Edges Detection from Aeromagnetic Data using the Wavelet Transform

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Abstract: The main goal of this paper is to use the 2D Directional Continuous Wavelet Transform (DCWT) for structural boundaries delimitation from geomagnetic data. The proposed idea is based on the mapping of maxima of the modulus of the 2D DCWT for each scale used in the DCWT calculation. Application to synthetic data shows robustness of the technique. Application to the real geomagnetic data of In Ouzzal area located in the West of Hoggar (Algeria) shows clearly the strength of this last. Comparison with the analytic signal solutions exhibits that the DCWT is able to predict a pattern of boundary that is hidden by the noise in the analytic signal and eliminated by a threshold. The proposed method proves to be more powerful easy to use and versatile where classical methods of potential field interpretation fail or are very constraining.

1 INTRODUCTION

The continuous wavelet transform has becoming a very useful tool in geophysics (Ouadeul, 2006); (Ouadfeul, 2007). In Potential field analysis it was used to locate causative sources point in 2D in combination with the analytic signal (Ouadfeul and Aliouane, 2011).

Ouadfeul and Alioaune (2012) have published a paper on the characterization of geological boundaries using 2D wavelet transform of gravity data, the proposed technique has been applied on the Hoggar.

Ouadfeul et al., (2012) have proposed a new technique of structural boundaries delimitation from aeromagnetic data using the 2D ditrectional continuous wavelet transform, obtained results show robustness of the proposed technique.

Here we propose a technique of boundaries delimitation from aeromagnetic data using the 2D continuous wavelet transform, we start the paper by describing the relation between the wavelet transform and the upward continuation, after that we apply the proposed idea to a synthetic and real data of an area located in the Algerian Sahara. We finalize the paper by a results interpretation and a conclusion.

2 THE CONTINUOUS WAVELET TRANSFROM AND POTENTIAL FILED DATA

The sharp contrasts that show the potential data are assumed to result from discontinuities or interfaces such as faults, flexures, contrasts intrusive rocks ... For contacts analysis between geological structures, we use usually the classical methods based on the location of local maxima of the modulus of the total (Nabighian, 1984) or the horizontal gradient (Blakely et al., 1986), or the Euler's deconvolution (Reid et al., 1990). This technique allows, in addition to localization in the horizontal plane of contact, an estimate of their depth. The potential field reduced to the pole, over a vertical contact, involving the presence of rocks of different susceptibilities is indicated by a low in side rocks of low susceptibility and a high in side rocks of high susceptibility. The inflection point is found directly below the vertical contact. We can use this characteristic of geomagnetic anomalous for localization of abrupt susceptibility change. If the contact has a dip, the maxima of horizontal gradients move in the direction of dip. To determine the dip direction of contacts, we upward the map of the potential field at different altitudes. At each level, the maxima of horizontal gradient are located. If the

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structures are vertical, all maxima are superposed. However, moving of maxima with the upward indicates the direction of the dip. The potential theory lends perfectly to a multiscale analysis by wavelet transform.

By choosing an appropriate wavelet, measurement of geomagnetic field or its spatial derivatives can be processed as a wavelet transform. Indeed, this analysis unifies various classical techniques: it process gradients that have been upward to a range of altitudes. The expressions of various conventional operations on the potential field are well-designed in the wavelet domain. The most important is the equivalence between the concept of scaling and the upward. Indeed, the wavelet transform of a potential field F_0 (x, y) at a certain scale a = Z/Z_0 can be obtained from measurements made on the level Z_0 by:

1. Upward continue the measured field a level $Z=a*Z_0$
2. Calculation of the horizontal gradient in x and y directions.
3. Multiplication by a.

For a multiscale analysis of contacts, it is sufficient to look for local maxima of the modulus of the continuous wavelet transform (CWT) for different scales to get exact information about geological boundaries (Ouadfeul et al., 2010).

