Using Savitzky-Golay filtering method to optimize surface phosphate deposit "disturbances"

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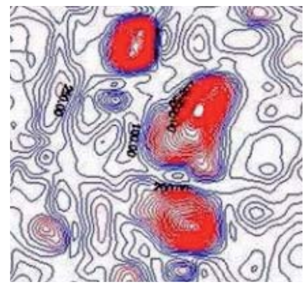

ABSTRACT

One of the several methods that are currently in use for optimizing edges and contours of geophysical data maps is the Savitzky-Golay filtering method, which has been successfully applied to analysis of steady data. An imaged 2D resistivity map of a mining zone in Morocco was built, showing anomalies that correspond to disturbances in phosphate deposits. The Savitzky-Golay filtering method was used as a tool for denoising the data allowing an improved geophysical map and an easier decision making under field conditions.

KEYWORDS

Resistivity, phosphate, Savitzky-Golay, filtering, Morocco.

RESUMEN

Uno de los métodos actualmente en uso para optimizar los bordes y los contornos de mapas geofísicos es el método de filtrado de Savitzky-Golay, el cual se ha aplicado con éxito al análisis de datos constantes. Se elaboró un mapa de la resistividad en 2D de una zona minera en Marruecos, mostrando anomalías que corresponden a perturbaciones en depósitos de fosfato. El método de Savitzky-Golay fue utilizado como una herramienta para eliminar ruido en los datos permitiendo un mapa geofísico mejorado y facilitando la toma de decisiones bajo condiciones del campo.

PALABRAS CLAVE

Resistividad, fosfato, Savitzky-Golay, filtrado, Marruecos.

INTRODUCTION

Resistivity is an excellent parameter for distinguishing between different types and degrees of alteration of rocks. Resistivity surveys procedures are well established[1] and they have been long and successfully used by geophysicists and engineering geologists.

The studied area is the Oulad Abdoun (Morocco) phosphate basin which contains the Sidi Chennane, which is a sedimentary deposit that contains several distinct phosphate-bearing layers. These layers are found in contact with alternating layers of calcareous and argillaceous hardpan. Therefore, a new deposit contains many inclusions or lenses of extremely tough hardpan locally known as "derangements" or "disturbances" (figure 1), found throughout the phosphate-bearing sequence. 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 for estimating phosphate reserves. They interfere with field operations and introduce severe bias in the estimation of phosphate reserves[2, 3] (figure 2).

The studied area was selected for its representativity, and the apparent resistivity profiles[4] were designed to contain both disturbed and enriched areas (figure 3). The sections were also calibrated by using vertical electrical soundings[5] (figure 4).

High 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.[6,7] Such anomalous sections are also classified as disturbances. Local apparent resistivity values in these profiles exceeded 200 $\tilde{\Omega}$.m. The apparent resistivity map (figure 5) obtained from the 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. Hence, the apparent resistivity map might be considered a map of scalar potential differences assumed to be harmonic everywhere except over the perturbed areas.

Fig. 1. Example of "disturbance" affecting the phosphate strates.

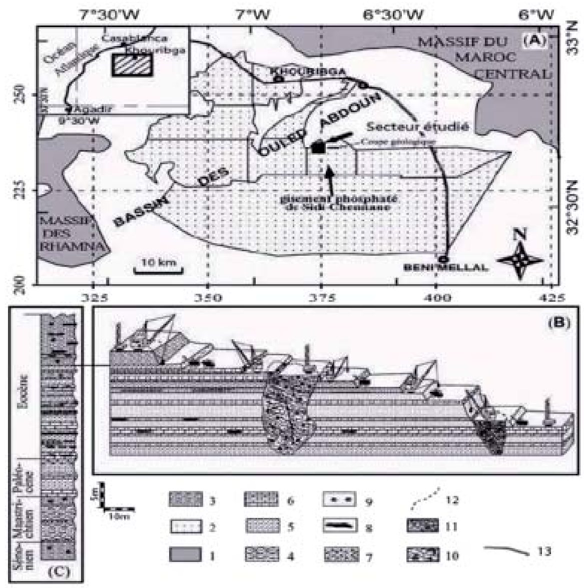

Fig. 2. (A) Location of the studied area in the sedimentary basin of Ouled Abdoun. (B) Section showing the disruption of the exploitation caused by disturbances. (C) Stratigraphical log of the phosphatic series of Sidi Chennane: (1) Hercynian massif; (2) phosphatic areas; (3) marls; (4) phosphatic; marls; (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.

