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USING A SHADING METHOD TO OPTIMIZE ANOMALIES IN A MOROCCAN PHOSPHATE DEPOSIT

[Optimización de anomalías en un depósito de fosfatos de Marruecos mediante el método del sombreado]

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RESUMEN: El sombreado es una poderosa herramienta para destacar los bordes de cualquier cosa presentes en cualquier clase de imágenes. Sabiendo la dirección y la elevación de la fuente de iluminación, se puede calcular la reflectancia de las distintas superficies representadas por los datos para facilitar la interpretación de los mismos. El sombreado se ha convertido en una herramienta universal a la hora de interpretar datos de campo geofísicos de tipo potencial. En la cuenca fosfatada de Orlad Abdoun, la presencia de caliches estériles (denominados anomalías) son difíciles de detectar durante las campañas de prospección geofísica, y su presencia interfiere con la extracción de los fosfatos. El estudio de la resistividad de los caliches estériles indica que ésta tiene un valor superior a los 200 Ωm, que contrasta con los valores de 80 a 150 Ωm de la mineralización de fosfato. En este trabajo se presenta una campaña de resistividad en un área de 50 ha. Basándose en los resultados de resistividades, y en la subsiguiente comprobación geológica durante la explotación, se concluye que los modelos geológicos obtenidos a partir de las imágenes sombreadas de las anomalías fueron satisfactorios. De esta manera se ha desarrollado y comprobado un nuevo método para cartografiar la extensión de los límites de las anomalías. Como resultado de los modelos establecidos, las reservas de fosfatos del yacimiento han sido ampliadas y su ubicación precisada.

Palabras clave: Campaña geofísica, resistividad, fosfato, sombreado, Marruecos.

ABSTRACT: Shading is a powerful tool for the enhancement of edges in all kind of images. Given the azimuth and elevation of an illumination source we can calculate the reflectance from the different surfaces provided by the data, helping its interpretation. Shading has become a standard tool in the interpretation of geophysical potential field data. In the Oulad Abdoun phosphate basin, the presence of sterile hardpan (caliche) –so-called "disturbances"– are hard to detect during the geophysical exploration surveys and their presence interfere with the phosphate extraction. The resistivity of the sterile hardpan is above 200 m in contrast to the 80 to 150 m for the phosphate-rich mineralization. In this paper a Schlumberger resistivity survey over an area of 50 hectares is presented. Based in the resistivity data and after direct geological evidence, we conclude that the geological models were successfully obtained from the analysis of the shaded maps of the "disturbances". A new field procedure was tested to map the extension and edges of the "disturbances" anomalies. As a result, the phosphate reserves were improved and better constrained.

Key words: Geophysical survey, anomalies, phosphate, sunshading, Morocco.

INTRODUCTION

Morocco is a major producer of phosphate, with an annual output of 19 million tons and reserves in excess of 35 billion cubic meters. This represents more than 75% of world reserves. Resistivity surveys have been successfully used in the Oulad Abdoun phosphate basin in Khouribga Province (figure 1), which is about 120 km south of Casablanca. The present survey were carried out in the Sidi Chennane deposit which is a part of Oulad Abdoun basin, extending over some 800,000 hectares. The Sidi Chennane deposit is sedimentary and contains several distinct phosphate-bearing layers. These layers are found in contact with alternating layers of calcareous and argillaceous hardpan. In this field, extraction was begun after Grand Daoui deposit was exhausted. However, the new deposit contains many inclusions or lenses of extremely tough hardpan locally known as "dérangements" or disturbances, found throughout the phosphate-bearing sequence. The hardpan pockets are normally detected only at the time of drilling. They interfere with field operations and introduce a severe bias in the estimates of phosphate reserves.

Direct exploration methods such as well logging or surface geology are not particularly effective. However, the chemical changes which are detectable at the hardpan/phosphate rock interface produce an important resistivity contrast. Other factors such as changes in lithofacies and clay content and consistence appear to account for some additional resistivity difference. It was found that normal phosphate-bearing rock has a resistivity of 80 to 150 Ωm while the hardpan typically features resistivity values of between 200 and 1.000 Ωm. A pilot resistivity survey was performed over an area of 50 hectares. The objective of this experiment was to try and map and constrain the anomalous regions corresponding to hardpan. A resistivity map was expected to allow the electrical resistivity signals to be imaged in 3D. We used a Schlumberger array with a span of 80 and 120 m (Bakkali & Bahi, 2005). designed to reach respectively a depth of 15 and 40 m. The so-called

