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Mapping Sterile Bodies in the Sidi Chennane phosphatic deposit (Morocco) using geoelectrical Investigations

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Abstract

The anomalies detected in phosphatic series of Sidi Chennane, one of phosphatic basins in Morocco, hinders the proper exploitation of phosphate levels and the assessing phosphate reserves seems incorrect. The aim of the study by the electrical resistivity method is to delineate these disturbances. Thus, a geophysical survey was conducted using the vertical electrical sounding, 41 VES have been established in an area covering 50ha.

The resistivity dataset were processed using computer interaction interpretation of the sounding curves. A maximum of four subsurface geologic units were delineated from the VES-curves. These subsurface geoelectric layers correspond to (1) The normal phosphatic bearing rock with a resistivity ranging between 100 and 450 Ωm, (2) the calcareous Thersitean slab with a resistivity ranging between 700 and 1700 Ωm (3) the anomalies, highlighted in the area, have a resistivity ranging between of 400 Ωm and 900 Ωm and (4) marls with a lower resistivity (<100 Ωm).

The resistivity contour maps kriged were used to delimit these sterile bodies and to model their distribution. The results of the sounding data revealed that the Anomalies have two principal directions NS and NE-SW, and are at 25 meters to 60 meters of depth. Therefore these anomalies are in the upper part of the phosphate layer.

Key words: Moroccan phosphate, Geoelectric prospecting, mapping, krigeage,

Introduction

Morocco is the world's third largest phosphate producer, after the USA and China. Total mine production recorded by the Ministry of Energy and Mines in 2003 was 29.39 Mt so more than 75% of world reserves. Four major phosphate basins are now known and are being exploited, three of which are located in central-northern Morocco. The four main deposits of phosphate are: the Oued Eddahab basin situated in Sahara, the central ganntour basin near Youssoufia, the Meskala basin at east of Essaouira and the Oulad Abdoun basin situated near Khouribga. The existence of morocco sedimentary phosphate rock has been known since 1908 in the Meskala basin, but it had not generated significant interest until the discovery, in 1917, of the Oulad Abdoun basin.

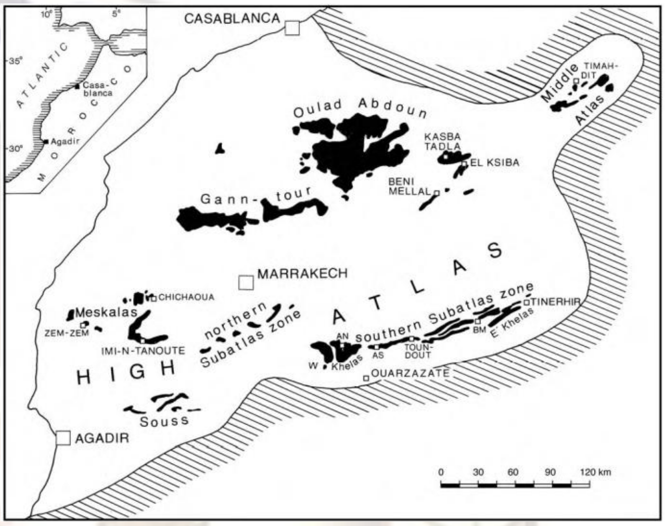


Fig. 1: The central Moroccan phosphate basins (Ganntour, Oulad Abdoun and Meskala)

The geological investigations carried out in Sidi Chennane phosphatic deposit in the Oulad Abdoun basin revealed a phenomenon of sterile hardpan inclusions called "dérangements", these sterile bodies are formed by accumulations of silicified limestones or by limestone blocks within an argillaceous matrix [1] which interfere with phosphate extraction and their resistivity is higher than the phosphate-rich mineral resistivity. The application of the electric prospection methods constitutes a suitable means to map these sterile bodies in order to establish a model of their distribution and would permit the definition of these structures before the mining front reaches them.