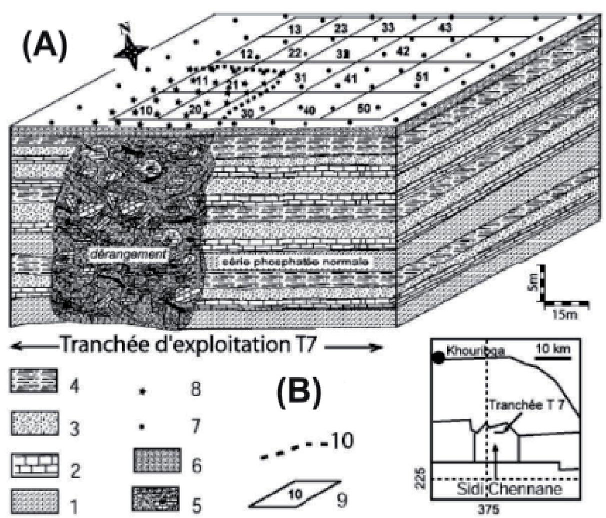

Fig. 3. (A) Geological section of the T7 exploitation trench showing a "disturbance" and position plan of the soundings tests. Apparent resistivity profiles positions while passing from the deranged zone to a normal phosphatic series (B): (1) phosphatic marls; (2) limestones; (3) phosphatic layer; (4) 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.

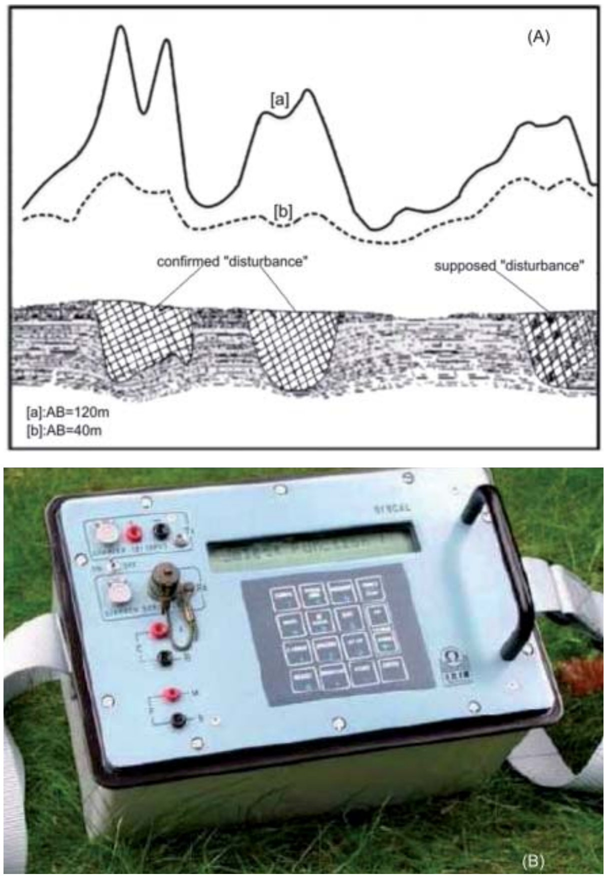

Fig. 4. A synthetic apparent resistivity traverse over three disturbances (A) and the Syscal resistivity meter used in the study (B).

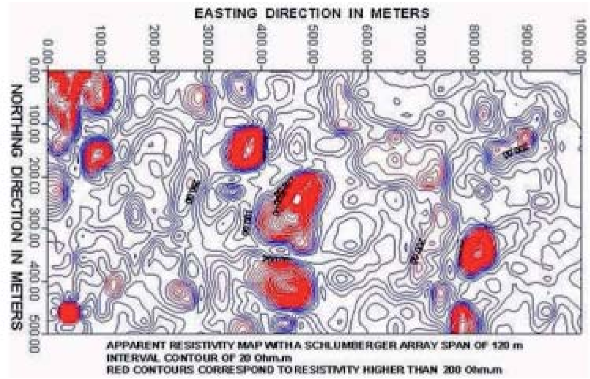

Fig. 5. A map of resistivity anomalies for AB=120 m.

