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INTERPRETATION OF GROUND GEOPHYSICAL SURVEY DATA OF WADI EL-BOLLA AREA, ENTRAL EASTERN DESERT, EGYPT

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تفسير بيانات المسح الجيوفيزيائي الأرضي لمنطقة وادي البولا الصحراء الشرقية الوسطى ، مصر

الخلاصة: تغطى منطقة البولا بشكل أساسي صخور الأمفيبوليت والجرانوديوريت والجرانيت الأحدث والبيجماتيت ويتناول هذا العمل تطبيق المسح المغنطيسي الأرضي وقياسات الجهد الذاتي والكهرمغنطيسية ذات الحلقة الأفقية، وذلك لتحديد اتجاهات التراكيب الرئيسية ونطاقات التمعدنات وتتبع امتداداتها أفقياً وعمودياً.

أظهر المسح المغنطيسي الأرضي أن متوسط الأعماق المقدرة لكل من المصادر المغنطيسية الضحلة والعميقة، على النحو المحسوب من منحنى طيف القدرة ، يبلغ ١٥ م و ٤٨ م ، على التوالي. ترتبط اتجاهات شرق شمال شرق، وشمال شمال الشرق، وشمال–جنوب ، وغرب شمال الغرب بالشاذات المغنطيسية الضحلة التي تعتبر من أهم الأهداف لاستكشاف المعادن بالمنطقة تحت الدراسة.

تُظهر بيانات الجهد الكهربي الذاتي أن هناك العديد من نطاقات التمعدنات. تتوزع معظم هذه النطاقات على امتدادات خطوط التماس بين الجرانوديوريت والجرانيت الأحدث والبيجماتيت، وكذلك بعض مناطق التصدع . كشف التفسير الكمي ضحالة أعماق هذه النطاقات حيث تتراوح بين ٦,٦ م إلى ٢٥ م، مع عرض تتراوح بين ٥ م إلى ٢٠ م وميول منخفضة باتجاهات الجنوب والشمال.

تم تنفيذ ثلاث جانبيات بتقنية الكهرمغنطيسي ذي الحلقة الأفقية باستخدام أربعة ترددات: ١١٠ و ٤٤٠ و ٨٨٠ و ٣٥٢٠ هرتز. كشفت بيانات هذا المسح عن وجود أجسام موصلة ذات مقادير مختلفة في تمعدناتها .أوضح التفسير الكمى لهذه البيانات أن الأجسام الموصلة لها اتساعات ضيقة أقل من أو تساوى ٥م وأعماق تتراوح من ١١ م إلى ٢٦ م ، وتميل بشكل حاد في اتجاهي الشمال والجنوب، وأسماك موصلية تتفاوت من ١١,٤ الى ١٨١,٩ سيمنز/م. من خلال تكامل تفسير البيانات الجيوفيزيائية الثلاثة تم تحديد أنسب النطاقات لاستكمال الاستكشاف المعدني فى منطقة الدراسة.

ABSTRACT: *Wadi El-Bolla area, Centeral Eastern Desert, Egypt, is mainly covered by amphibolites, granodiorites, younger granites and pegmatites. This work deals with the application of magnetic, self potential (SP) and horizontal-loop electromagnetic (HLEM) techniques, to identify the main structural trends, delineate the mineralized zones and follow their extensions laterally and vertically in the study area.*

The magnetic survey showed that, the estimated average depths for the shallow and deep magnetic sources, as calculated from the power spectrum curve, reach 15 m and 48 m, respectively. The ENE-WSW, NNE-SSW, N-S and WNW-ESE structural lineaments are related to shallow structures, which in economic terms, represent the most important targets for mineral exploration in the study area.

The self-potential (SP) electric data show that there are numerous of mineralized zones. Most of these zones are distributed mainly along the contacts between the granodiorites, younger granites, pegmatites and some fault zones. The quantitative interpretation revealed shallow depths to the centers of eight of the selected anomalies (ranging from 6.6 m to 25 m), with half-widths (ranging from 5 m to 20 m) and shallow to moderate dips towards south and north directions.

Three horizontal - loop electromagnetic (HLEM) profiles was conducted using four frequencies: 110, 440, 880 and 3520 Hz. The HLEM data revealed the presence of some conductive bodies with different magnitudes in their mineralizations. The quantitative interpretation of these data showed that the conductive bodies have narrow widths (less than or equal to 5 m) and depths ranging from 11 m to 26 m, dipping steeply towards the north and south directions and conductivity thicknesses varying from 11.4 to 181.9 Siemens/m. The integration of SP and HLEM data defined the most appropriate zones for exploration development at the investigated area.

1. INTRODUCTION

Wadi El-Bolla area represents a part of the Central Eastern Desert (CED) of Egypt. It is located to the south of Qena - Safaga road, at about 40 km west of Safaga city on the western shore of the Red Sea, between latitudes 26º 37′ 40″ N & 26º 39′ N and longitudes 33º 35′ 55″ E & 33º 37′ 20″ E (Fig. 1).

The study area is covered by amphibolites, granodiorites, younger granites, pegmatites as well as Wadi sediments.

Radiometric exploration works in the CED of Egypt showed the potentiality of younger granites as a source of uranium [1, 2, 3, 4, 5 and others].