I- Geological framework and methodology of work

The Ouled Abdoun basin is the largest phosphate basin in Morocco. It's located about 100 km in south-east of Casablanca. The phosphate deposits of Ouled Abdoun area belongs to the western Moroccan Meseta, commonly considered being stable. The local sedimentary deposits resulting from a large transgression occurred in mid-Cretaceous. It consists of [2]: marly limestone and gypsum of Cenomanian, Turonian white limestones, Senonian marl and yellow marly limestones, phosphatic series dated from Maastrichtian to

Ypresian and Lutetian calcareous Thersitean slab. The Neogene continental deposits cover locally the marine series.

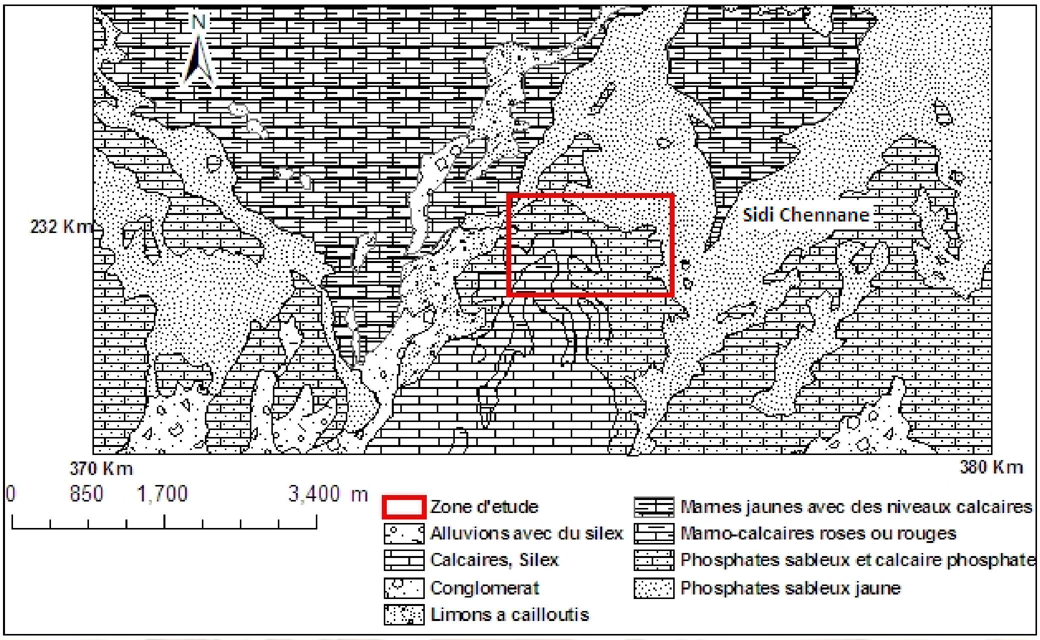


Fig. 2: Localization map of the study area.

The loose phosphatic Levels exploited are cited according to their succession [3]:

Layer III: Maastrichtian, Layer II: Paleocene, Layers I and 0, “forrow” A and B: Ypresian. They are typically separated by phosphatic indurated limestone benches, more or less important and more or less regular called "infill", II / I layers infill, III / II layers infill, etc...

