ABOUT SPATIAL FILTERING RESPONSES OF THE BOUGUER GRAVITY ANOMALIES MAP OF THE NORTH OF MOROCCO*

ACERCA DE LAS RESPUESTAS DE FILTRADO ESPACIAL EN EL MAPA DE ANOMALÍAS DE GRAVEDAD DE BOUGUER DEL NORTE DE MARRUECOS

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Resumen: este artículo presenta los resultados y las interpretaciones del mapa transformado de las anomalías de la gravedad de Bouguer de la región de Tanger-Tetuan a partir de los datos suministrados por sondeos gravimétricos aéreos y terrestres en dicha región. Se aplicó el análisis de filtración basado en los procesos clásicos de tratamiento de señales. Se utilizaron para ello operadores de señales como el gradiente vertical, el gradiente horizontal y la continuación descendente. Este estudio da también la oportunidad de utilizar otros métodos adecuados para el análisis de la gravedad en la región de Tanger-Tetuan.

Palabras clave: anomalías gravimétricas – Marruecos, filtrado espacial, series de Fourier.

Abstract: This paper reports the results and interpretations of gravity signatures of the transformed map of Bouguer gravity anomalies of the Tangier-Tetuan area according with the data provided by aerial and terrestrial gravimetric surveys carried out in that area. Filtering analy-

* *Fecha de recepción: 22 de noviembre de 2006. Fecha de aceptación para publicación: 8 de marzo de 2007.*

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sis based on classic signal process was applied. Operators signal process like vertical gradient, horizontal gradient and downward continuation were used. This study also brings the possibility to define other adequate methods under consideration for the analysis of the gravity of the Tangier-Tetuan area.

Key words: gravity anomalies — Morroco, spatial filtering, Fourier series.

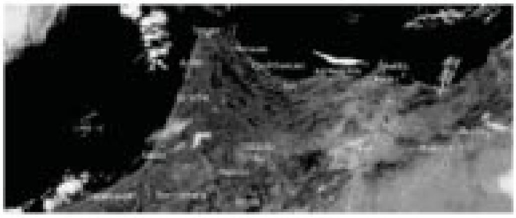
1. Introduction

Gravitation is the force of attraction one mass has for another. Gravity is the gravitational attraction of the Earth. According to Newton's law of gravitation, the force increases with increasing mass. The force of the attraction also increases as we approach the centre of mass. If one geological body is denser than another, it will have a greater mass per unit volume and a greater gravitational attraction. Measurements of gravity yield little direct geological information, other than to represent the Earth's oblate spheroidal shape, unless corrections are made to account for variations in the Earth's shape and topography. Gravity data are used to define the figure of the Earth. In geophysics, the data are used to constrain subsurface density variations to help understand problems related to tectonics or commodity exploration. The aim in geophysics is to remove global and other large-scale gravity effects that mask the local anomalies that are of direct interest. In order to fully achieve the goal of removing large-scale gravity effects, the geophysicist should actually either compute gravity disturbances or gravity anomalies. This paper presents some mathematical tools applied to analyze Bouguer gravity anomalies of the north of Morocco as assistance for interpreting geophysical data.

2. Geography

The Tangier-Tetuan area (Figure 1) is located at the extreme North-West of Morocco. It is limited to north by the Strait of Gibraltar; in the West by the Atlantic Ocean, in the East and the South by the provinces of Tetouan and Asilah. The area of Tangier is characterized by a Mediterranean climate, with an annual average pluviometry of about 800 mm and an average temperature of 17°C, approximately. Precipitations start as from September, reach their maximum in December and then decrease gradually to reach the minimum in August and July. The broad marine opening of Tangier's external unity softens the temperatures, whose values lower than 0°C and higher than 40°C are exceptional. The average diurnal variation is of 8°C.