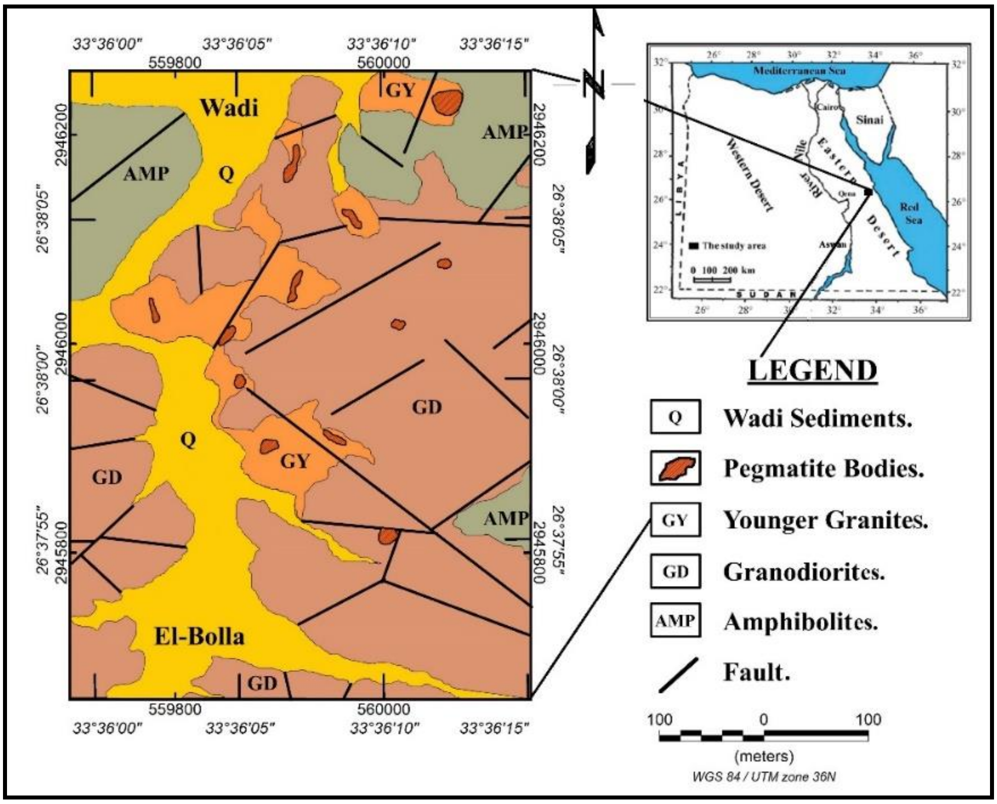

Fig. 1: Geologic map of Wadi El-Bolla area, Central Eastern Desert, Egypt (Modified after Oraby, 1995).

The results of radiometric investigations in Abu-Farad, Um-Taghir area (including the study area) discovered some radiometric anomalies, associated mainly with some pegmatite bodies, intruding Abu-Farad granitic mass and El-Bolla granodiorites [6].

The aims of this study are to identify the main structural trends affecting the study area using the magnetic survey, especially the shallow ones, follow any metallic mineralization that may be associated with radioactive mineralization at depth, using self-potential (SP) electric and horizontal-loop electromagnetic (HLEM) surveys.

2. GEOLOGIC SETTING

Wadi El-Bolla area is mainly covered with Precambrian basement rocks (Fig. 1), arranged from oldest to youngest as follows [6 and 7]:

2.1. Amphibolites

They are characterized by low relief and fine grain-size. Their contacts with granodiorites are sharp and frequently injected by pegmatitic lenses and veins, with high radiometric values, beside acidic dykes and veins.

2.2. Granodiorites (Older granites)

These rocks are highly fractured and jointed, commonly weathered to isolated low-lying hills. They are intruded by some younger granites forming peaks.

2.3. Younger Granites

These rocks are distinguished by their red to pink colour. Their contacts with all the surrounding rocks are sharp and well-defined. These granites are fine-grained and intruded by pegmatite lenses and dykes, with great variations in both length and thickness [8].

3. METHODS OF GROUND GEOPHYSICS

In the present study, magnetic, SP electric and HLEM surveys were applied (Figs. 1 and 4a). Magnetic survey measures the variations in the earth's magnetic field to identify the locations of subsurface objects, minerals and map basement structures [9]. SP method depends on the measurement of natural potential differences as a guide to the existence of mineralization [10 and 11]. The potentials of concern are permanently negative above a mineralized body. HLEM survey was conducted using frequencies (110 Hz, 440 Hz, 880 Hz and 3520 Hz). This method is always used to discover the conductive zones, especially which are related to shear zones, fractures and fault [14].

3.1. Data Acquisition and Corrections

A detailed systematic ground magnetic survey was conducted at this study for an area of 440 m x 560 m (0.246 km^2), with a grid pattern of 23 parallel profiles trending in the N-S direction. The data were taken with a profile length of 560 m, profile spacing of 20 m and station interval of 20 m. The magnetic survey was performed using a portable proton-precession magnetometer (PMG1, Geofyzika, Brno, Czech Republic). The magnetic data were subjected to diurnal, normal field and tie-line corrections.

