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USING MORLET WAVELET FILTER TO DENOISING GEOELECTRIC "DISTURBANCES" MAP OF MOROCCAN PHOSPHATE DEPOSIT "DISTURBANCES"

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Abstract: *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. A Schlumberger resistivity survey over an area of 50 hectares was carried out. A new field procedure based on analytic signal response of resistivity data was tested to deal with the presence of phosphate deposit disturbances. A resistivity map was expected to allow the electrical resistivity signal to be imaged in 2D. 2D wavelet is standard tool in the interpretation of geophysical potential field data. Wavelet transform is particulary suitable in denoising, filtering and analyzing geophysical data singularities. Wavelet transform tools is applied to analysis of a Moroccan phosphate deposit "disturbances". Wavelet approach applied to modeling surface phosphate "disturbances" was found to be consistently useful.*

Keywords: *resistivity, Schlumberger, phosphate, wavelet, Morocco*

INTRODUCTION

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. The study area is the Oulad Abdoun phosphate basin (figure 1) which contain the Sidi Chennane deposit.

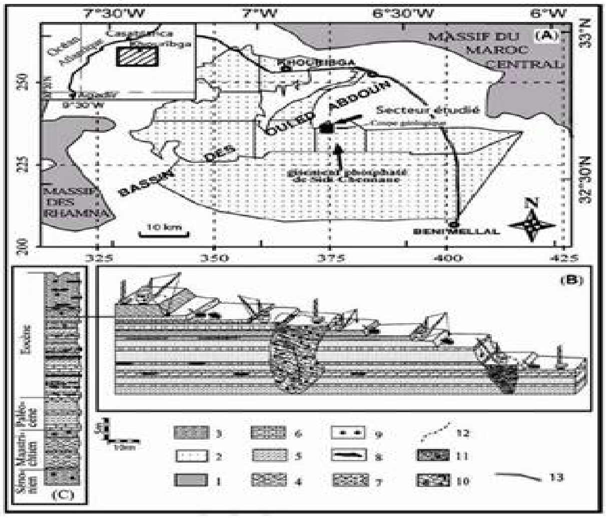

Figure 1. *(A) Location of the studied area in the sedimentary basin of Ouled Abdoun. (B) Section showing the disruption of the exploitation caused by disturbances. (C) Stratigraphical log of the phosphatic series of Sidi Chennane: (1) Hercynian massif; (2) phosphatic areas; (3) marls; (4) phosphatic; marls; (5) phosphatic layer; (6) limestones; (7) phosphatic limestone; (8) discontinuous silex bed; (9) silex nodule; (10) "disturbance" formed exclusively of silicified limestone; (11) "disturbance" constituted of a blend of limestone blocks, marls and clays; (12) "disturbance" limit; (13) roads.*

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. However, the new deposit contains many inclusions or lenses of extremely tough hardpan locally known as dérangements or disturbances (figure 2), found throughout the phosphate-bearing sequence.

Figure 2. *Example of "disturbance" affecting the phosphate strates*

The hardpan pockets are normally detected only at the time of drilling. Direct exploration methods such as well logging or surface geology are not particularly effective.

They interfere with field operations and introduce a severe bias in the estimates of phosphate reserves (figure 3) (Kchikach et al., 2002) (Bakkali, 2005).

The study area was selected for its representativity and the resistivity profiles were designed to contain both disturbed and enriched areas. The sections were also calibrated by using vertical electrical soundings. High

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values of apparent resistivity were encountered due to the presence of near-vertical faulting between areas of contrasting resistivity, and fault zones which may contain more or less highly conducting fault gouge. The gouge may contain gravel pockets or alluvial material in a clay matrix (Bakkali & Bahi, 2006) (Bakkali, 2006). Such anomalous sections are also classified as disturbances. Apparent resistivity values in these profiles locally exceeded 200 Ω. □m.

