Induced Polarization Measurements for Gold Exploration at the Eastern Desert of Egypt

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Abstract

Induced polarization (IP) is one of the most commonly used geophysical methods for mineral exploration. We have tested the method for gold exploration in the Eastern Desert of Egypt during the summer of 2005 but we were unable to acquire IP measurements due to the extreme aridity of the Egyptian desert. In order to prove that the IP method can detect gold deposits in Egypt if the conditions are appropriate, we conducted IP laboratory measurements on 25 rock samples collected from the Umm Rus gold mine area in Egypt. Some of the measured rock samples contain geo-electrochemical minerals such as pyrite, chalcopyrite and others contain quartz veins in contact with zones of disseminated gold deposits. The calculated stationary polarizability for the measured rock samples ranged from 10 % for samples rich in polarizable minerals such as gabbro to less than 1% for samples barren in polarizable minerals such as pure quartz. The results demonstrate the feasibility of using IP for detecting gold deposits in rock samples from the Eastern Desert of Egypt and prove that the field application of IP will also be feasible if the contact resistance between the measuring electrodes and ground can be lowered and\or high-power source is used.

Key words: Induced polarization, gold deposits, laboratory measurements, Egypt.

1. Introduction

Since ancient times, Egyptians thought of gold jewelry as a sign of royalty and stylishness. Pharaohs used gold to decorate their luxurious palaces and temples and were buried with much gold to signify their importance. Because of this culture, Egypt has observed over five-thousand years of extensive gold-mining. This exhausted most of the gold mines and shafts and has made modern gold exploration in Egypt a difficult task. Recently, the search for gold deposits in Egypt has grown significantly in new areas and in previously mined areas, which in turn increased the demand for utilizing low-cost and non-invasive exploration techniques. Among these techniques are geophysical methods, in particular the induced polarization (IP) method. The IP method has proven to be very successful in mineral exploration at different subsurface settings in many places in the world (Kormelcev, 1968; Yuval and Oldenburg, 1996; Denne, 2001).

The phenomenon of induced polarization (IP) was introduced to geophysics community by the French geophysicist Conrad Schlumberger some 80 years ago (Telford et al., 1990). Schlumberger tried to apply the IP method in open field for mineral exploration but his trials did not succeed due to the lack of adequate measuring instruments at that time. Later during the 1930's, geophysicists from different countries picked up Schlumberger's idea and tried to develop methods for reliable recording of IP effects in open fields. Instead of direct polarized current, Muller (1932, 1940) utilized an alternating current but achieved very limited success. Later attempts to measure the IP effect in the field were generally unsuccessful mainly because of the lack of measuring instruments. During the late 1940's and early

1950's, the IP method and instrumentation were developed significantly, which made measuring the IP effect in the laboratory and open fields not only possible but also diverse. It now includes different methods of measuring such as time domain IP, frequency domain IP, spectral induced polarization (SIP) and others.

Despite the great successes of the IP methods in mineral exploration, applying this technique in arid areas such as the desert of Egypt is still very limited. In an attempt to test the IP method for gold exploration in Egypt, we conducted an IP survey at a famous gold deposit site in the Eastern Desert of Egypt during the summer of 2005. The survey was conducted using the TLT-30 Transmitter and TLR-IP-003 receiver manufactured by Tellur SPB geophysical company and the middle gradient electrode array. The nature of the igneous rock hosting the gold deposits and the extreme arid conditions of the survey site caused the contact resistance between the ground and the measuring electrodes to be extremely high so that no electric current connection was obtained and the survey has failed.

In order to prove that the IP method is capable of detecting gold deposits in the study site if the appropriate conditions exist, we conducted IP laboratory measurements on 25 representative rock samples collected from the site. The results of the laboratory measurements successfully showed a definitive IP response to the gold deposits and other associated minerals. The success of the laboratory measurements has encouraged us to diagnose the problems facing the application of the IP methods in open fields and to suggest some solutions to make the field application of method relevant in the Eastern Desert of Egypt and similar environments.

2. Gold Occurrence in Egypt

Most of the gold deposits and occurrences in Egypt are mainly of the quartz-vein type (Gabra, 1986). Quartz veins intrude and cut through various basement rocks forming part of the Arabo-Nubian massif of Precambrian age. The basement rock outcrops in the Eastern Desert of Egypt in a wedge-like form in the area between latitude 28° 30' N and the Sudanese border to the south. The fact that most of the known gold deposits in Egypt, including those mined by ancient Egyptians 5000 years ago, are of the quartz-vein type, has historically led investigators to focus the exploration on this type of deposit.