The self-potential technique measures the differences of electrical potentials between pairs of non-polarizable electrodes through a high impedance multimeter. These electrodes contact the ground surface at survey stations. The SP survey was conducted along 18 profiles trending N-S, with a profile spacing of 20 m and a station interval of 20 m. An additional tie-line was selected in the perpendicular direction to assist in data correction. Figure (4a) illustrates the locations of the selected SP survey profiles. The SP data were corrected to a suitable reference station for the whole area and the results of self-potential survey were presented as a filled-colour map (Fig. 4b).

The HLEM survey was conducted using transmitter and receiver (Maxmin-8, Scintrex 1998), along three selected profiles with coil separation of 100 m and 20 m station separation. The HLEM profiles were performed nearly normal to the important structural lines and self-potential anomalies. Three profiles (coded 780, 880, and 940, Fig. 4a) were carried out. Two profiles were trending in an N-S direction and the third profile was conducted perpendicularly in the E-W direction (Fig. 4a). The 4 selected frequencies were 110 Hz, 440 Hz, 880 Hz and 3520 Hz. This selection helps to delineate the conductors at different depth levels.

3.2. Analysis and Interpretation

3.2.1. Magnetic survey data

The total-intensity magnetic map (Fig. 2a) was reduced to the north magnetic pole (RTP), utilizing the known inclination and declination: I = 39.11º, D = 3.8º of the study area. The RTP magnetic map (Fig. 2b) displays nearly the same magnetic characters, which are illustrated on the total magnetic-intensity map, with some stretching and repositioning of magnetic anomalies.

Fast Fourier Transform (FFT), was applied on the RTP magnetic data using Geosoft (2010), to explore the frequency content of these data and select the suitable cut-off frequencies for both the high-pass and low-pass filtered maps. The inspection of the power spectrum curve (Fig. 2c) distinguished the regional-magnetic component by a frequency band ranging from 0.0 to 6.0 cycle/grid unit. Meanwhile, the frequencies of the residual-magnetic component range between 6.0 and 39.0 cycle/grid unit. The residual and regional magnetic-component maps were produced using these frequency bands (Figs. 2d and 2e), by band-pass filter technique [12]. The estimated average depths for the shallow- and deep-seated magnetic sources, as calculated from the power spectrum curve, are 15 m and 48 m, respectively (Fig. 2c).

Close investigation of the RTP, residual- and regional-magnetic component maps show the existence of four magnetic zones according to their magnetic characters (Figs. 2b, 2d and 2e).

The first magnetic zone (Z1) extends from the southeastern to the mid-western part of the study area and trends in the NW-SE direction. All the positive anomalies that are encountered on the RTP and residual maps (Figs. 2b and 2d) disappeared on the regional map (Fig. 2e). This may reflect their shallow causative sources with shallow roots.

The second and third magnetic zones (Z2 and Z3) occupy the southwestern part and the northeastern parts of the study area, respectively. The high positive magnetic anomalies, which are observed along the RTP and residual maps (Figs. 2b and 2d) are also encountered along the regional magnetic anomalies in the same sites (2e), suggesting that their causative sources are of basic nature and deep roots.

The fourth and last zone (Z4) is located at the northern part of the study area. The continuity of the negative anomalies through the three maps (Figs. 2b, 2d and 2e) may suggest an acidic source that extends at deeper depths.

The interpreted structural magnetic lineaments (IMSL) at shallow and deep depths of the study area, were deduced from the RTP, residual and regional maps (Figs. 2b, 2d and 2e). Statistical trend analysis was achieved here for the frequency resolution of the azimuths and lengths of the outlined interpreted lineaments. The rose diagram of the RTP magnetic map (Fig. 3a) shows six trends that include NE-SW, E-W, N-S, NNE-SSW, NW-SE and WNW-ESE. These trends dominate on such map and are arranged in a diminishing order of magnitude. These trends are related to both near-surface and deep structures in the study area. For the residual map (Fig. 3b), the shallow structures affecting the study area have trends E-W, NNE-SSW, NE-SW, NW-SE and N-S. Finally, the regional map (Fig. 3c) shows the E-W, NW-SE, NNE-SSW, NE-SW and NNW-SSE trends. They represent the deep trends in the study area. Figure (3c) shows the rose diagram for the structural lineaments that affect the study area as deduced from the geologic map (Fig. 1). Comparison between this diagram and the residual (shallow) and the regional (deep) diagrams shows that, the E-W, NE-SW, NW-SE and NNW-SSE structural lineaments are related to deep structures. On other hand, the ENE-WSW, NNE-SSW, N-S and WNW-ESE structural lineaments are related to shallow structures. In economic terms, they represent the most important targets for mineral exploration in the study area. The interpreted magnetic structural lineaments (ISML), as deduced from the RTP, the residual and the regional magnetic maps are illustrated on Figures (3e, 3f and 3g).