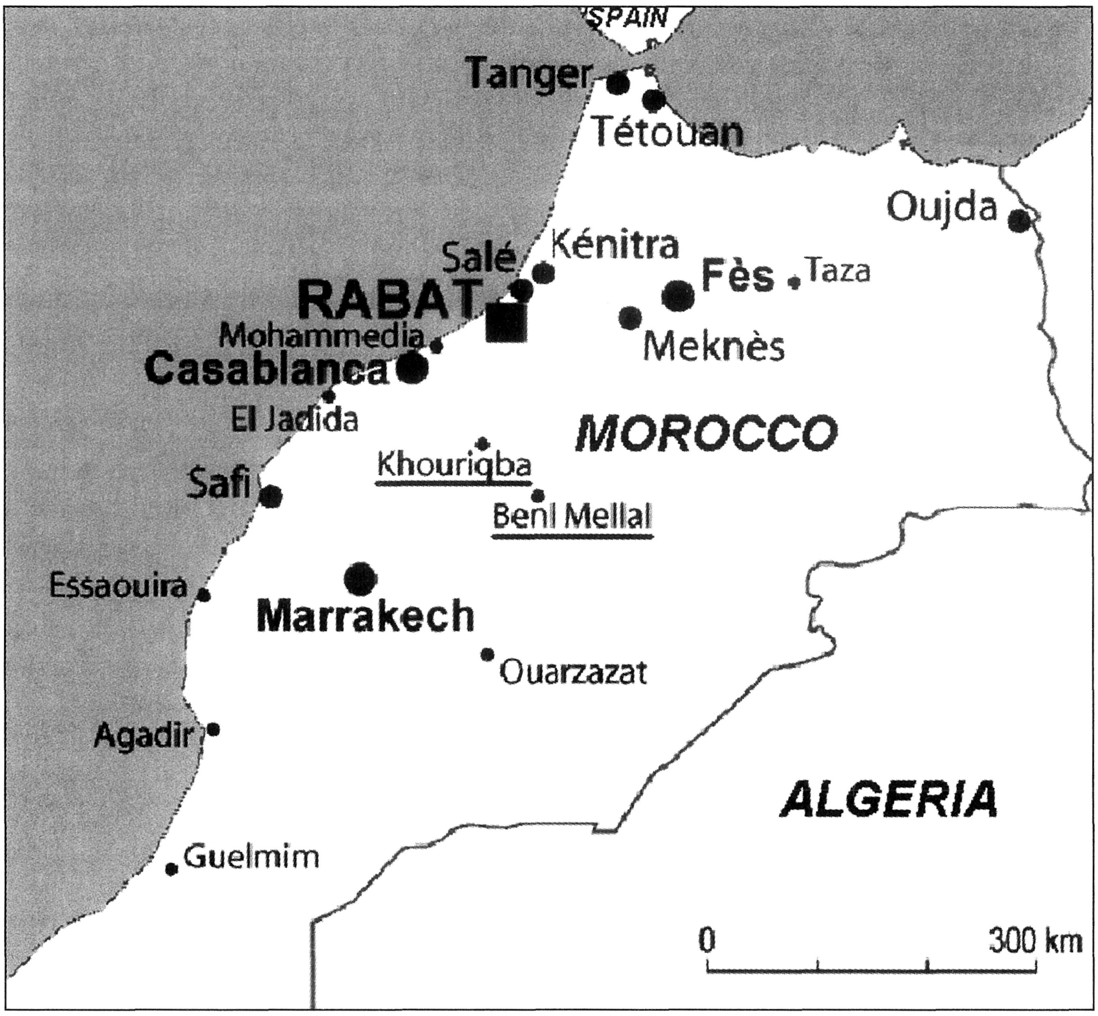

Figure 1. Location of the study area.

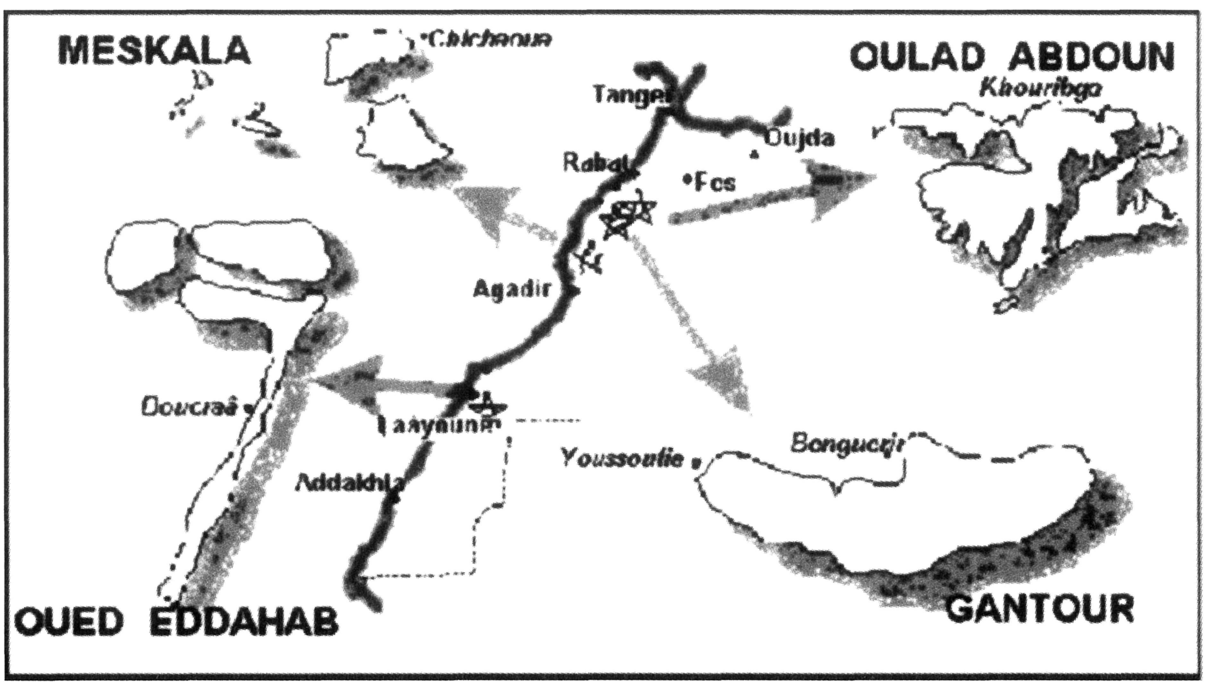

Figure 2. Main phosphate basins in Morocco.