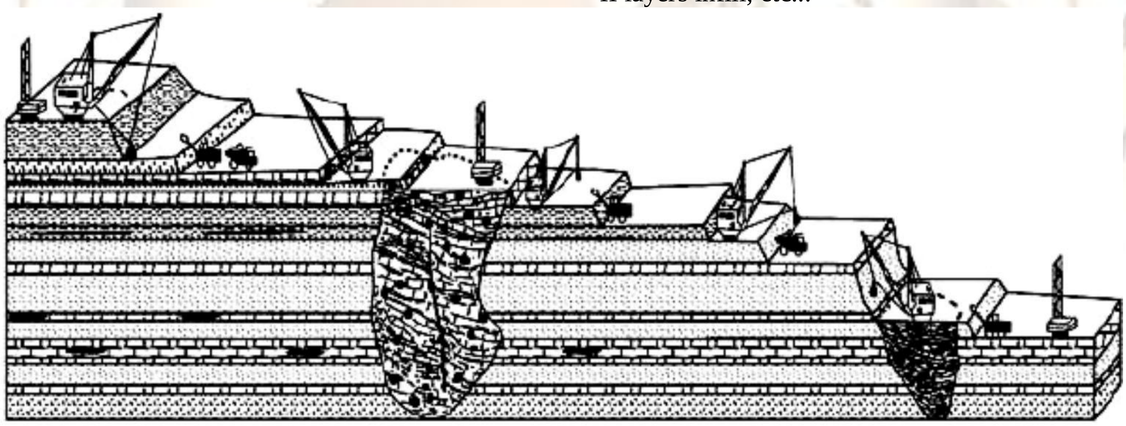


Fig. 3: Disturbance which affects the phosphatic exploitation

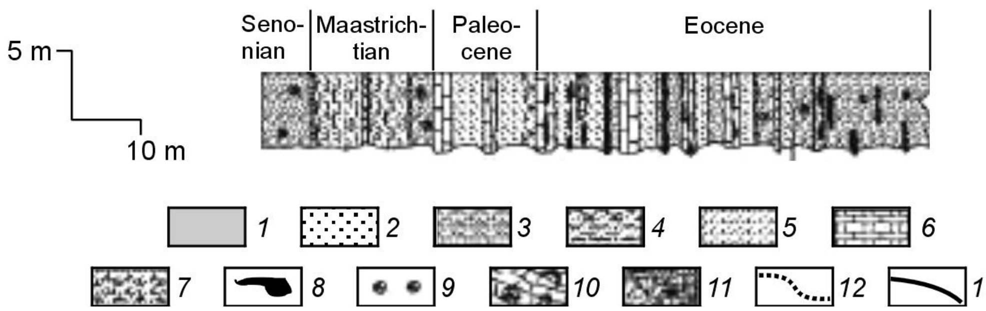


Fig. 4: Stratigraphical log of the phosphatic series of Sidi Chennane :

1— Hercynian massif; 2— phosphatic area 3— marls; 4— phosphatic marls; 5— phosphate-bearing horizon; 6— limestones; 7— phosphatic limestones; 8— broken flint bed; 9— siliceous concretions; 10— siliceous limestone disturbances; 11— sterile body composed of blocks of limestones, marls, and clays; 12— limit of disturbances; 13— road.

II- GEOELECTRICAL PROSPECTING

The aim of VES is to deduce the variation of resistivity with depth below a given point on the ground surface and to correlate with the geological information available to deduce the depth and resistivities of the present layers.

To cover all the zones being able to be disturbed, we carried out, during the geophysical prospection in a parcel of 50 ha, 41 Vertical electrical soundings (VES) using the Schlumberger electrodes configuration (SYSCAL-R2 resistivity instrument IRIS Instruments, France) with a maximum electrode spacing (AB) of 300m (Figure 5). Schlumberger array was used because of its greater depth penetration [4]. In order to have a good description of the disturbances, the VES were arranged based on observable levels of the phosphatic series outcrop found within the vicinity of the study area.

In general, the resistivity method involves measuring the electrical resistivity of earth materials by introducing an electrical current into the ground and monitoring the potential field developed by the current. The most commonly used electrodes configuration for geoelectrical soundings, which was used in this field survey, is the Schlumberger array. Four electrodes (two current A and B and two potential M and N) are placed along a straight line on the land surface such that the outside (current) electrode distance (AB) is equal to or greater than five times the inside (potential) electrode distance (MN). Vertical sounding, in Schlumberger array, were performed by keeping the electrode array centered over a field station while increasing the spacing between the current electrodes, thus increasing the depth of investigation.