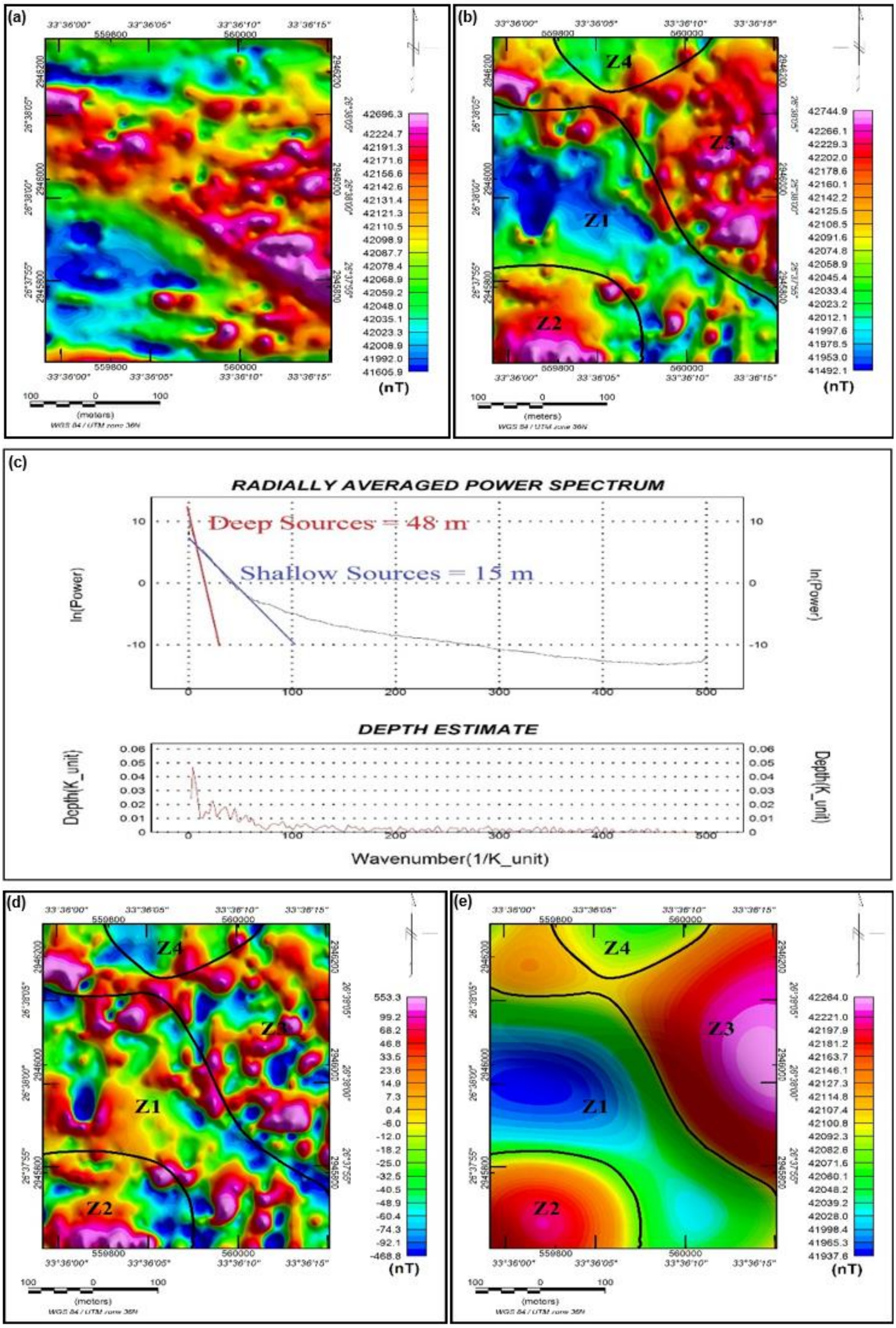

Fig. 2: Filled-colour maps of total magnetic-intensity in nT (a), reduced to the north magnetic pole (RTP), in nT (b). Average power spectrum curve of the RTP magnetic data (c), Filled-colour maps of the residual- magnetic-components (d) and the regional magnetic-components in nT (e), Wadi El-Bolla area, Central Eastern Desert, Egypt.