Kochin and Bassiuni (1968) classified the Egyptian gold deposits based on their areal distribution into five major groups: 1) the northwestern group, 2) the northern group, 3) the central group, 4) the southern group and 5) other occurrences. He also recognized a pattern in the areal distribution of the gold deposits consisting of three northwest trending belts. The eastern belt adjoins the eastern contact of the basement rocks, the central belt lies along the axis of the basement rocks which is parallel to the Red Sea Graben, the western belt and fourth belt may extend through Umm Tuyur and Umm Egat deposits as shown in figure (1). Kochin and Bassiuni (1968) also divided the gold deposits according to their mode of occurrence and the nature of the mineralization into three types: dykes, veins and placers. Two other types were later added to this classification; the gold-sulphide type and the gold-bearing ferruginous quartzite type.

3. Site Description and Samples Collection

The Umm Rus study area, where the IP field experiment was conducted and the rock samples were collected is located in the eastern desert of Egypt, ten km from Mersa Mubarak on the Red Sea coast. It extends over an area of 9 Km^2 with very rugged topography and where many different dykes cut through granodiorite (acidic, intermediate and basic dykes). Quartz veins and veinlets cutting through the dykes are very common in the area (Fig. 2). The Umm Rus gold deposits occurs in granodiorite and granites intruded into a gabbro massif north of Wadi Mubarak (Alford, 1900; Coxon, 1906; Jenkinss, 1925; Hume, 1937; Amin, 1955; Sabet, 1961). Most of the mineralized quartz veins intrude into the granodiorite (Fig. 2). The rock samples for this study were collected along the geological profile A-A` in figure (2) to represent different rock units in the study area.