Figure 1. Situation of the studied area

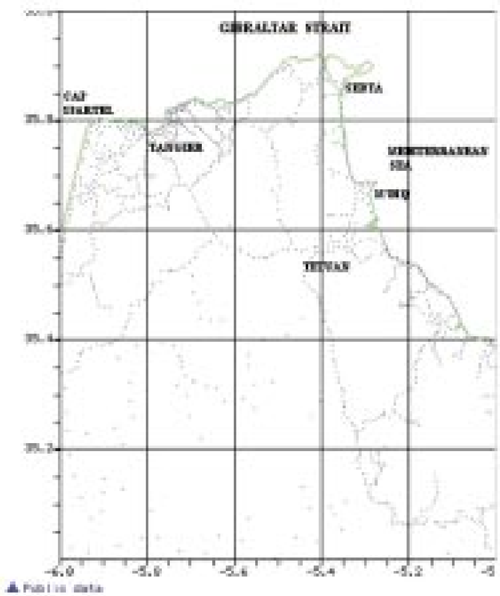


Source: Moroccan Royal Center of Spatial Teledection in www.crts.gov.ma.

3. Bouguer gravity anomaly

The field area lies between latitudes 35°N and 36°N. The studied zone is also limited between longitudes 5°W and 6°W. The gravity data used were obtained from the Bureau Géodésique International (Figure 2) and were supplemented by aerial gravity data.

Figure 2. Data gravity reference map



Source: (BGI,2005)

All measurements were brought back to the level of reference of the international Network of gravimetric standardization of 1971. The theoretical values of gravity were calculated using the gravimetric formula of the geodetic system of reference (IAG, 1967). The Bouguer anomaly was calculated by employing a vertical gradient of the gravity of 0,3086 $mGal \cdot m^{-1}$ (Swick, 1942) and a density of 2.67 $g.cm^{-3}$ for crustal lithologies.

If ϑ represents the geographical latitude of the station in degrees of a point given to the surface of the earth, the theoretical value of gravity g_T in this point is provided by the following international gravimetric formula:

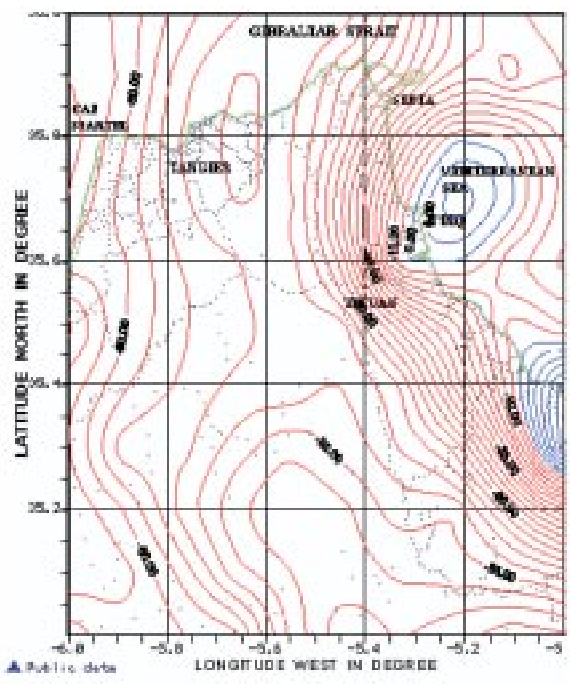
$$g_T = 978031{,}85(1+0{,}005278895 \sin^2(\vartheta) + 0{,}000023462 \sin^4(2\vartheta))\text{mGal} \quad (1)$$

Bouguer (Δg_B) anomalies for each station were calculated using the following expression:

$$\Delta g_B = g_{obs} + (0.386 - 2\pi G\rho)H - g_T \quad (2)$$

where g_{obs} is the observed gravity, H is the orthometric altitude in meters, ρ is the average density of the crust (2.67 $kg.m^{-3}$) and G the universal gravitational constant which value is $6.673x10^{-11}$ $N.m^2.Kg^{-2}$. We applied this method to the gravimetric map of the area. This map (Figure 3) was generated using about 1050 free public data and 1200 measured data which made it possible to calculate a regular grid with a step of 450 m and with about 1 mGal of precision. The Bouguer anomaly reflects the lateral variations of the density of the rocks.