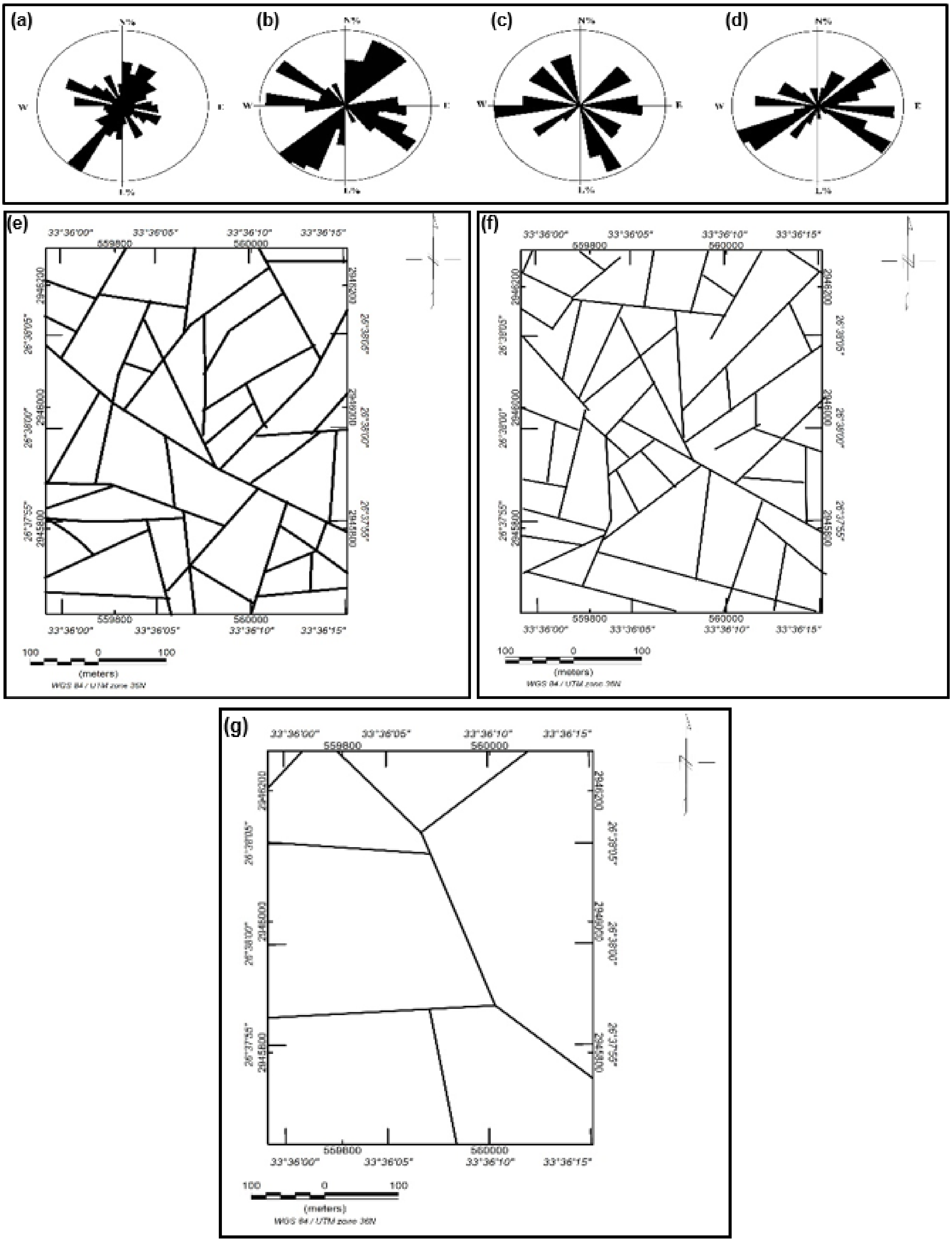

Fig. 3: Rose frequency diagrams showing the main interpreted magnetic structural lineaments (IMSL) as deduced from RTP magnetic map (a), residual magnetic-component map (b), regional magnetic-component map (c) and geologic map of the study area (d). Interpreted magnetic structural lineaments (ISML) maps as deduced from the RTP magnetic map (e), the residual magnetic-component map (f) and the regional magnetic-component map (g), Wadi El-Bolla area, Central Eastern Desert, Egypt.