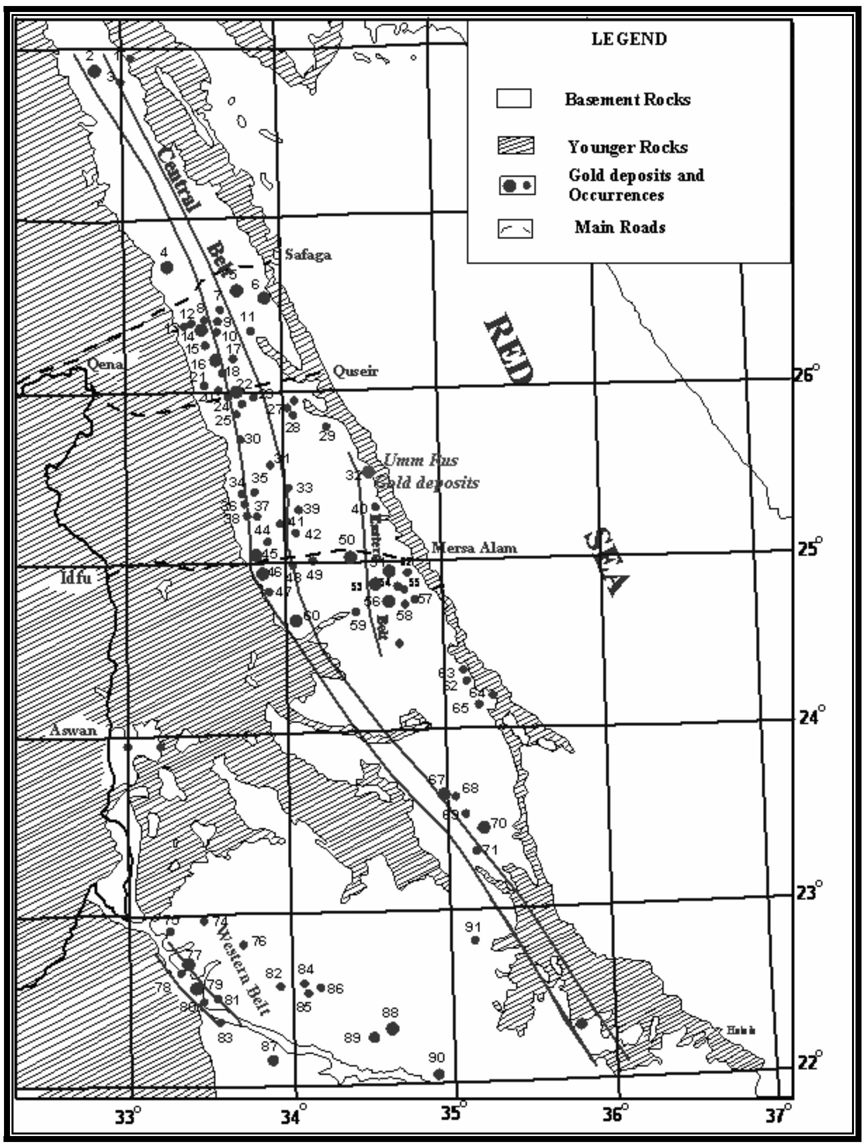

Figure 1: Gold deposits in Eastern Desert, Egypt (Gabra, 1986).

