depth and thickness) of anomaly by profile are indicated in the appendix 2. Four types of anomaly according to resistivity values are observed: very high (1 to 7 Ohm.m), high (7 to 10 Ohm.m), medium (10 to 19 Ohm.m) and low (19 to 52 Ohm.m). The projection of anomaly depth (Figure 8) show that the high values of depth are concentrated in East corresponding to Z1 of the survey zone and relative low values of depth in Northwest corresponding to Z2 and in South Z3. These observations reveal that the anomaly zone Z1, located in upstream (Figure 1c), corresponds to the deep anomaly (primary) and Z2 and Z3 subsurface anomalies (secondary). The secondary anomalies zone Z2 and Z3, located in downstream can be interpreted as result of upstream (Z1) high alteration.

4. Discussion

Petrographically, the survey area consists of altered black schists crossed by dolerite, quartz and granite dykes (Claude Jobin et al., 2010). The observation on field shown that the conductive lenses highlighted by the resistivity anomaly map (Figure 4) correspond to auriferous quartz veins and/or highly altered manganese schists, operated by using the mining wells up to 20 meters in depth (Figure 5). Petrographic observations carried out in the artisanal mining wells shown that the black schist formations and acidic intrusive units are the main host rocks of conductive lenses. The geochemical prospection carried out in these host rocks revealed the gold contents varying from 20 ppb to 300 ppb (JICA, 1993). According to Claude Jobin et al. (2010), these black schist formations represent a chemical trap favorable to the gold precipitation from mineralized fluids. According to the same authors, a structural control of gold mineralization is associated to the features oriented N60° (M'Banga, Tiringui cluster), N90° to N110° (Sefa Nangue), N130° to N140° (Samira, Libiri, Koma Bangou), N350° to N10° (Tera and Allareni clusters), all located in Southwest of survey area. Further in Southwest of studied zone, magnetic and aeromagnetic data from several auriferous sites of Burkina-Faso have showed the similar observations. Indeed, in these regions, gold mineralization is tectonically controlled by an irregular NE-SW (N60° to N90°) shear zone and hosted by small geophysical anomalies units corresponding to an altered and silicified green schist facies (Sawadogo et al., 2018; Aziz et al., 2016; Bilardello & Jackson, 2014).

5. Conclusion

This study focused on the geophysical mapping of gold occurrences in Sirba greenstone belt, specifically in the Sorbon Haoussa area. Using multi-electromagnetic induction methods allowed to obtain thematic maps of deep and subsurface resistive anomalies. Geo-electric parameters such as resistivity, depth and thickness of conductive level are also determined. The projection of anomaly depth on resistivity map (all frequencies) led to determine the zone of high potential in conductive metals. This study helps to understand the geometry of anomalous zones as well as the depth and thickness of anomalous units. It constitutes also a guide to improve mining operations, which are hitherto artisanal.

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Appendixes

Appendix 1. Results of Electromagnetic Surveys

Profile	Number of Measurements by profile	Profile length (m)
Profile 1	56	2800
Profile 2	65	4200
Profile 3	75	3700
Profile 4	80	4000
Profile 5	86	4300
Profile 6	90	4500
Profile 7	97	4800
Profile 8	102	5050
Profile 9	107	5300
Profile 10	113	5600
Profile 11	115	5700
Profile12	116	5750
Profile 13	113	5600
Profile 14	116	5750
Profile 15	113	5600
Profile 16	109	5400
Profile 17	104	5150
Profile 18	104	5150
Profile 19	96	4750
Profile 20	92	4550
Profile 21	88	4350
Total	2 037	101 000