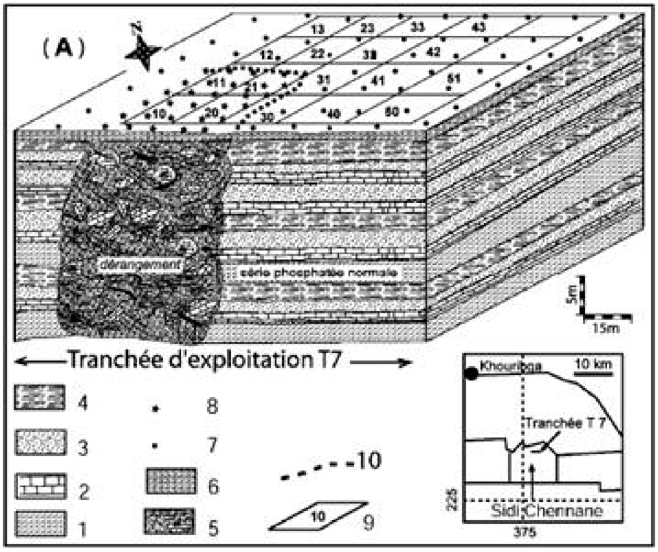

Figure 3. (A) Geological section of the T7 exploitation trench showing a "disturbance" and position plan of the soundings tests. Apparent resistivity profiles positions while passing from the deranged zone to a normal phosphatic series : (1) phosphatic marls; (2) limestones; (3) phosphatic layer; (4) marls; (5) "disturbance" ; (6) Quaternary cover; (7) borehole crossing a normal phosphatic series; (8) borehole crossing a "disturbance"; (9) measures loop number 10; (10) "disturbance" limit.

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. 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 of 40 m we carried out 51 traverses at a spacing of 20 m (figure 3). There were 101 stations at 5 m distance for every traverse, which makes 5151 stations all together in the survey. The apparent resistivity map (figure 4) which one obtains from such a survey is actually a map of discrete potentials on the free surface, and any major singularity in the apparent resistivities due to the presence of a perturbation will be due to the crossing from a "normal" into a "perturbed" area or vice versa.

In other words, the apparent resistivity map may be considered a map of scalar potential differences assumed to be harmonic everywhere except over the perturbed areas. Interpretation of resistivity anomalies is the process of extracting information on the position and composition of a target mineral body in the ground. In the present case the targets were essentially the inclusions called perturbations. The amplitude of an anomaly may be assumed to be proportional to the volume of a target body and to the resistivity contrast with the mother lode. If the body has the same resistivity as the mother lode no anomaly will be detected. Thus assumed in fact and in first approach that the resistivity anomalies would be representative of the local density contrast between the disturbances and the mother lode. Level disturbance of the anomalous zones is proportionnal to resistivity intensity (figure 5).

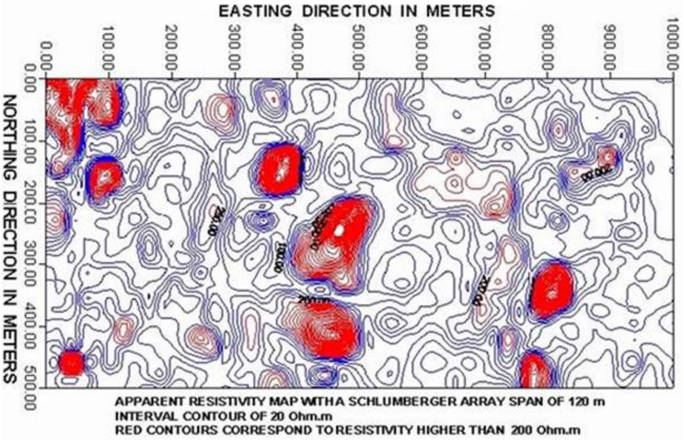

Figure 4 . A map of resistivity anomalies for AB=120 m

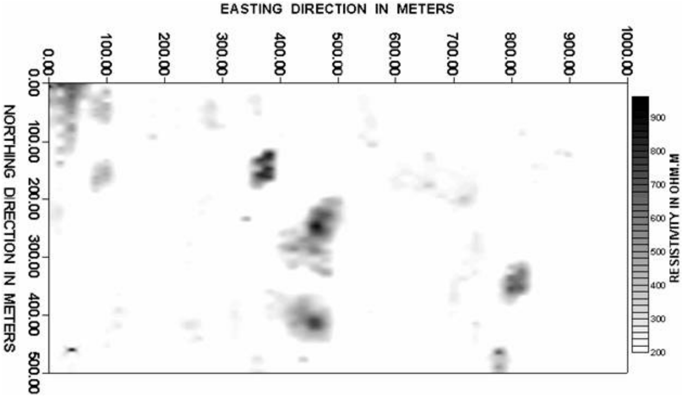

Figure 5. A map of disturbed phosphate zones corresponding to Figure. 4

2D WAVELET TRANSFORM & PROCESSING DATA

The wavelet transform is a time-frequency decomposition which links a time (or space) domain function to its time-scale wavelet domain representation. The concept of scale is broadly related to frequency. Small scales relate to short duration, high frequency features and correspondingly, large scales relate to long duration, low frequency features. Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other function. In the signal analysis framework, the wavelet transform of the time (or space) varying signal depends on the scale that is related to frequency and time (or space) (Ridsdill & Dendith, 1999). The 2D wavelet method provides information on many more resolution than the former method. It is a powerfful tool particulary suitable in denoising, filtering and analyzing problems and potential singularities (Sanz et al., 1999). Moreover this property is crucial for performing an efficient linear denoising resistivity anomaly map of the moroccan phosphate deposit "disturbances". The wavelet transform of a 2D signal $f(x,y)$, where x and y represent respectively the easting and the northing directions, and f the apparent resistivity data □, is defined as:

$$\omega(X,Y,a,b)=\int\int\frac{1}{\sqrt{|XY|}}f(x,y)\psi\left(\frac{x-a}{X},\frac{y-b}{Y}\right)dxdy \quad (1)$$

where $\frac{1}{\sqrt{|XY|}}\psi\left(\frac{x-a}{X},\frac{y-b}{Y}\right)$ *is the wavelet coefficient associated to the scales* X *and* Y *at the point with coordinates* a *and* b *(TORRENCE & COMPO, 1998). The limits in the double integral are* $-\infty$ *and* $+\infty$ *for the two variables.* ψ *is the wavelet "mother" function that satisfies the constraints*

$$\iint dxdy\,\psi=0 \quad (2)$$

and

$$\iint dxdy\,\psi^2=0 \quad (3)$$

The 'admissibility' condition that allows to reconstruct the function f *, i.e there exists the following integral :*

$$C_\psi=(2\pi)^2\iint dk_1dk_2\frac{\left|\hat{\psi}(k_1,k_2)\right|^2}{|k_1k_2|} \qquad (4)$$

where $\hat{\psi}(k_1,k_2)$ *represents the 2D Fourier transform of* ψ *and denotes the modulus of the complex number* C_ψ *. A reconstruction of the original geophysical signal corresponding to resitivity data can be achieved using the inversion formula expressed by :*

$$f(x,y)=\frac{1}{C_\psi}\iint\frac{dXdY}{|XY|^2}dadb\,\omega(X,Y,a,b)\frac{1}{\sqrt{|XY|}}\psi\left(\frac{x-a}{X},\frac{y-b}{Y}\right) \quad (5)$$

We have chosen in our study the Morlet wavelet "mother" (UCAN et al., 2000) (figure 6) defined in 1D by the following equation :

$$\psi_{Morlet}(x)=\frac{1}{\pi^{4}}e^{(j\alpha_0 x)}e^{(-x^2/2)} \quad (6)$$

where α_0 *is an adjustable parameter (wavenumber). The adjustable parameter have been put to 6. This is the smallest wavenumber that allows for an accurate resistivity signal reconstruction.*

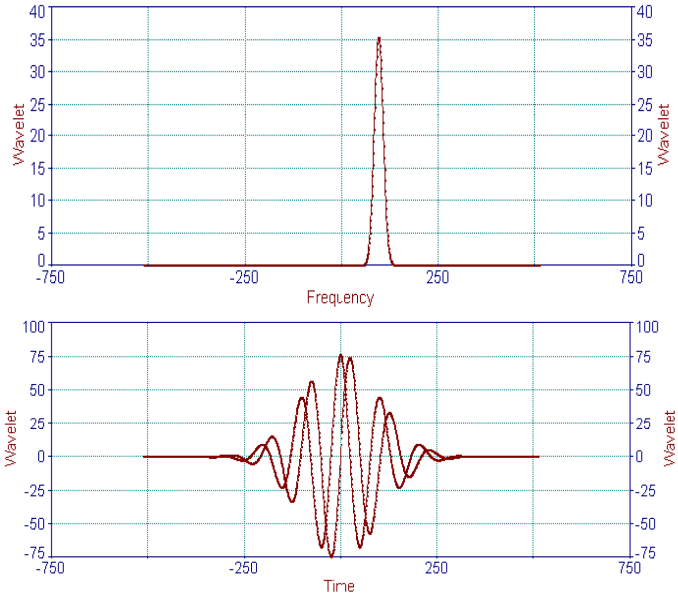

Figure 6. *Time and frequency Morlet wavelet "mother" responses*

The resistivity data base is a compilation of 51 traverses at a spacing of 20 m. There were 101 stations at 5 m distance for every traverse, which makes 5151 stations all together in the resistivity survey. We calculated the magnitude square of the wavelet transform coefficients using AutoSignal routine (SYSTAT, 2002) for each resistivity traverse (figure 7). Then we deferred all the results to built a 2D wavelet spectrum regular maps which represent in fact filtering and denoising map of the phosphate deposit "disturbances".

Since a major potential application of wavelets is in image processing, the 2D wavelet transform is a necessity to be applied as a detector and analyser of singularities like edges, contours or corners (TSIVOURAKI-PAPAFOTIOU et al., 2005).