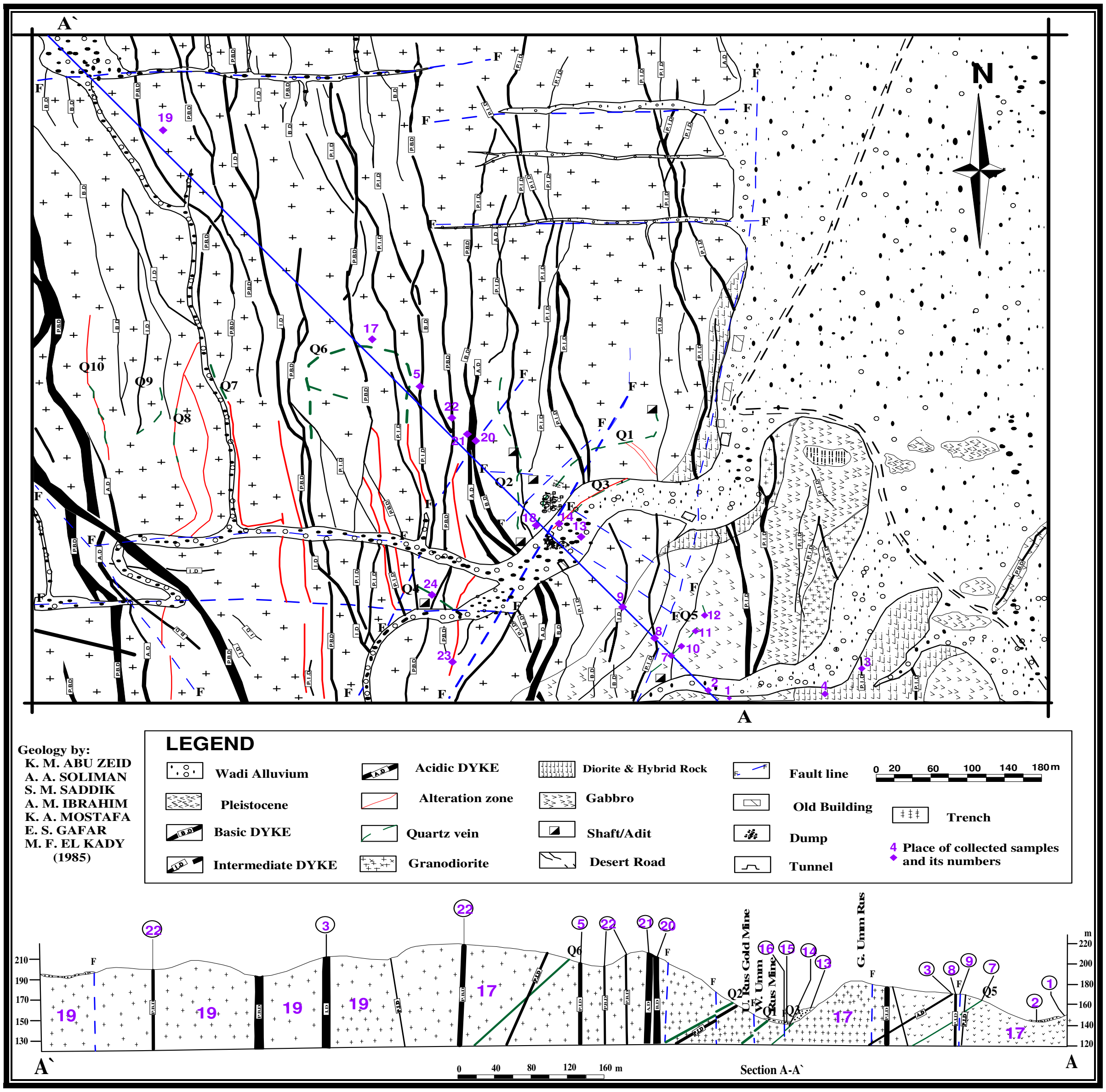

Figure 2: Geological map of the Umm Rus gold deposits (Abu Zeid et al, 1985). -samples for this study were collected along geological cross-section A-A`

4. Induced Polarization (IP) Method

Induced polarization (IP) is a current-stimulated electrical phenomenon observed as a delayed voltage response in earth materials (Sharma, 1997). Measurements of induced polarization are made using conventional electrical resistivity electrode configurations involving two current and two non-polarizable potential electrodes and can be carried out in field or laboratory conditions. In general, the IP response can be measured by sampling the time-decaying potentials observed after switching off DC currents. This type of IP is called the time domain IP method. When the applied current is switched off, the voltage between the potential electrodes does not decay to zero instantaneously because the ground temporarily stores charges (i.e. becomes polarized) and acts somewhat like a capacitor. The stored energy or the polarization can be in different forms; most important of them is the chemical energy form. The chemical energy storage originates from either the variations in the mobility of the ions in fluids throughout the rock structure (electrolytic polarization) or variations between ionic and electronic conductivity where metallic minerals exist (overvoltage polarization).

After sampling the time-decaying potentials in the time domain IP process, several parameters are derived from equations 1, 2 and 3 respectively (Ahmed & Komarov, 2006). These parameters include the transition character of polarizability (F(*x*)), which is the logarithmic function of the charging voltage during the current injection into the earth, the stationary polarizability (**η_0**) which is the maximum polarizability value when the charging time reaches infinity, and the differential polarization (D(*x*)), which is the first derivative of the polarizability function in the decimal logarithm of the charging time (Ahmed, 2006).

$$F(x) = b.\log(B \cdot \frac{B \cdot x + 1}{x + B}) \qquad (1)$$

Where

b is the amplitude parameter and its value is close to the maximum differential polarization,.

B is a parameter equal to the logarithmic width of the transition character of polarizability,

x is the time of transition character, and is equal to *t/Tm,* where t is the time after the current turn off and T_m is the constant of time.

F(x) will be close to zero when $x<<1$, while ***F(x)*** will be a maximum and reaches a value close to stationary polarizability when $x>>B$.

$$\eta_0 = 2b \log (B) \qquad (2)$$

Where **η_0** is the stationary polarizability

$$D(x) = 2.303x \frac{d}{dx} F(x) \qquad (3)$$

Where (D(*x*)) is the differential polarization.

5. The Laboratory Measurements

The rock samples we measured for IP were collected from the Umm Rus area along the geological profile A-A` in figure (2), which means that the samples represent various geologic features and rock textures. The IP laboratory measurements were conducted using the "TL-01" instrument manufactured by TELLUR SPB Company with charging/discharging times ranging from 1.64 to 26.24 seconds. To ensure that all the rock samples have the same conditions during the measurements, they were all placed in fresh water for 24 hours before the measuring process. During the measurements, both the rock samples and the electrodes were immersed in water having 100 Ohm electrical resistance to maintain uniformity in the electric current. The temperature during the measurements ranged between 20 and 22C°. The lateral surface area of the samples was adjusted to 20-25 cm^2 with a fixed thickness of 0.5 cm that provided a current density at the surface that ranged from 0.04-0.05 mA/cm^2.

To measure the apparent polarizability of the rock samples, a 1 mA DC electrical current with a bipolar rectangular waveform was applied. The charging time was set to different values (1.64, 3.28, 6.56, 13.12 and 26.24 sec). The measured decay-curve of apparent polarizability was used to calculate the stationary polarization "η_0" and maximum differential polarization "$\tilde{\eta}_m$" for each of the rock samples and the results of these calculations listed in Table (1). Figure (3) shows the distribution of the calculated stationary polarization "η_0" along the geological cross section (A-A`). As shown in figure (3) and table (1), the average value of the stationary polarizability of the country rock "granodiorite" was about 2% while it increased to 4-6% for ore-bearing dykes. Such difference in the stationary polarizability between the two types of rocks is considered significant and demonstrates the ability of the IP measurements to differentiate between the ore-hosting dyke complex and the country rock.