disturbances appear at random so that the apparent resistivity maps which are numerical maps (Bakkali & Bahi, 2005) may be used by the operating personnel as a kind of radar to plan the sequence of field operations. We use in this study sunshading (Horn, 1982) approach to the enhancement edges in images obtained from resistivity data process. The resulting reflectance intensity from a surface which is composed of the geoelectric data to be interpreted will represent in first approach a level of disturbance corresponding to the anomalous zones (disturbed phosphate zones).

OVERVIEW OF THE AREA OF STUDY

The Sidi Chennane phosphate deposit is within the Oulad Abdoun basin about 33 km south-east of Khouribga (figure 2). Its boundaries are: West, meridian 372500 (Lambert), South, meridian 22800 (Lambert), East, highway RP22, and North, the outcrops of the basement of the phosphate-rock sequence. The climate of the phosphate plateau is essentially arid. Rainfall is from November to May and is usually below 400 mm. Vegetation is of sparse dwarf palm trees. Rural population subsists on cattle ranching and seasonal agriculture in small villages, or douars. Ground water is increasingly scarce. Scattered wells depend on an aquifer in the Turonian limestones at depths of 100 m or more, which is sealed by the Senonian marls. This aquifier is also the sole water supply for the various mining operations.

GEOLOGY

The phosphate mineral was deposited over a long time window from Maestrichtian (late Cretaceous, about 80 ma), to Lutetian (early Eocene, 40 ma). However, deposition was irregular. Some layers are missing. Oulad Abdoun Basin occupies most of the phosphate plateau which is bounded toward the north by red outcrops of pre-Cenomanian sediments forming an extension of the south edge of the Central Massif. The Western boundary is the Rhamna Range, the Beni Amir plain is to the South and the Upper Atlas of Beni Mellal extends to the East. The geology of the study area is well understood (see figure 3 for stratigraphy).

The geologic section rests unconformably on Paleozoic schists and quartzites. The basement is well located and the sedimentary cover is fairly thick. The uppermost formations of the Maestrichtian and Eocene contain the phosphate-bearing strata which are 30 to 50 m thick. The earlier deposits, i.e. the lower 5 to 28 m, are clayey phosphates of Maestrichtian age. The upper 20 to 30 m are less homogeneous. They are layered phosphate marls and sandstones with some limestones of Eocene age.

Below the phosphate-bearing strata one finds up to 70 m of Senonian marls and limestone marls; 20 to 60 m of Turonian limestones; a Cenomanian formation of alternately gypsum marls and limestone marls; and finally 10 to 60 m of red marls and mudstones of pre-Cenomanian age.

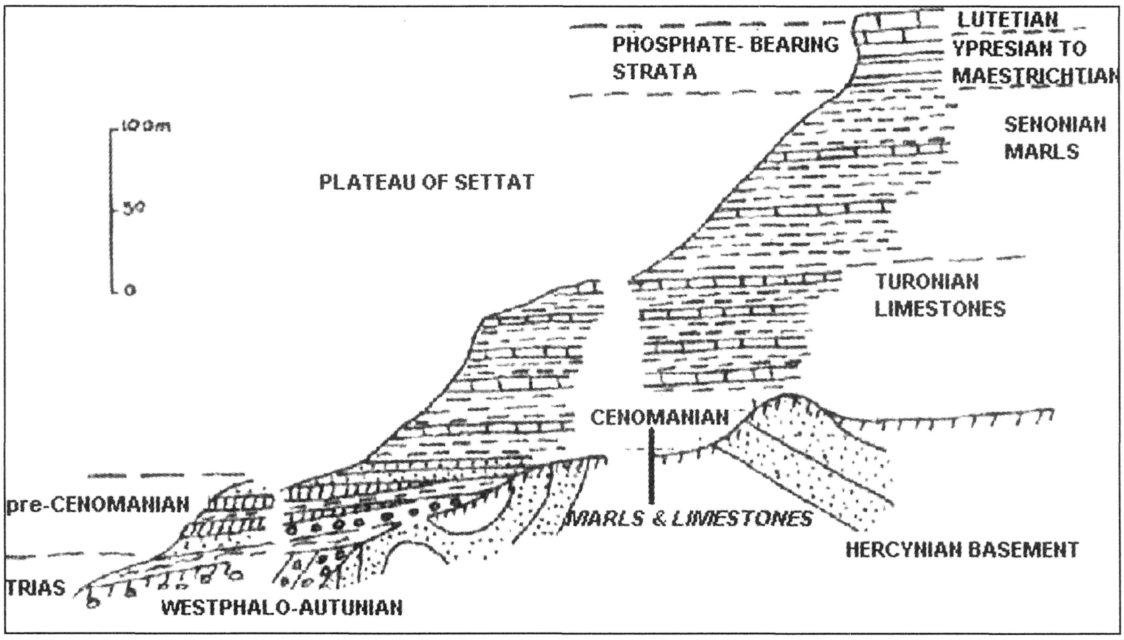

Figure 3. General outline of the stratigraphy.