The potential difference (ΔV) and the electrical current (I) are measured for electrode spacing and the apparent resistivity (ρ_{app}) is calculated by the equation:

$$\rho_{app} = K\frac{\Delta V}{I}$$

Where K is the geometrical factor that depends on the electrodes arrangement [5]. In the case of the configuration of Schlumberger, it is given by this equation:

$$K = \pi\frac{(L^2 - l^2)}{2l}$$

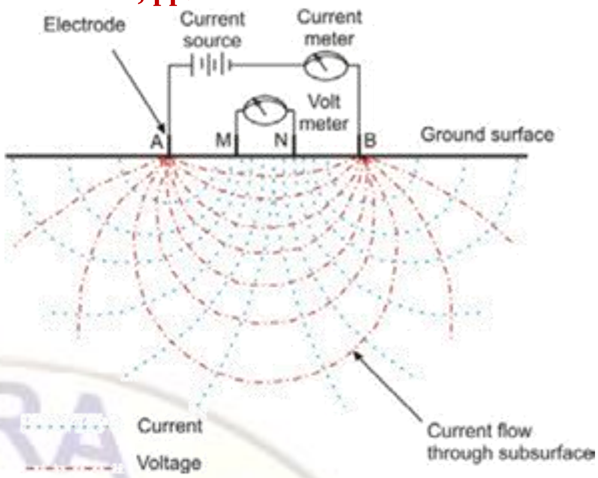


Fig.5: The basic principles of Schlumberger device

III- VES Results and discussion

From field trip observations, we note that in the phosphate series there are three sets in the sequence of layers: (1) Maastrichtian phosphatic sequence capped with calcareous Thersitean slab, (2) The complete phosphatic series and (3) The set from the B furrow to the lower layer III.

The best fit with measurements of a model of ground is obtained with a correlation between the observations and the position of the surveys to the touches of the phosphatic series.

The data from boreholes drilled by the Moroccan company "Office Chérifien des Phosphates (OCP)" were analyzed and used to correlate the results of the standard geoelectrical surveys: (1) The normal phosphatic bearing rock have a resistivity ranging between 100 and 450 Ωm, (2) the calcareous Thersitean slab with a resistivity ranging between 700 and 1700 Ωm (3) the anomalies, highlighted in the area, have a resistivity ranging between 400 Ωm and 900 Ωm and (4) marls with a lower resistivity (<100 Ωm).

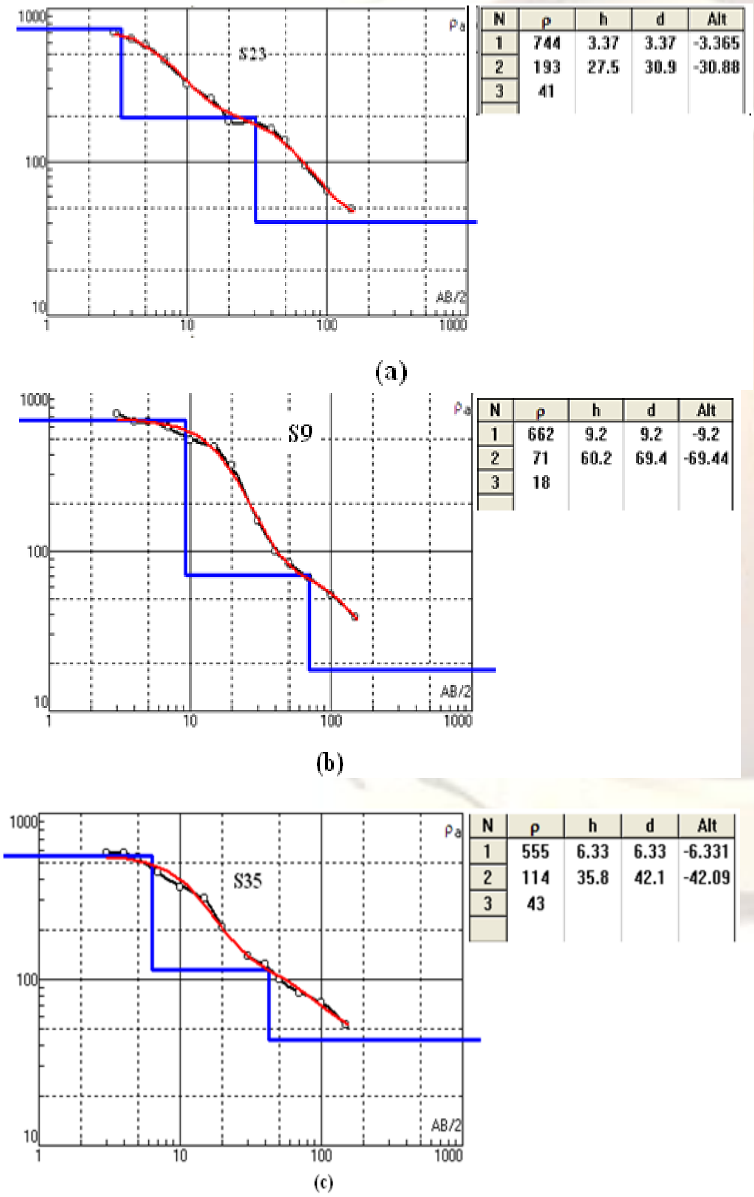
The VES data was plotted on a log–log paper and curve matched. One-dimensional inversion of geo-electrical resistivity sounding data by computer iteration is done by using the software IPI2Win [GEOSCAN-M Ltd., 2001][6]. This generates the thickness and the true resistivity of both phosphatic series and anomalies. Curves of observed apparent resistivity as a function of the half distance between current electrodes (AB/2), together with the curves of the fitting model are shown in Figure 6.