Table 1: Transition characters of the Umm Rus gold deposit rock samples

No.	Rock name	T_m, Sec	η_0 , %	$\tilde{\eta}_m$, %
1	Gabbro	0.64	9.854	2.786
3	Acidic dyke	0.86	8.223	2.325
4	Diorite	0.923	2.453	0.694
5	Intermediate dyke	0.93	3.772	1.066
6	Quartz from contact zone	0.52	0.951	0.269
7	Smoky Quartz	0.64	1.373	0.388
8	Intermediate dyke	0.6	5.403	1.528
9	Alteration zone	0.86	2.157	0.683
11	Gabbro	0.72	3.534	1.0
12	Alteration zone	0,8	2.363	0.748
15	Friable sample	1.0	3.313	0.937
16	Alteration zone	1.64	5.063	1.432
17	Granodiorite	1.2	3.058	0.865
19	Granodiorite	0.72	1.869	0.528
20	Acidic dyke	1.1	6.796	1.922
21	Acidic dyke	0.59	4.078	1.153
22	Basic dyke	0.72	4.145	1.172
24	Granodiorite	0.7	4.757	1.345
25	Alteration zone	0.74	3.228	0.913

T_m – time constant, η_0- stationary polarization and $\tilde{\eta}_m$ - maximum differential polarization.