3 APPLICATION TO SYNTHETIC DATA

The proposed idea has been applied at a synthetic model of a cylinder and prism, parameters of these last are resumed in tables 01 and 02. Figure 1 is the magnetic response of this model generated with a grid of dimensions 100mx100m. The first operation is to calculate the modulus of the continuous wavelet transform. The analyzing wavelet is the Poisson Kernel defined by equation below (Ouadfeul et al., 2012).

$$P(x,y)=\frac{1}{2\Pi}\frac{1}{\left[x^2+y^2+1\right]^{3/2}}$$

The choice of the analyzing wavelet is based on the analogy between the upward continuation and the continuous wavelet transform, if the analyzing wavelet is the Poisson's Kerenel, the Modulus of the continuous wavelet transform at a scale *a* is equivalent to the upaward continuation of this field at the same scale(Ouadfeul et al, 2010). Calculation of maxima of the continuous wavelet transform of the geomagnetic field reduced to the pole at the scale *a* is equivalent to maxima of the horizontal gradient of this filed upwarded to *Z=a* (Ouadfeul et al., 2010).

Scales are varying following a power law:

$$a_j = a_0 * 2^{j*dj} \quad j=0,1,\ldots\ldots,N$$

$$a_0 2 * \sqrt{(\Delta X)^2 + (\Delta Y)^2}$$

ΔX is the grid dimension following the x dimension.

ΔY is the grid dimension following the y dimension.

$$N=\frac{1}{d_j}\log\left(\frac{(\Delta X * N_{\max})^2+(\Delta Y * M_{\max})^2}{a_0}\right)/\log(2)$$

d_j is a real number, in this case we take $d_j = 0.3$

$N_{max}=100$

$M_{max}=100$

Figure 2 shows this modulus plotted at the smaller scale a=282m. The second step consists to calculate its maxima, figure 3 is a map of these maxima for the full range of scales (Scales varied from 282m to 1131m). Solid curves are the exact boundaries of the prism and the cylinder. One can remark that the maxima of the continuous wavelet transform are positioned around the two exact boundaries.

Table 1: Physical parameters of the Cylinder.

Coordinates of the center	(5000, 2500, -250).
Ray	1500m.
High	2500m.
Magnetic Susceptibility	K=0.015 SI.
F	37000 nT
Declination	D=0°
Inclination	I=90°

Table 2: Physical parameters of the Prisme.

Coordinates of the center	(5000, 7000, -300).
Width	3000m
Length	3000m.
High	2000m.
Magnetic Susceptibility	K=0.01 SI.
F	37000 nT
Declination	D=0°
Inclination	I=90°

4 APPLICATION TO REAL DATA

The proposed idea is applied to the aeromagnetic data of In Ouzzal, it is located in Hoggar. We start by describing geology of massif of the area.

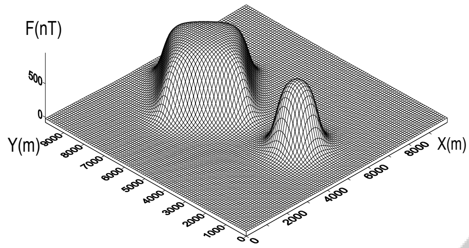


Figure 1: Magnetic anomaly map of the synthetic model.

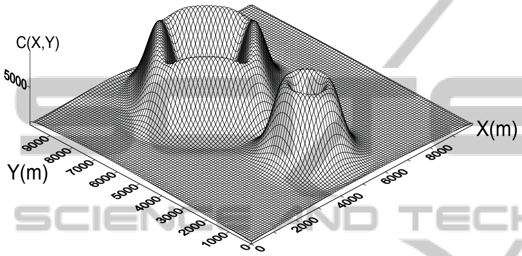


Figure 2: Modulus of the 2D CWT at the smaller scale a=282m.