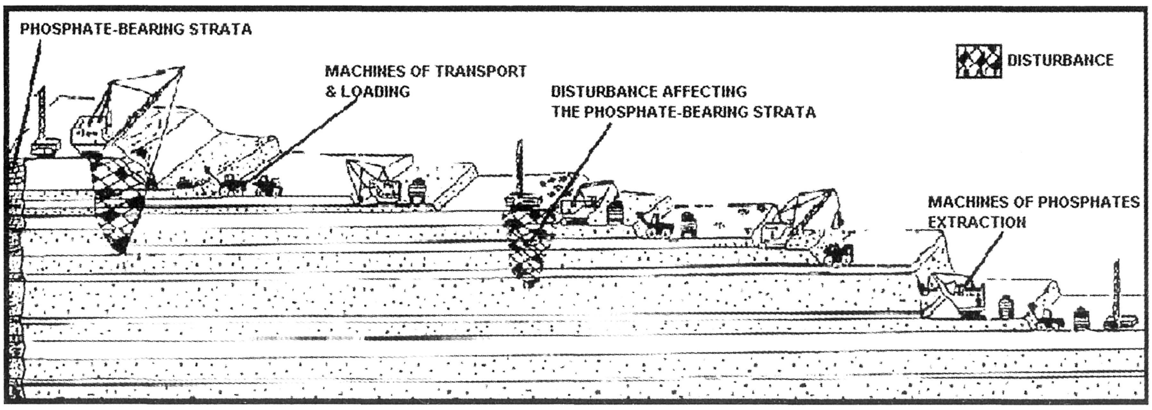

Figure 4. Adverse effects of "disturbances" on mining operations.

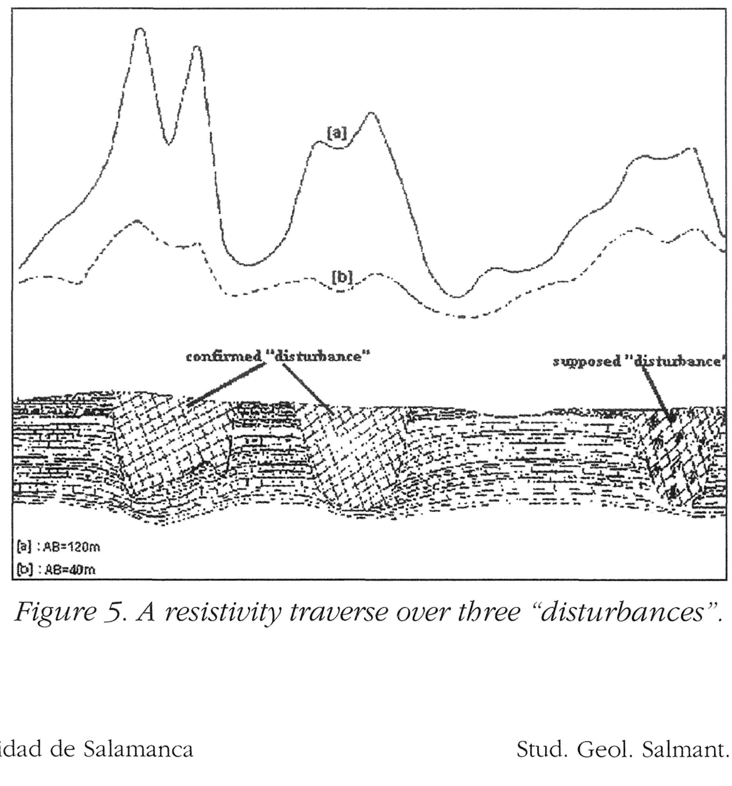

Figure 5. A resistivity traverse over three "disturbances".

The disturbances may be differentiated by size of the pocket or inclusion, type of material, hardness, clay content, or type of contact with the phosphate rock. Two main types of disturbances are found. The first type is found throughout the mineral deposit: it appears to be a random mixture of limestones, marls, clays, cherts and low-grade phosphate with large amounts of cherty limestone. The second type is highly disturbed and lacks any dominant facies (Kchikach & Hiyane, 1991). It appears as an accumulation of low-grade phosphate limestone blocks with large nodules of chert, marl, some fragments of chert and phosphate rock. The latter type forms inclusions of 10 to more than 150 m and is the most abundant during mining operations (figure 4).

GEOPHYSICAL DATA

These pockets are found both in the underlying formation and in the upper members of the phosphate sequence, and as a result there are strong resistivity contrasts between the disturbances and the normal phosphate-bearing rock (Kchikach *et al.*, 2002). These contrasts were confirmed in the test runs (figure 5). Geophysical prospection could thus be based on prior evidence from field data.