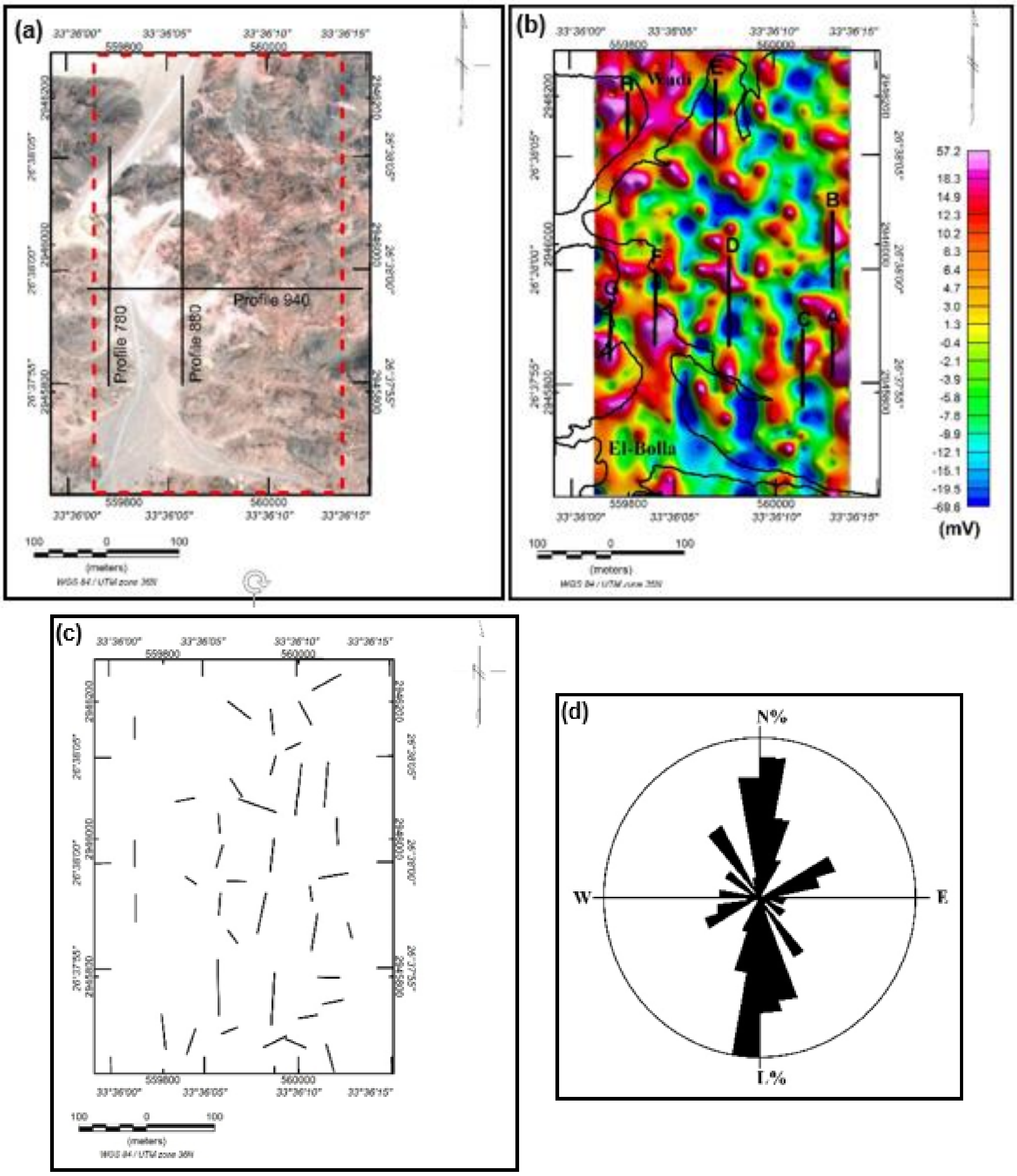

Fig. 4: (a) Google earth image showing the study area and the locations of self-potential (SP) survey profiles (red-dashed polygon) and ground horizontal-loop electromagnetic (HLEM) profiles (black-lines), (b) Self-potential (SP) filled-colour map showing the selected anomalies for quantitative interpretation, (c) interpreted structural lineaments as deduced from the SP map and (d) Rose frequency diagram showing the main interpreted structural lineaments as deduced from SP map, Wadi El-Bolla area, Central Eastern Desert, Egypt.

3.3. Self-potential (SP) electric survey data

The SP electric filled-colour map (Fig. 4b) shows that the study area possesses a range of about 125 mV of the potential differences between the measured stations. Generally, the increase of the SP negative values indicate the increase of mineralization. Relatively strong negative SP anomalies (-20 to -69 mV) are located along the contacts between younger granites, granodiorites and amphibolites; beside on some parts on the granodiorites and amphibolites. Meanwhile the relatively strong positive anomalies (10 to 57 mV) occur over Wadi sediments, located on the western part of the study area, beside over some parts of the granodiorites and amphibolites.

The interpreted structural lineament trends as deduced from the SP anomalies (Figs. 4c and 4d), revealed a relatively well agreement with both residual-magnetic component structural trends and geologic structural fault directions (Figs. 3b and 3d). This agreement confirmed the probable relation between the accumulations of mineral deposits within the shallow geologic structures.

The quantitative interpretation of the SP data depends usually on the transformation of the SP anomaly to a physical model of simple geometric shape and the model parameters (shape, depth and polarization angle) using several graphical methods. In the present study, eight SP anomaly profiles, representing eight anomalies, were selected for quantitative interpretation (Fig. 5). The parameters of the source anomaly were evaluated using the method of characteristic curves [13], where the field profile can be easily and accurately interpreted in a very short time. The obtained results for the eight selected SP anomalies are illustrated on Table (1) and on Figure (5).

Table 1: Results of the quantitative analysis for the eight SP anomalies, Wadi El-Bolla area, Central Eastern Desert, Egypt.

Profile (Fig. 4a)	Calculated parameters			
	θ (°)	**Dipping direction**	**h (m)**	**a (m)**
A	32	South	6.6	9
B	28	North	20	20
C	38	North	18	19
D	46	North	17	21
E	42	North	10	5
F	28	South	25	37
G	58	North	9	13
H	28	South	17	11

θ = Dipping angle, in degrees, h & a = Depth to the center & Half-width of the anomalous body in meters.