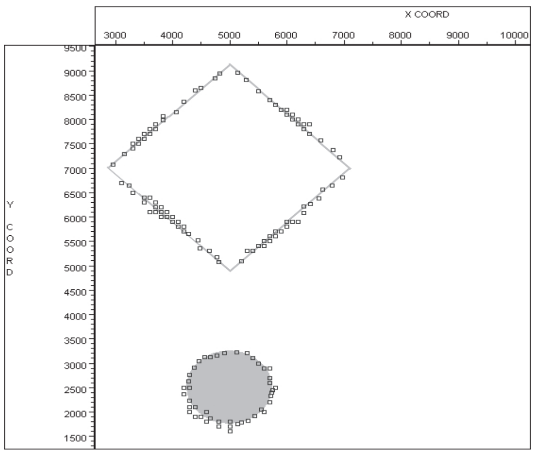


Figure 3: Structural boundaries delimited by the 2D CWT.

4.1 Geological Setting of in Ouzzal

The In Ouzzal terrane (Western Hoggar) is an example of Archaean crust remobilized by a very-high-temperature metamorphism during the Paleoproterozoic (2 Ga). Structural geometry of the In Ouzzal terrane is characterized by closed structures trending NE-SW to ENE-WSW(figure 04) that correspond to domes of charnockitic orthogneiss. The supracrustal series are made up of metasediments and basic-ultrabasic rocks that occupy the basins located between these domes. In In Ouzzal area, the supracrustal synforms and orthogneiss domes exhibit linear corridors near their contacts corresponding to shear zones. The structural features in In Ouzzal area, observed at the level of the base of the crust, argue in favour of a deformation taking place entirely under granulite-facies conditions during the Paleoproterozoic. These features are compatible with D_1 homogeneous horizontal shortening of overall NW-SE trend that accentuates the vertical stretching and flattening of old structures in the form of basins and domes. This shortening was accommodated by horizontal displacements along transpressive shear corridors. During the Pan-African event, the brittle deformation affected the granulites which were retrogressed amphibolite and greenschists facies (with the development of tremolite and chlorite, in the presence of fluids along shear zones corridors. Brittle deformations were concentrated in the southern boundary of In Ouzzal. An important NW-SE-trending dextral strike-slip pattern has been mapped along which we can see the Eburnean foliation F1 overprinted. This period was also marked by ductile to brittle deformation along the eastern shear zone bordering the In Ouzzal terrane with steep fracture cleavage (NNW-SSE) and conjugate joint pattern. All these structural features are compatible with an ENE-WSW shortening in relation with the collision between the West African Craton and the Hoggar during the Pan-African orogeny (Djemai et al., 2009).

4.2 Data Processing

In this section we have analyzed the aeromagnetic data of In Ouzzal to demonstrate the power of the 2D CWT method to identify geological contacts. Source codes in C language are developed to calculate the 2D continuous wavelet transform and the spatial distribution of its maxima at different scales.

The geomagnetic field data are processed with a regular grid of 750mX750m.

Figure 5 is the map of the anomaly magnetic field ΔT after reduction to the pole. Parameters of reduction to the pole (RTP) are illustrated in table 03. After RTP the maximum of the anomaly magnetic field will be found at the vertical of the physical structures. The data are then filtered to remove high frequency noise using a low pass Butterworth filter with cut-off frequency of 0.29 cycles by km. The next step consists to calculate the

2D continuous wavelet transform of the filtered data. The analyzing wavelet is the Poisson's Kernel. Parameters of scales calculation are:

$$d_j=0.3,\ N_{max}=255,\ M_{max}=268.$$

The next operation consists to calculate maxima of the modulus of the continuous wavelet transform for each scale (scales varied between 2.12 and 9.09 km). Figure 6 shows the chains of maxima in the X, Y, log-scales coordinates. They are called the Skeleton of the modulus of the wavelet transform. At each scale we map points of maxima in the plan. The obtained set of maxima for all ranged scales will give the geometry of geologic contacts (Figure 7).