Resistivity is an excellent parameter and marker for distinguishing between different types and degree of alteration of rocks. Resistivity surveys have long been successfully used by geophysicists and engineering geologists and the procedures are well established. Resistivity map method has many applications. Its principal advantages lie in the speed of its setting and in the simplicity of the qualitative interpretation of the results. The apparent resistivity reflect the corresponding changes to the distribution of the true resistivities in a section of ground of given depth. They return count variation of the resistivity in the horizontal direction. The maps of resistivity connect which translate the results are similar to the maps of surface observations used by the geologists except that they are physical measurements of parameters interesting a section of ground. It is often useful to measure the apparent resistivity on the same profile with several arrays to obtain results on several sections of ground.

The study area was selected for its representativity and the resistivity profiles were designed to contain both disturbed and enriched areas (Bakkali & Bahi, 2005). The sections were also calibrated by using vertical electrical soundings (Bouyalaoui & Bakkali, 2005). The lateral inhomogeneities of the ground can be investigated by means of the apparent resistivity obtained from the survey. As the surface extension of the layers is displayed we may infer the presence or absence of any disturbances as well as any facies variations. We used a Schlumberger array with a span of 80 and 120 m designed to reach respectively a depth of 15 and 40 m. Our resistivity measurements were performed by means of a Syscal2 resistivity meter by BRGM Instruments using a rectangular array of 20 m x 5 m. In order to reach a mean depth of exploration respectively of 15 and 40 m we carried out 51 traverses at a spacing of 20 m for each Schlumberger array span respectively of 80 and 120 m. There were 101 stations at 5 m distance for every traverse, which makes 5151 stations altogether in the survey for each Schlumberger configuration.

SUNSHADING APPROACH

The enhancement of edges in geophysical potential data is useful as it allows lineaments to be made more apparent, thus helping the geological interpretation process. One method which is in current usage is termed sunshading. Sunshading considers the data as if it were a topographic surface and illuminates it with light from a source at infinity which is specified by its azimuth and elevation. Different reflectance models are available for different types of surface. It is common to assume that the surface is ideal: it reflects all light incident upon it and reflects light equally in all directions. This is termed a Lambertian reflector and its normalized reflectance (Pelton, 1987) map is given by the following expression:

$$R=\frac{1+p_0 p+q_0 q}{\sqrt{1+p^2+q^2}+\sqrt{1+p_0^2+q_0^2}}$$

where $p_o = -cos\phi tan\vartheta$ and $q_o = -sin\phi tan\vartheta$, ϑ the sun elevation measured from the vertical and ϕ is the azimuth measured from anticlockwise from East. p and q are the gradients of the data in the East and North directions respectively, and may be calculated in the space domain by the following expressions:

$$p=\frac{\partial\rho_{app}(x,y)}{\partial x}=\frac{\rho_{i+1,j}-\rho_{i-1,j}}{2\delta x} \quad \text{and} \quad q=\frac{\partial\rho_{app}(x,y)}{\partial y}=\frac{\rho_{i,j+1}-\rho_{i,j-1}}{2\delta y}$$

where x is the eastern coordinate and y the northern coordinate. $\rho_{i,j}$ is the pseudo-apparent resistivity defined at grid point (i,j). Grid intervals in the x-direction and y-direction are δ_x and δ_y respectively.

The elevation and azimuth are chosen by the interpreter. Since the same order of derivative is used for both horizontal gradients, the orientation of the surface normal which controls the reflectance is not altered.

Features that lie at 90° to the sun azimuth are enhanced, while those which lie parallel to it are reduced in amplitude. To enhance edges in the map that lie at any orientation, the azimuth should be set to 180° from the direction of steepest slope at each point on the surface (Cooper, 2003).