The 41 VES stations reveal three types of curves : Type I, Type II and Type III.

The Type I curve (Figure 6a) generally shows: (1) a relatively thin surface layer (about 3m) representing the calcareous Thersitean slab having apparent resistivity of 744 Ωm, followed by (2) the phosphatic sequences of 193 Ωm apparent resistivity and 27.5m thickness and (3) a lower resistivity third layer with apparent resistivity <45 Ωm corresponding to marls.

The Type II curve (Figure 6b) is composed by (1) a surface layer of disturbed phosphatic sequences till 9m with an apparent resistivity of about 662 Ωm, (2) a second layer of 60m (<100 Ωm) corresponding to the normal phosphatic series, and (3) a third layer with a relatively low-resistivity (<20 Ωm) indicating the marls.

The Type III (Figure 6c) field curves describe qualitatively a model composed of 3 layers where the layer resistivity relationship is $\rho 1 > \rho 2 > \rho 3$ (1) a layer of 6.50m representing deposits of phosphatic limestone with an apparent resistivity about 555 Ωm, (2) a second layer of 36m (114 Ωm) corresponding to the normal phosphatic series, and (3) finally marls with low-resistivity (43 Ωm).



N	ρ	h	d	Alt
1	744	3.37	3.37	-3.365
2	193	27.5	30.9	-30.88
3	41			

N	ρ	h	d	Alt
1	662	9.2	9.2	-9.2
2	71	60.2	69.4	-69.44
3	18			

N	ρ	h	d	Alt
1	555	6.33	6.33	-6.331
2	114	35.8	42.1	-42.09
3	43			

Fig. 6: Typical geoelectric profiles across the study area

IV- Mapping anomalies

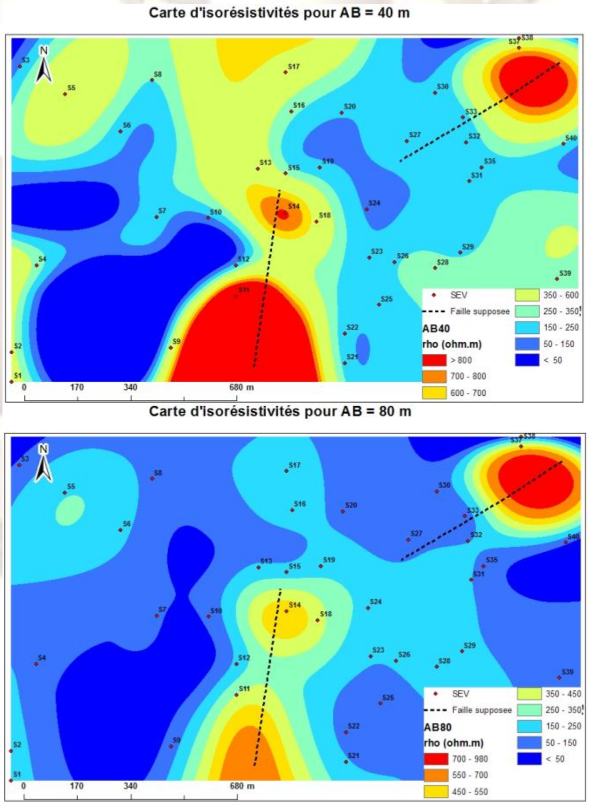
Ordinary kriging is a linear interpolation approach that provides a best linear unbiased estimator for quantities that vary spatially. This geostatistical method has been applied widely in electrical survey to map ground formation [7].