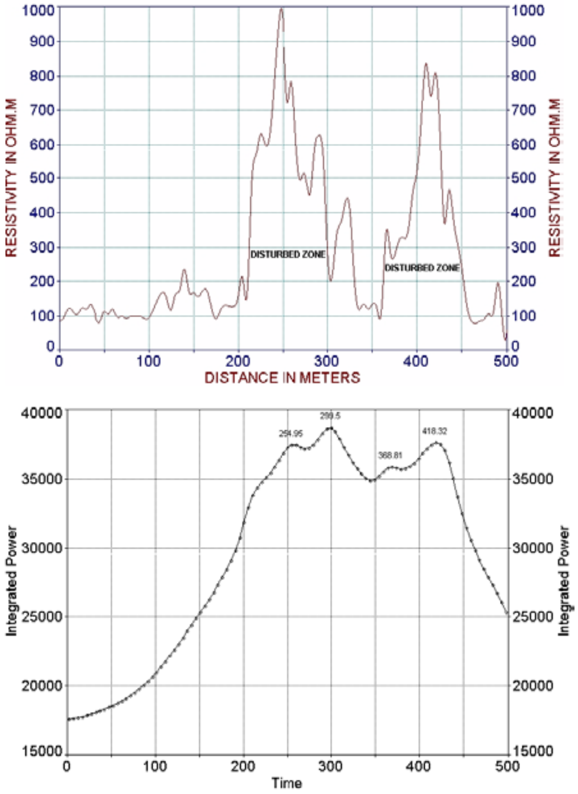

Figure 7*. Example of real resistivity traverse data of the survey and the corresponding continous wavelet transform using Morlet "mother".*

RESULTS & CONCLUSIONS

Figure 8 represents an indicator of the level of variation of the contrast of density between the disturbances and the normal phosphate-bearing rock. The surface modeling of resistivity anomalies is obtained by AutoSignal routine from our apparent resistivity survey.These procedure enables us to define the surface phosphate disturbed zones.

The continous wavelet analysis surface of phosphate deposit disturbance zones modeling as obtained by the above procedure in the study area provided a direct image for an interpretation of the resistivity survey. These method enable us to identify the anomalies area which turned out to be strongly correlated with the disturbances. The disturbances as detected from surface measurements were distributed apparently at random as confirmed by figure 8. These figure represents an effective indicator of the intensity level of "disturbance". The use of magnitude square of the continous wavelet transform represent an effective filtering method which makes it possible to attenuate considerably the noise represented by the minor dispersed and random disturbances. The overall effect is that of scanning and denoising the anomalous bodies. Comparatively to classical approaches used in filtering and denoising *geophysical data maps, the advantage of the 2D continous wavelet transform method is doesn't introduce significant distorsion to the shape of the original resistivity signal .*

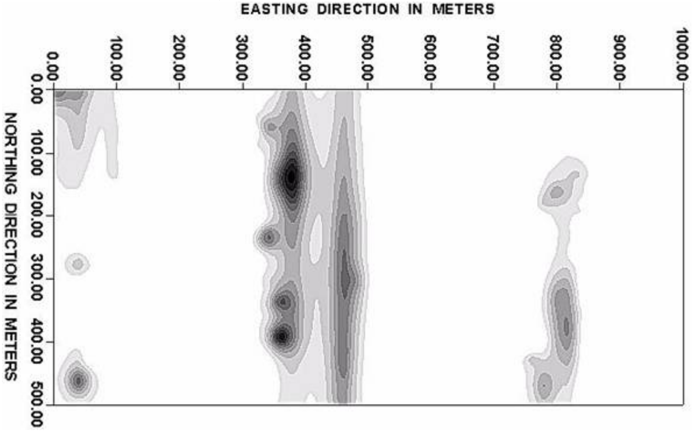

Figure 8. *Wavelet output of the phosphate deposit "disturbances" map given in Figure 6*

The wavelet output of the apparent resistivity which correspond to the wavelet output of the anomalous phoshate deposit map obtained from such a technical tool represent the crossing dominate area from a "normal" into a "perturbed" area or vice versa. Moreover the level of disturbance is very clearly shown.

The proposed filtering and denoising method using 2D continous wavelet transform tends to give a real estimation of the surface of the phosphate deposit "disturbances" zones with a significant suppression of the noise. The level disturbance resulting from such method is also more defined in all the disturbed zones.

We have described an analytical procedure to analyze the anomalies of a specific problem in the phosphate mining industry. The results proved satisfying. Data processing procedures as 2D wavelet transform of resistivity data map was found to be consistently useful and the corresponding map may be used as auxiliary tools for decision making under field conditions.

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