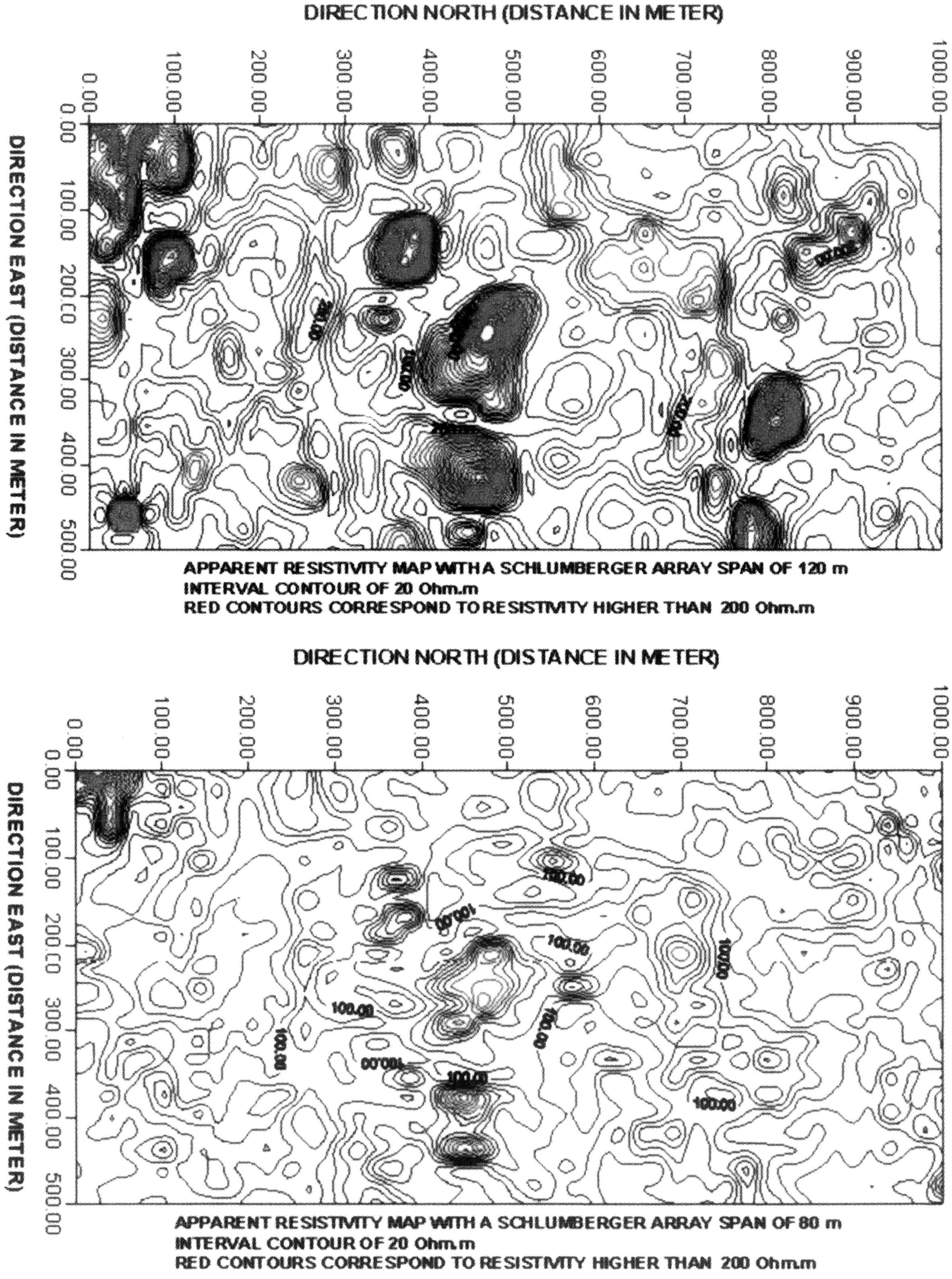

Figure 6. Resistivity maps of the study area with a Schlumberger array span of 80 and 120 m (intervall contour: 20 Ωm).