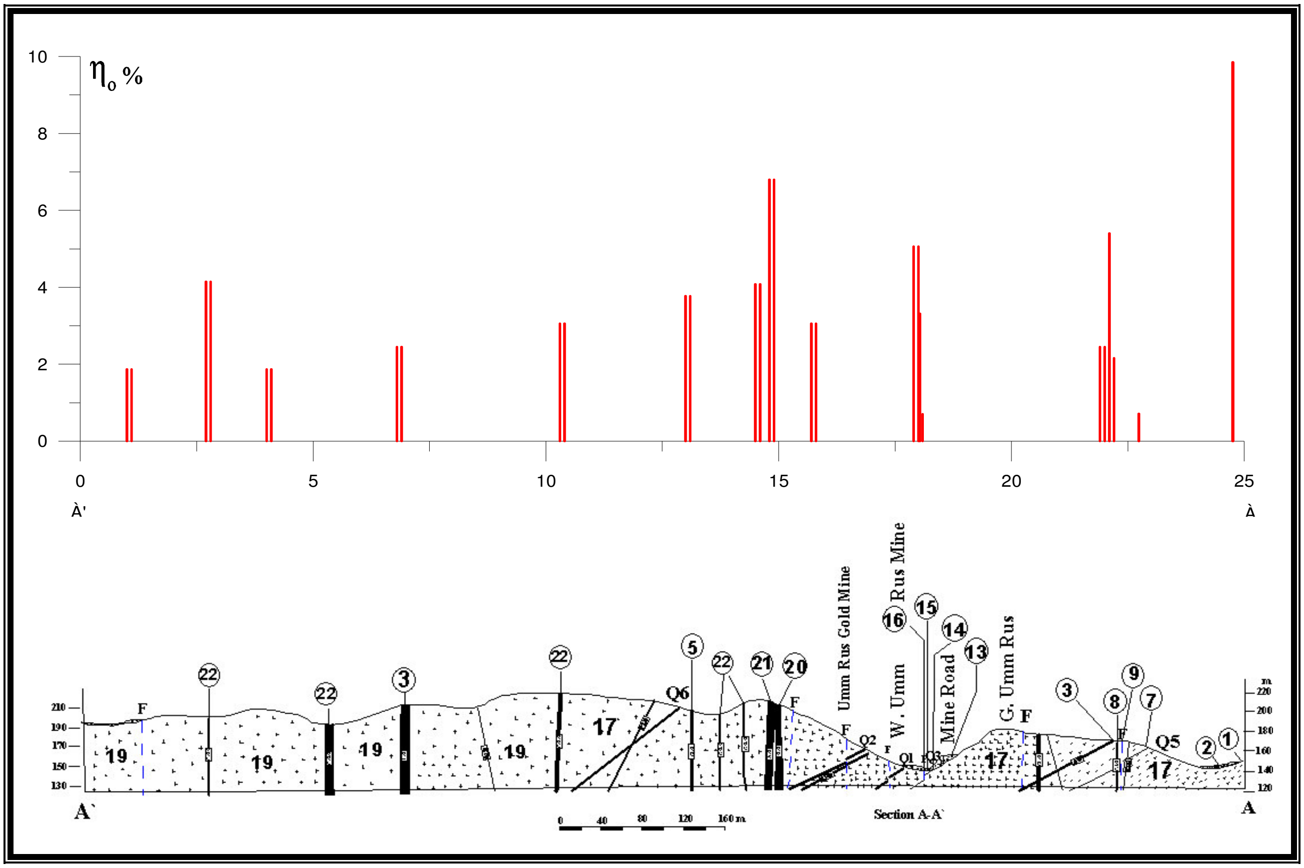

Figure 3: Geological cross section A-A` across the Umm Rus gold deposits with the value of the stationary polarizability measured for the rock samples are plotted against the concerned sample location. .

6. Mathematical Modeling of the Time Domain IP Field Measurements

The results of the laboratory measurements and the calculated survey parameters were used to construct a theoretical forward-geoelectric model along the geological cross section A-A`. The first step to construct a theoretical IP model is to select the appropriate survey parameters. The most popular electrode array in mineral exploration is the middle gradient array because it scans a wide area in a short time and with low cost. Also it is sensitive for detecting veins, dykes and contact zones. The classical scheme of the middle gradient array is shown in figure (4). The investigated area is the middle third zone between the current electrodes (AB), which provides practical uniformity of a field and equal depth of research over the site. The measurements must be taken parallel to the AB line and perpendicular to the geological structure. The AB distance is chosen based on the required depth of investigation and must exceed 10 -12 times this depth. The distance between MN is determined by the required resolution and according to the amplitude of the received signal.

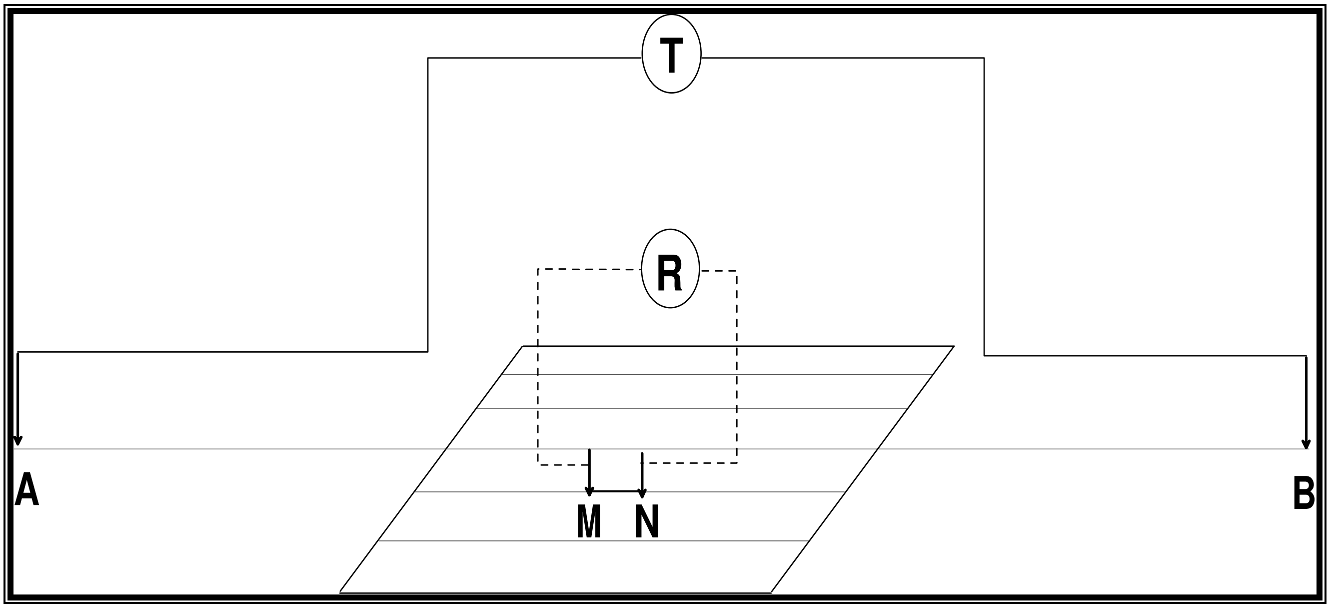

Figure 4: Scheme of the middle gradient array used for field measurements.