Appendix 2. Geo-electrical Parameters of Anomalies by Profile

Profile (P)	anomal stations	Ohm.m	Thickness (meters)	Depth (m)	Depth corrected (m)	RMS (%)	Anomaly
	S1	7.22	10.58	19	36	6.04	High
	S2	8.77	6.02	9.55	23.46	5.64	high
P2	S3	22.39	20.00	21.23	33.03	3.62	low
	S4	5.01	3.62	12.84	16.80	7.35	Very high
	S5	14.40	10.60	13.51	15.45	2.65	medium
	S1	9.04	11.16	19.99	40.37	2.31	high
	S2	2.47	5.16	18.05	41.67	4.95	Very high
P3	S3	6.04	7.58	22.08	51.22	2.29	Very high
	S4	6.53	13.77	23.62	53.85	2.62	Very high
	S1	15.04	17.30	36.37	69.45	4.93	Medium
	S2	15.61	16.73	35.79	67.12	4.81	medium
P4	S3	5.22	11.74	18.23	45.49	6.00	Very high
	S1	2.48	5.56	15.59	21.98	3.569	Very high
	S2	3.35	8.74	17.88	27.46	4.127	Very high
	S3	6.62	19.11	26.26	36.75	2.3819	Very high
P5	S4	2.27	6.00	15.01	25.69	3.3145	Very high
	S1	19.41	17.81	23.49	26.38	7.14	medium
	S2	18.44	16.88	17.63	19.73	4.91	medium
	S3	40.92	25.90	87.16	111.27	1.69	Low
	S4	2.52	5.01	20.01	49.59	8.79	Very high
	S5	3.62	7.67	19.16	51.62	2.35	Very high
P6	S6	6.35	10.71	21.04	53.07	4.44	Very high
	S1	19.64	32.56	38.54	73.88	1.57	Low
	S2	5.13	11.34	22.66	56.98	8.33	Very high
P7	S3	5.55	11.88	22.79	55.70	8.07	Very high
	S2	7.39	12.02	30.94	74.03	3.53	high
P8	S3	21.36	52.09	64.01	80.76	4.94	Low
	S1	3.34	7.96	18.32	59.11	2.48	Very high
	S2	5.68	13.86	25.30	65.94	8.21	Very high
	S3	6.99	25.86	34.05	56.25	10.10	Very high
	S4	2.05	6.91	16.22	16.22	36.47	Very high
P9	S5	19.16	24.78	49.03	68.16	3.07	low

	S6	13.00	23.14	33.50	49.01	8.59	medium
	S7	16.63	16.03	27.79	31.81	2.96	medium
	S1	8.81	17.27	38.14	52.81	8.64	High
	S2	6.11	34.85	37.78	57.74	12.85	Very high
P10	S3	2.35	7.20	16.95	39.24	3.30	Very High
	S1	52.02	18.79	89.90	89.86	3.37	low
	S2	6.98	7.62	46.41	59.54	3.80	Very High
	S3	7.16	12.04	17.46	21.11	3.16	high
P11	S4	22.82	11.61	13.05	16.33	3.29	low
	S1	5.48	10.20	12.77	13.66	11.99	Very High
	S2	10.58	17.32	27.00	27.86	5.31	medium
	S3	2.06	0.92	0.92	3.34	2.96	Very High
	S4	10.84	7.18	7.75	13.02	2.94	medium
	S5	19.56	14.98	25.22	28.85	10.38	low
	S6	6.40	18.79	44.50	48.39	8.47	Very High
	S7	13.95	14.55	27.34	54.27	7.39	medium
	S8	13.61	20.79	22.37	45.56	6.69	medium
P12	S9	38.88	25.79	37.97	60.63	8.39	low
	S1	9.44	14.33	22.23	31.65	9.53	high
	S2	21.39	22.15	22.15	45.45	1.49	low
	S3	23.85	22.08	22.08	41.48	6.55	low
	S4	6.05	26.07	26.72	45.61	13.76	Very high
	S5	27.63	1.55	28.27	47.16	13.76	low
	S6	12.47	0.16	0.16	20.45	12.02	high
P13	S7	6.82	33.11	33.26	53.55	12.02	Very high
	S1	11.96	15.75	19.04	20.45	3.36	medium
	S2	15.36	31.37	31.37	33.54	9.50	medium
	S3	14.30	26.01	27.89	30.31	6.21	medium
	S4	7.05	16.27	25.87	28.69	7.48	high
	S5	10.76	18.26	25.32	31.49	10.52	high
	S6	3.26	2.07	3.23	17.21	6.74	Very high
	S7	7.41	21.51	29.06	44.64	6.69	high
	S8	6.87	2.44	3.99	22.99	6.58	Very high
P15	S9	9.32	23.31	27.30	46.30	6.58	high
	S1	20.43	29.43	37.24	42.81	9.96	low
P16	S2	16.83	23.76	27.94	37.85	23.71	medium

	S3	11.85	22.84	23.70	35.12	9.06	high
	S4	4.27	22.34	23.87	38.43	12.53	Very high
	S5	3.49	13.46	14.06	31.60	7.32	Very high
	S1	8.25	10.65	11.07	26.38	3.09	high
P17	S2	1.43	0.81	1.52	12.67	7.22	Very high
	S1	6.75	15.08	15.66	21.44	2.19	Very high
	S2	6.84	24.48	27.12	36.72	11.55	Very high
	S3	6.97	0.25	0.25	10.64	13.47	Very high
	S4	3.18	17.69	21.72	33.22	7.57	Very high
P18	S5	5.23	19.95	22.25	36.99	4.32	Very high
	S1	4.58	15.45	18.55	34.70	5.79	Very high
	S2	4.08	9.97	19.20	32.85	5.07	Very high
	S3	4.35	13.33	15.17	27.36	2.98	Very high
P19	S4	4.58	15.45	18.55	29.85	5.79	Very high