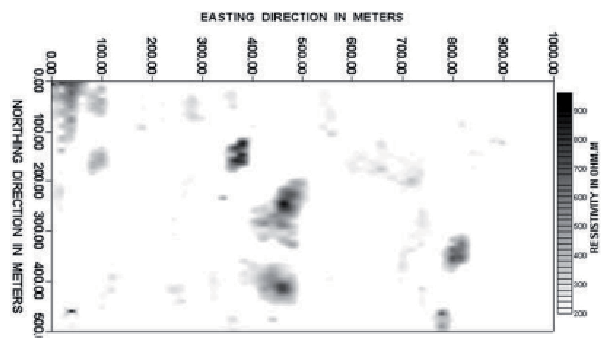

Fig. 6. A map of the disturbed phosphate zones corresponding to figure 5

Information regarding the position and composition of a target mineral body in the ground was obtained from interpretation of resistivity anomalies. 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. Indeed, a first approach is 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[8,9] (figure 6).

Collected resistivity data is often contaminated with noise and artifacts coming from various sources. Noise in data resistivity distorts the characteristics of the geophysical signal, resulting in poor quality of any subsequent processing. Consequently, the first step in any processing of such geophysical data is the “cleaning up” of the noise in a way that preserves the signal sharp variations. The Savitzky-Golay filtering method[10,11] has become a powerful signal and image processing tool which has found applications in many scientific areas. This method is a widely used technique that is applicable to the filtering geophysical data.[12]

The present paper deals with analyzing resistivity data map using the Savitzky-Golay filtering to denoise anomalous zones map of phosphate deposit disturbances. The results show a significant suppression of the noise and a very good recovery of the resistivity anomalies signal. So, the Savitzky-Golay processing is thought to be a good method to geophysical anomaly filtering.

THE SAVITZKY-GOLAY FILTER

The Savitzky-Golay filter was introduced for smoothing data and for computing the numerical derivatives. The smoothing points are found by replacing each data point with the value of its fitted polynomial. The process consists of finding the coefficients of the polynomial which are linear with respect to the data values for fictitious data and applying this linear filter over the complete data. The size of the smoothing window is odd, and the polynomial function is defined as:

$$\rho(x_i, y_i) = a_{00} + a_{10}x_i + a_{01}y_i + a_{20}x_i^2 + a_{11}x_iy_i + a_{02}y_i^2 + ... + a_{0k}y_i^k \quad (1)$$

where x_i and y_i represent the east and north coordinates of a gidded point of the resistivity map. Then the polynomy of type in Eq.(1) is fitted to the data with coefficients found by least squares method. The process started with the general equation, $A\,x\,a = \rho$ where a is the vector of polynomial coefficients $a = (a_{00} \quad a_{01} \quad a_{10} ....a_{0k})^T$ and ρ the corresponding apparent resistivity data vector. Then the coefficient matrix is $(A^T x\ A)x\ a = (A^T x\,\rho)$, which in least squares can be written as $a = (A^T\ x\ A)^{-1}\ x\ \ (A^T\ x\ \rho)$ where A^T is the transposed matrix of A . Due to the linear-square fitting of the resistivity data, the coefficients can be independent and the general coefficient matrix becomes $C = (A^T\ x\ A)^{-1}\ x\ A^T$.

The general coefficient matrix can be reassembled back into a traditional looking filter that achieves the reconstruction of the filtered geophysical signal corresponding to resitivity data. The advantage of the Savitzky-Golay filter has the ability to preserve higher moments in the resistivity data and thus reduce smoothing on peak heights. It is a powerfull tool particulary suitable for denoising, filtering and analyzing problems and potential singularities.[11] Moreover this property is crucial for performing an efficient linear data denoising resistivity anomaly map of phosphate deposit “disturbances”.

METHODOLOGY AND PROCEDURE

The resistivity data base is a compilation of 51 traverses spaced at 20 m. There were 101 stations at 5 m between them for every traverse, which makes 5151 stations all together in the resistivity survey. Savitzky-Golay filtered signal output was calculated using AutoSignal[13] routine for each resistivity traverse (figure 7), and all the results were used for building a regular map which represents indeed Savitzky-Golay filtering and denoising map of the phosphate deposit “disturbances” (figure 7).