After choosing the array parameters, we assumed values for the apparent polarizability and geometrical parameters of some expected anomalous features. This information was assumed based on our understanding of the geology of the study area and results of our laboratory measurements. For instance, the average specific resistance of the country rocks in the Eastern Desert of Egypt, (e. g. granodiorite, gabbro and granite) varies from 15,000 – 30,000 Ohm.m (Dortman, 1992). Quartz samples collected from quartz veins have higher resistance (30,000 – 50,000 Ohm.m) as shown from laboratory measurements, especially if they do not contain disseminated pyrite or dispersed gold.

Figure (5) shows a theoretical resistivity and polarizability model we have constructed based on the results of the IP lab measuremnts and our understanding of the nature of the different rock types in the study area. Figure (5) indicates that the different rock types have distinguishable resistivity and polarizability values. For example, the granodiorite shows resistivity on the order of 20,000 Ohm.m and polarizability of 2% which is significantly different from the other types of dykes and contact zones where its resistivity ranges from 1700 to 14200 Ohm.m and its polarizability ranges from 4% to 9%. Areas barren in polarizable minerals such as pure quartz are characterized with resistivity of 39000 Ohm m and polarizabilty of 1%.

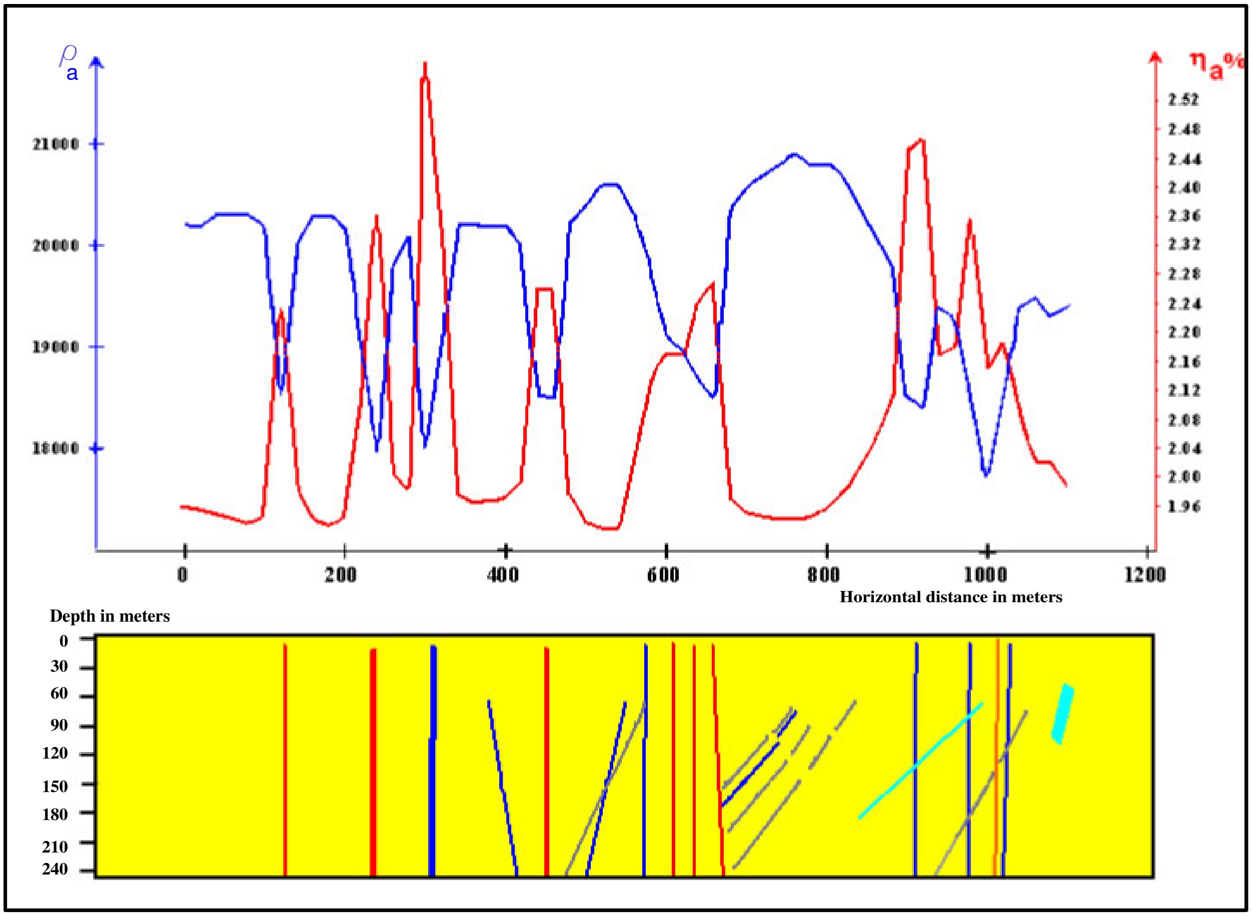

Figure 5: Resistivity and polarizability values plotted against the samples along geological cross section (A-A`).

<u>Legend:</u>

-Basic dykes where (ρ=9800 Ohm, η_0=5%)

-Intermediate dyke with (ρ =14200 Ohm, η_0=4%)

- Quartz vein (ρ=39000 Ohm, η_0 =1%)

- Acidic rocks with (ρ=1700 Ohm, η_0 =9%)

Blue curve is - ρ_a(apparent resistivity), red curve is- η_a (apparent polarizability)

7. Discussion and Conclusions

The nature of the igneous rock hosting the gold deposits and the effect of extreme arid conditions cause the contact resistance between the ground and the measuring electrodes to be extremely high. Normal IP or resistivity survey in such areas seems to be impossible. Therefore, it is very important to test some parameters and run laboratory measurements on rock samples collected from the surveyed site before starting a field IP or resistivity surveys. Among these parameters is the electric current intensity that can flow through the mostly dry subsurface. This in turn will determine the specifications of the instruments to be used in the field survey. The intensity of the electric current that we need to inject into the ground during a resistivity or IP survey depends on many factors, most importantly, the contact resistance between the measuring electrodes and the ground and the required depth of investigation. The contact resistance between the electrodes and the ground can be determined from the following formula (5):