4.3 Results Interpretation and Conclusions

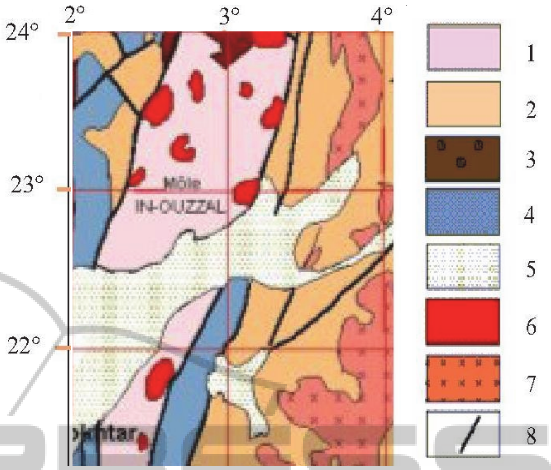
The obtained contacts by CWT are compared with the geological map. Obtained results show that the proposed technique is able to identify contacts that exist in the structural geology map.

We have proposed a technique of boundaries identification based on the 2D directional continuous wavelet transform. Firstly we have applied this idea to a synthetic model, obtained results shows robustness of CWT. Application on noised model shows that CWT is sensitive to noise.

Table 3: Parameters of Reduction to the pole.

Longitude	3°
Latitude	22.5°
Elevation	1000m
Inclinaton	27.6
Declination	-4.38

We have applied this technique to the aeromagnetic data of In Ouzzal. Obtained results are compared with the geological map and the analytic signal solutions. One can remark that the 2D continuous wavelet transform is able to detect boundaries defined by geologists. Comparison with analytic signal shows that the CWT is able to identify contacts that not exist in the map of contacts defined by AS. The results of this study show that the proposed technique of edge detection based on the wavelet transform is very efficient for geological contacts analysis from maps of geomagnetic anomalies. Indeed, this kind of analysis of potential field maps can enhance conventional structural studies. The identified geological structures have a big importance in hydrogeological exploration, mining and in the study of earthquakes and landslides.



1-Archaean granulites; 2- Gneiss and metasediments; 3- Gneiss with facies amphibole; 4- Indif gneiss; 5- Paleozoic curvature; 6- Panafrican granite; 7-Volcano-sediments of Tafassasset; 8- Major faults.

Figure 4: Structural boundaries of in Ouzzal.

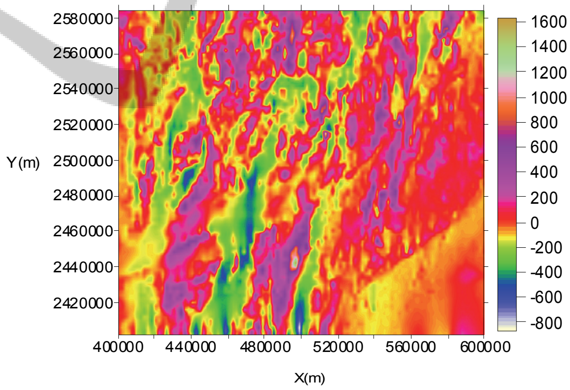


Figure 5: Magnetic anomaly map reduced to the pole.

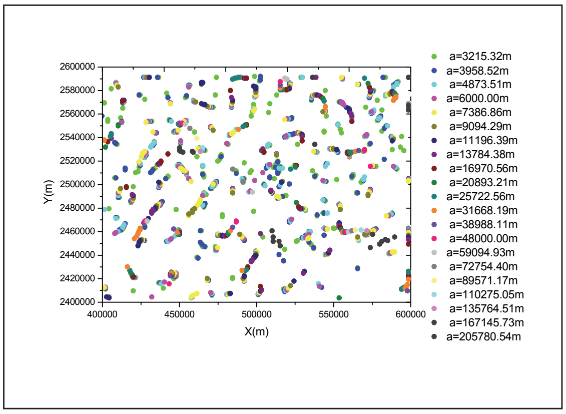


Figure 6: Mapped contacts by the 2D CWT.

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