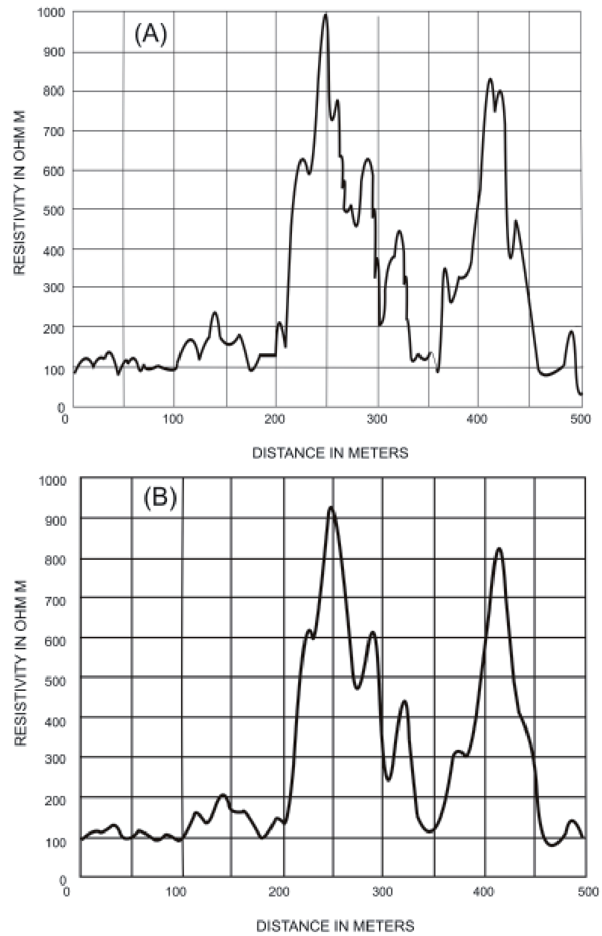

Fig. 7. Example of real resistivity traverse data of the survey (A) and the corresponding Savitzky-Golay output filtering (B).

RESULTS AND DISCUSSION

The 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 Savitzky-Golay filtering output map correponding to surface modeling of resistivity anomalies is obtained by AutoSignal routine. This procedure enables us to define the surface phosphate disturbed zones. The Savitzky-Golay filtering analysis surface of phosphate deposit disturbance zones as obtained by the above procedure in the study area provided a direct image for an interpretation of the resistivity survey.

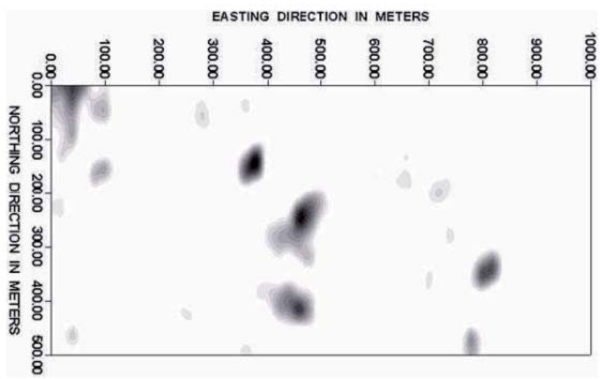

Fig. 8. Savitzky-Golay filtering output of the phosphate deposit "disturbances" map given in figure 6.

This method allowed to identify the anomalies area which turned out to be strongly correlated with the disturbances. This figure represents an effective indicator of the intensity level of "disturbance". The use of the Savitzky-Golay filtering method represents an effective filtering method which makes possible to attenuate considerably the noise represented by the minor dispersed and random "disturbances". The overall effect is that scanning and denoising the anomalous bodies was achieved.

CONCLUSION

Compared to classical approaches used in filtering and denoising geophysical data maps, the advantage of the Savitzky-Golay filtering method is that it does not introduce significant distorsion to the shape of the original resistivity signal.

The Savitzky-Golay filtering output of the apparent resistivity map which corresponds to the Savitzky-Golay filtering output of the anomalous phoshate deposit map obtained from such a technical tool represents the crossing dominate area from a "normal" into a "perturbed" area or vice versa. Moreover, the level of disturbance is clearly shown.

The proposed filtering and denoising method using Savitzky-Golay filtering 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 a singular procedure to analyze the anomalies of a specific problem in the phosphate mining industry. Data processing procedures as the Savitzky-Golay filtering technique shown to denoise resistivity data map was found to be consistently useful and the corresponding map may be used as an auxiliary tool for decision making under field conditions.

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