$$R \approx \frac{\rho}{2\pi a} \ln \frac{2a}{r} \qquad (5)$$

Where, ρ= average specific resistance of the country rock, r= radius of a rod electrode, a=depth of its immersing in the ground (Tarkhova, 1980).

When, ρ= 3000 Ohm, a=0.5 m, r= 0.5 cm then R ≈ 5.0 K-Ohm. To lower the value of R from 5.0 K-Ohm to 300 Ohm, this will require using 26 current electrodes instead of just one electrode assuming that the applied potential difference is 800 V and the current intensity is 1 Amp. At the extremely arid conditions, such as at the Eastern Desert of Egypt, specific resistance of the country rock (ρ) can reach 30000 Ohm. According to equation 5 and even using 26 electrodes, the net contact resistance of these electrodes (R) will be as high as 2000 Ohm. It has been found that using a copper foil as grounding significantly reduces the contact resistance in areas of high specific resistance. The contact resistance of 26 rod electrodes is equivalent to that of 18 m2 of copper foil. Using plate electrodes or non-polarizing electrodes were found to work better in reducing the contact resistance.

The specifications of the measuring instrument are key factors in achieving a successful IP and resistivity surveys as well. High internal resistance of the measuring instrument is needed to overcome the high contact resistance that the current and potential electrodes encounter. Also, increasing the output voltage and current of the measuring instrument helps to overcome the high contact resistance at the current and potential electrodes. Now, measuring instruments with a current source of more than 5 A and an output voltage of 10,000 V are available. Instruments with such specifications can be found in the IRIS instruments company website. These types of measuring instruments are expected to make resistivity and IP field surveys in arid areas, such as the Eastern Desert of Egypt a more practical.

Conducting IP laboratory measurements on rock samples from the surveyed sites along with some knowledge about the geology of those sites were used to build IP forward models of the IP field measurements. These forward models provided a reasonable sense on the expected variation of the IP effect and other controlling parameters at the survey site. They also helped in selecting the measuring instrument, the type of the measuring electrodes and the electrode arrays.

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