In general the ordinary Kriging model is more accurate for nonlinear problems and also flexible in either interpolating sample points or filtering noisy data. The VES data were gridded using the Kriging algorithm. A contour map for various schlumberger half-electrode spacing was then created from the grid file (figure 7).

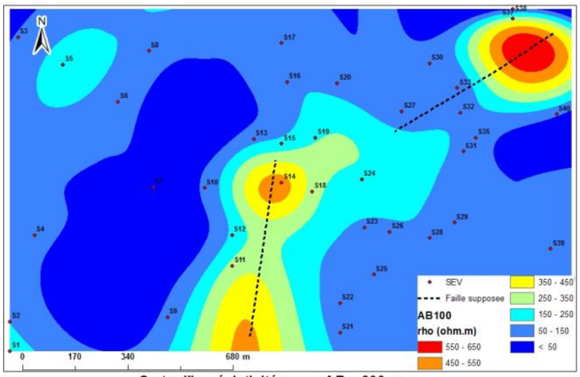
The kriged contour maps of electrical resistivity distribution for AB=40m corresponding to the surface formations shows great values of resistivity which is probably due to the calcareous Thersitean slab.

The kriged contour maps of electrical resistivity distribution for AB=80 and AB=100 show anomalous zones of directions NE-SW and NS located at an average depth of 25m.

The kriged contour maps of electrical resistivity distribution for AB=300 revealed the disappearance of the NS anomalous zones and the persistence of the NE-SW anomalous zones, they reach depths of 60m. Thus, the majority of anomalies affect only the subsurface of the phosphate series.



Carte d'isorésistivités pour AB = 100 m



Carte d'isorésistivités pour AB = 300 m

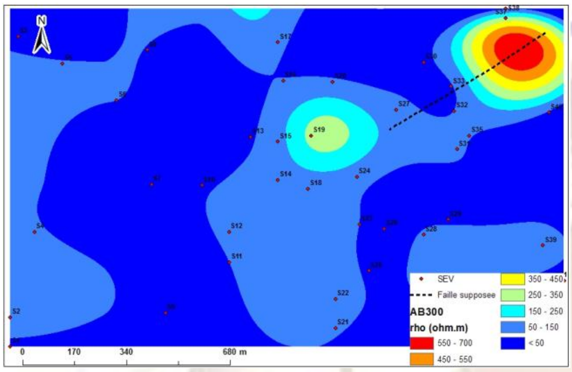


Fig. 7: Kriged contour maps of the apparent resistivity for various Schlumberger electrodes spacing

V- Conclusion

This study highlights the interest of the electrical resistivity method for mapping subsurface. This method sensitive to structures with high resistivity, revealed some apparently anomalous zones of Sidi Chennane phosphate series: in the study area we found three sets in the sequence of layers: (1) Maastrichtian phosphatic sequence capped with calcareous Thersitean slab, (2) The complete phosphatic series and (3) The set from the B furrow to the lower layer III.

The interpretation of contour maps of electrical resistivity distribution improved the quality of subsurface layers delimitation and specified their spatial variability: (1) for AB=80 and AB=100 the contour maps show anomalous zones of directions NE-SW and NS located at an average depth of 25m. (2) For AB=300 the contour map reveals the disappearance of the NS anomalous zones and the persistence of the NE-SW anomalous zones, they reached depths of 60m. Thus, the majority of anomalies affect only the subsurface of the phosphate series

The electrical method is an effective tool as it has successfully mapped the resistivity distribution and helped to delineate the geometry of the sterile body of Sidi Chennane deposit, it may be adapted to this special problem in the phosphate mining.

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