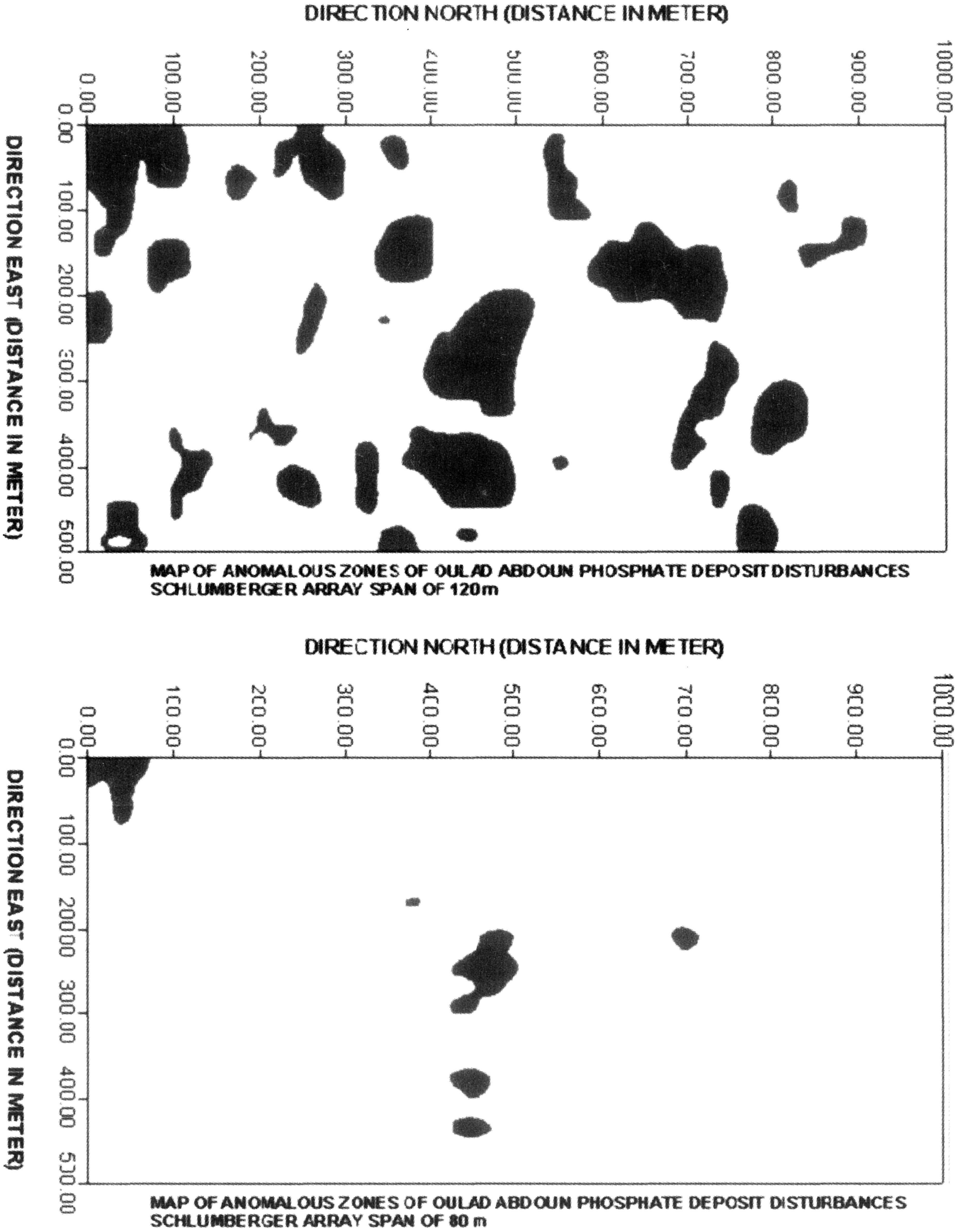

Figure 7. Maps of resistivity anomalies for Schlumberger array span of 80 and 120 m.

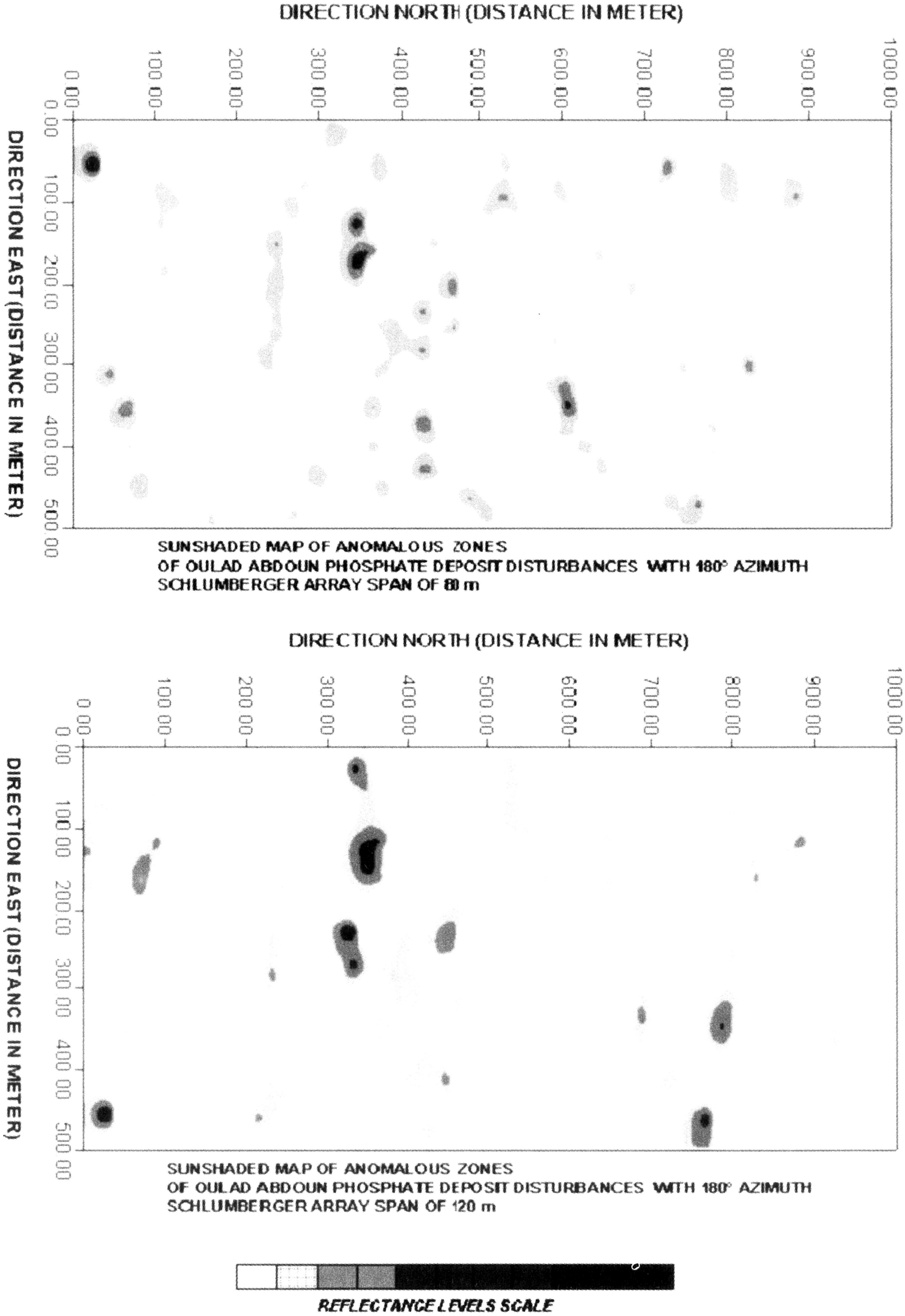

Figure 8. Sunshaded maps of anomalous zones of Oulad Abdoun phosphate disturbances with 180° azimuth.