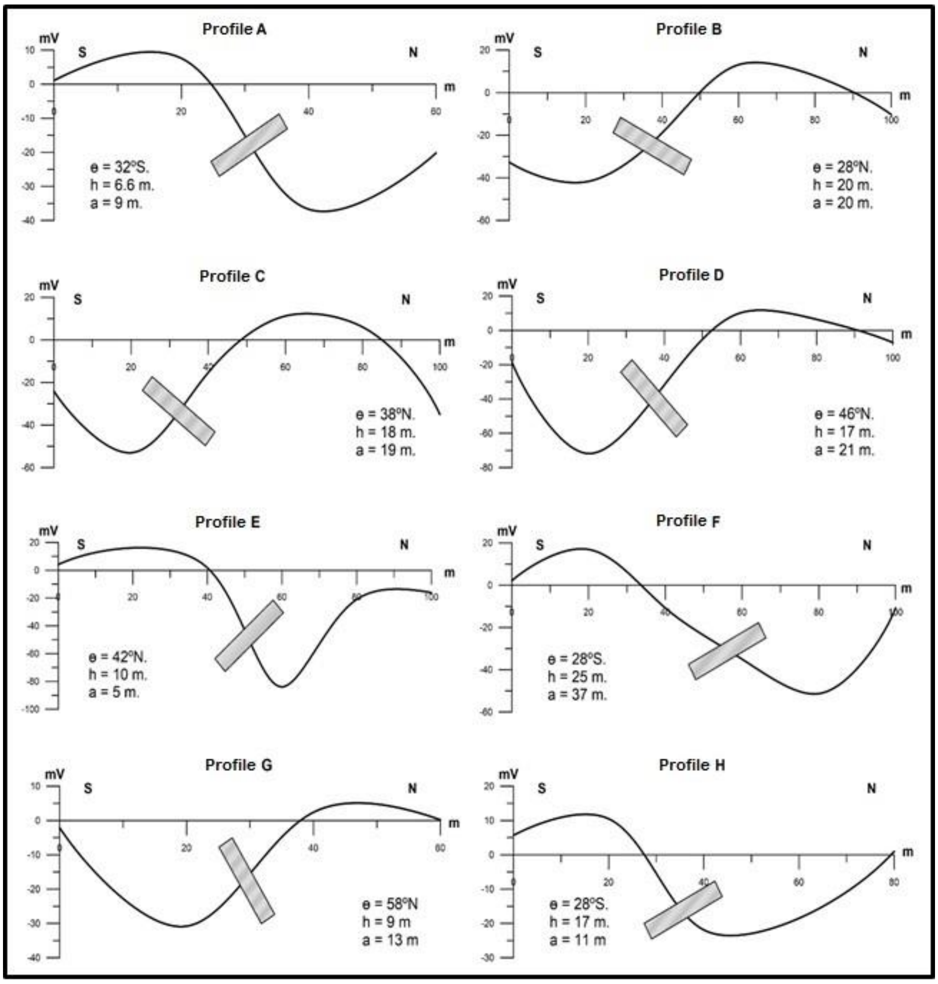

Fig. 5: Characteristic curves, with the calculated parameters of the 8 SP profiles (Fig. 4a) along N-S direction for eight SP anomalies, Wadi El-Bolla area, Central Eastern Desert, Egypt.

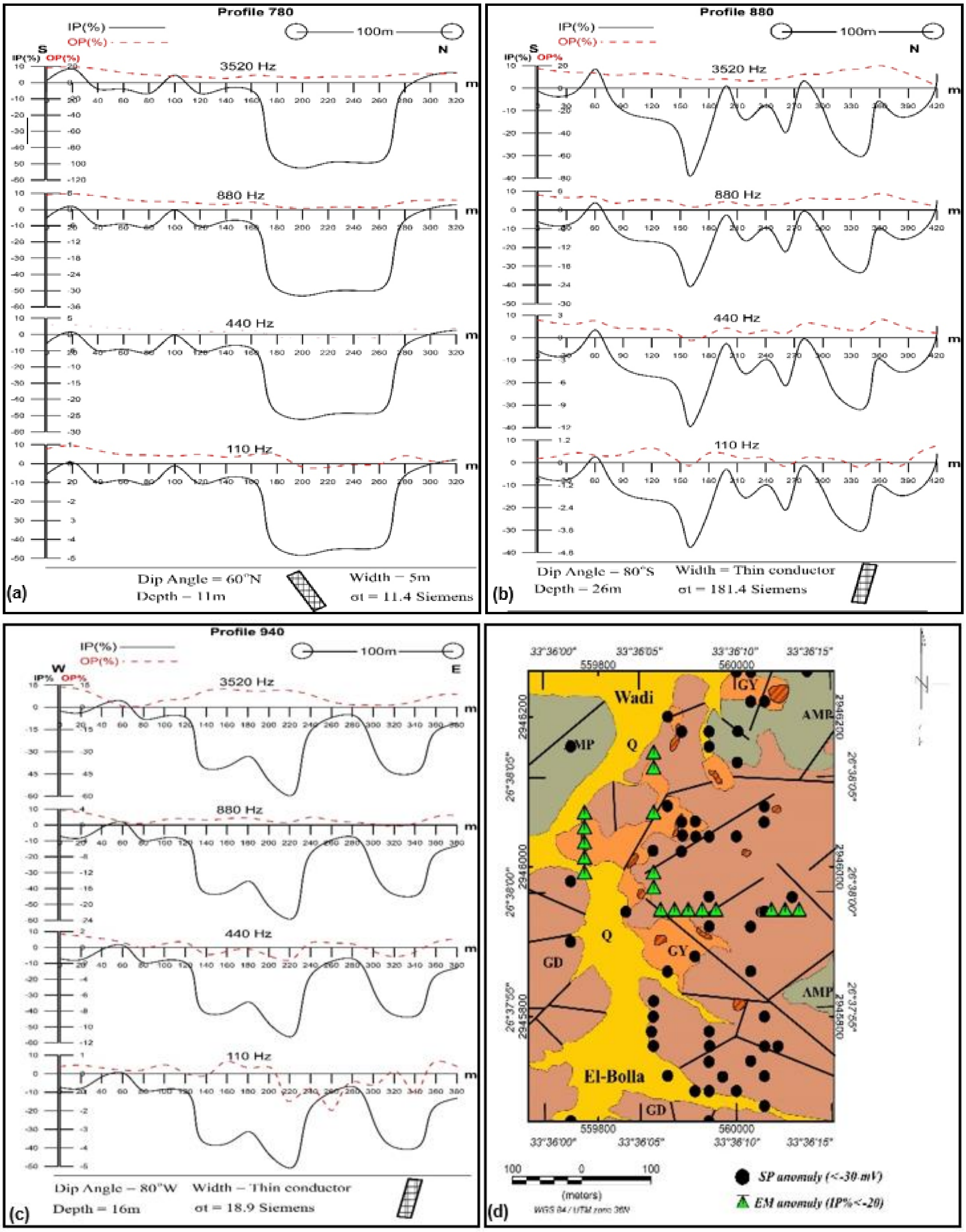

Fig. 6: Horizontal-loop electromagnetic (HLEM) data along the three profiles (a) No. 780 (b) No. 880 (c) No. 940 (Figs. 4a, b and c) Geologic map (4d) of Wadi El-Bolla area showing the locations of the self-potential (SP) electric and the horizontal-loop electromagnetic (HLEM) anomalies, Wadi El-Bolla area, Central Eastern Desert, Egypt.

3.3.1. Horizontal-loop Electromagnetic (HLEM) survey data

Generally, the quantitative interpretation of HLEM data aims to determine the location of the top surface of the conductor, its dipping direction, depth to the top and the conductivity thickness value [14]. The results of the conducted profiles are discussed hereafter:

A. Profile No. (780)

This profile is situated at the western part of the study area with a length of 320 m. The in-phase components indicate a wide conductive zone, centered at station 180 m (Fig. 6a) along the four used frequencies, which may reflect a good conductor source, situated at a shallow depth (Fig. 6a). The in-phase and out-of-phase curves reveal that the conductor body is dipping to the north, with an angle of 60° N, a width of 5 m, a depth of 11 m and a conductivity thickness of 11.4 Siemens/m.

B. Profile No. (880)

The shapes of the negative and positive peaks of the in-phase component along this profile illustrate a well-defined EM anomaly, centered at station 340m (Fig. 6b). This anomaly is recorded along the four used frequencies and has relatively high amplitude. This may reveal a shallow good conductor. The calculated parameters of this anomaly indicated that the causative body is a thin conductor dipping towards the south, with an angle of 80ºS, a depth of about 26 m and a conductivity thickness of 181.4 Siemens/m.

C. Profile No. (940)

It is located at the central part of the study area and carried out along an E-W direction, with a length of 380m. The HLEM data acquired along this profile indicate that a well-defined EM anomaly is centered at the station 320m (Fig. 6c). This anomaly is recorded along the four used frequencies and the quantitative interpretation indicates that the causative body has a conductivity thickness of 18.9 Siemens/m, a depth of about 16 m, a thin width and dip angle of 80º W.

As illustrated on the constructed anomaly map (Fig. 6d), there was a relatively good agreement in the spatial distribution between the SP anomalies (< -30 mV) and the HLEM anomalies (IP% < -20). The SP and the HLEM anomalies, especially at the matched locations, could be considered as promising targets for using more detailed exploration methods, such as induced polarization (IP) method.

CONCLUSIONS

The results of ground magnetic, SP electric and HLEM studies for Wadi El-Bolla area, Central Eastern Desert, Egypt, can be concluded in the following:

1) The magnetic survey data revealed that the estimated average depths for the shallow and deep magnetic sources, as calculated from the power spectrum curve, attain 15 m and 48 m, respectively. The analyses of magnetic lineaments for the RTP, residual- and regional-component magnetic maps revealed that the E-W, NE-SW, NW-SE and NNW-SSE structural lineaments were related to deep-seated structures. Meanwhile, the ENE-WSW, NNE-SSW, N-S and WNW-ESE structural lineaments are related to shallow structures, which represent the most important targets for mineral exploration.

The SP electric data show relatively strong negative anomalies (-20 to -69 mV), located at the contacts between younger granites, granodiorites and amphibolites, beside some parts on the granodiorites and amphibolites. The relatively strong positive anomalies (10 to 57 mV) which occur over Wadi sediments, are located at the western part of the study area, beside over some parts of the granodiorites and amphibolites. The quantitative interpretation was conducted for eight SP electric anomaly profiles, representing eight anomalies. The obtained results of the quantitative interpretation for the selected SP anomalies revealed shallow depths to the centers of the eight selected anomalies (ranging from 6.6 to 25 m), with half-widths (ranging from 5 to 20 m) and shallow to moderate dips toward the south and north directions. Comparison of the interpreted structural lineament trends recorded on the residual-magnetic component, surface geology and Sp maps shows a fairly good agreement between these trends, indicating the concentration of mineralization along these directions.

The application of the HLEM method revealed the presence of many conductive bodies with different magnitudes in their mineralizations. The quantitative interpretation of the HLEM data revealed that the conductive bodies possess narrow widths, depths ranging from 11 m to 26 m, dipping steeply towards the north and the south directions and conductivity thicknesses varying from 11.4 to 181.9 Siemens/m. All anomalies were recorded along the four frequencies, which may reflect shallow conductors.

2) The constructed anomaly map for the data of SP and HLEM showed a relatively good agreement in the spatial distribution between the SP anomalies (< -30 mV) and the HLEM anomalies (IP < -20%). The matched locations of the anomalies between the two techniques could reveal promising targets for more detailed exploration, using IP method.

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