RESULTS

The apparent resistivity maps (figure 6) obtained from a survey had been considered as maps of discrete potentials on the free surface, and any major singularity in the apparent resistivities due to the presence of a perturbation would be due to the crossing from a "normal" into a "perturbed" area or vice versa (Bakkali, 2006). In other words, the apparent resistivity maps had been considered maps of scalar potential differences assumed to be harmonic everywhere except over the perturbed areas. Thus one assumes that the potential difference data maps may be processed by both in the space and frequency domains (Cooper & Cowan, 2003). The original resistivity maps obtained in a former study, and based under those hypothesis, had allowed us direct images for an interpretation of the resistivity survey. We were able to identify the anomalous zones which turned out to be strongly correlated with the disturbances (Bakkali & Bahi, 2005) (Bakkali, 2006). The result were maps of anomalous areas of Oulad Abdoun phosphate deposit disturbances (figure 7).

The data process was executed using the EasyMapping software (Monnereau, 2003). The sunshading tool is basically a spatial filter which enhance edges of anomalous zones. We used the sunshading process using an azimuth sun angle of 180° for enhancing edges in an image that lie at any orientation. The elevation sun was put to zero. Figure 8 shows the sunshaded maps of anomalous zones of Oulad Abdoun phosphate deposit disturbances corresponding to an azimuth sun angle of 180°. With the sunshading approach, we found that the disturbances as detected from surface measurements were distributed apparently at random as confirmed by the various sunshaded maps (figure 8).

The disturbances as detected from surface measurements which present depth lower than 15 m (Shlumberger array span of 80 m) seem to be not very significant regarding to surface study aerea. The disturbances as detected from surface measurements and corresponding to the phosphate deposit anomalous zones were dominating in depths ranging between 15 and 40 m. This fundamental result is the direct consequence of the comparison of the maps of the phosphate deposit anomalous zones corresponding to the two Schlumberger devices. The Schlumberger array span represent in our case a spatial filter applied to filter anomalous zones of phosphate deposit disturbances.

The sunshaded maps (figure 8) represent an effective indicator of the level of disturbance measured on the topographic surface corresponding to the study aerea. The maxima reflectance would be occur immediately over rock masses of contrasting densities. On the sunshaded maps, the reflectance will represent in this case an indicator of variation level of contrasting densities between the disturbances and the normal phosphate-bearing rock. A high reflectance ratio will represent a strong level of disturbance. In our case, the anomalous areas edges were better enhanced, and the reflectance level indicates the level of disturbances in the anomalous zones. According to the appreciation of the surveyors anomalous zones will be described as little, slightly, fairly, enough or highly disturbed. These properties will be correlated to the enhancement edges of the anomalous zones resulting from the sunshading process.

CONCLUSIONS

We found that the sunshading approach helps to better constrain the location of anomalous areas on the surface. We have described an analytical procedure, which is a spatial filter, to enhance edges of anomalous zones of a specific problem in the phosphate mining industry. The results proved satisfying. Data processing procedure as sunshading were found to be consistently useful and may be used as auxiliary tool for decision making under field conditions. It was found that the sunshaded images with 180° of an azimuth sun corresponding to the anomalous zones of Oulad Abdoun phosphate deposit disturbances were particular useful to the surveyors for improving and constraining their estimates of phosphate reserves in the deposit. While assimilating the reflectance level to disturbances level the sunshading tool appears to be an interesting technique of optimization of the reserves in the mining area.

BIBLIOGRAPHY

BAKKALI, S. (2006): A resistivity survey of phosphate deposits containing hardpan pockets in Oulad Abdoun, Morocco. *Geofísica Internacional*, **45 (1)**: (under press).

BAKKALI, S. & BAHI, L. (2005): Cartographie des "dérangements" de séries phosphatées par mesures de résistivités électriques. *Journal des Sciences Pour l'Ingénieur, J. S. P. I.*, **6**: (under press).

BAKKALI, S. & BOUYALAOUI, J. (2005): Essai d'optimisation de la capacité de retenue d'eau d'un lac par caractérisation géophysique du recouvrement argileux. *African Journal of Science & Technology, A. J. S. T.*, **6 (2)**: (under press).

COOPER, G. R. J. (2003): Feature detection using sunshading. *Computer & Geosciences*, **29**: 941-948.

COOPER, G. R. J. & COWAN, D. (2003): The application of fractional calculus to potential field data. *Exploration Geophysics*, **34**: 51-56.

HORN, B. K. P. (1982): Hill shading and the reflectance map. *Geoprocessing*, **2**: 65-146.

KCHIKACH, A. & HIYANE, M. (1991): *Apport de la géophysique à la détermination des dérangements à Sidi Chennane Nord.* Publ. École Mohammadia d'Ingénieurs, Rabat, Maroc, 67 pp.

KCHIKACH, A.; JAFFAL, M.; AIFA, T. & BAHI, L. (2002): Cartographie de corps stériles sous couverture quaternaire par méthode de résistivités électriques dans le gisement phosphaté de Sidi Chennane (Maroc). *Comptes Rendus Geosciences*, **334**: 379-386.

MONNEREAU, O. (2003): *About Easy Mapping software version 3.0, Manuel d'utilisation.* Copyright 2001-2003 OLIVIER MONNEREAU.

PELTON, C. (1987): A computer program for hill-shading digital topographic data sets. *Computer & Geosciences*, **13 (5)**: 545-550.