Figure 3. Bouguer anomalies map of the area of Tangier-Tetuan (interval contour 5 mGal, blue contours correspond to positive Bouguer anomalies)



Source: the authors.

4. The process

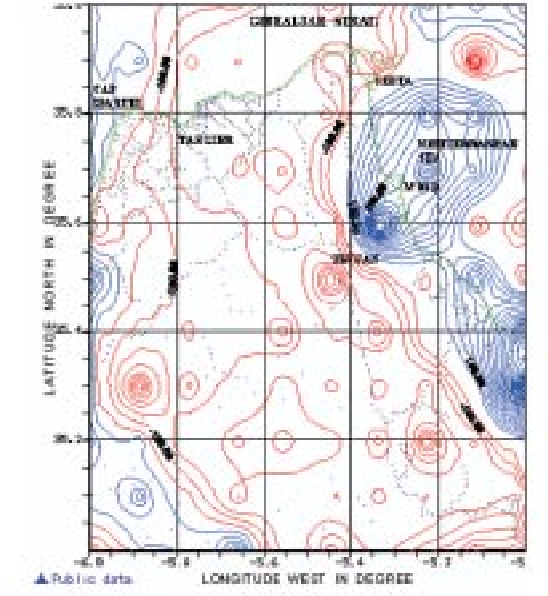
We applied to the data operators in the spectral domain. First vertical derivative and horizontal gradient are applied to the Bouguer gravity anomaly data. GeoGrid (Cooper, 2000; 2002) software was used for calculations. Indeed, the only knowledge of Bouguer gravity anomaly does not make it possible to delimit contours in a precise way. The interest of the spectral transformations appears thus fundamental in order to circumscribe the various gravity signatures of the studied zone f, g, h, are the expressions of the data, the transformed data and a filter respectively. F, G and H are their respective spectral expressions. FFT is the Fast Fourier Transform. The process is described as follows taking in consideration that the phenomena of aliasing and Gibbs being in addition perfectly circumscribe by the symmetrization of the data in the space domain (regular grid) (Lutz, 1999):

$$\underset{\text{(space domain)}}{\text{data}} \xrightarrow{\text{FFT}} \underset{\text{(spectral domain)}}{G(u,v)=F(u,v)} \xrightarrow{\text{Inverse FFT}} \underset{\text{(space domain)}}{\text{transformed data g}} \qquad (3)$$

4.1. Vertical gradient

A vertical gradient Bouguer gravity anomaly map (Figure 4) is calculated by application of a spectral domain or space domain filter to the grid file. The result is an anomaly enhancement related to the "curvature" of the input data gravity. The vertical gradient operator has the effect to sharpen anomalies. It makes it possible to better define contours of a structure as well as gravimetric discontinuities. The limits of the structure are characterized by a strong gradient of the transformed map. The vertical gradient operator in the spectral domain is $\left(2\pi\sqrt{u^2+v^2}\right)$, where u and v are the orthogonal wave-numbers present in the map. A strongly positive derivative (respectively negative) corresponds to a heavy structure (respectively lightly). As an operation of derivation corresponds to a high-pass filter, the vertical gradient underlines the effect of the surface structures and discontinuities. The utility of this map is to separate the details in the distribution of the anomalous masses thus removing the phenomenon of coalescence. In our case we notice that the positive anomaly centered on the zone of M'diq and radiant on the zone of Tetuan correspond probably to the basaltic base and also to the presence of peridotites. This map also clearly indicates the limit of the lateral variations of the densities of the base. The emergence of the positive and negative anomalies also results from the contrasted variations of topographic altitudes.

Figure 4. Vertical gradient of Bouguer anomalies map of the Tangier-Tetuan area (interval contour 50 mGal.m^{-1}, blue contours correspond to positive first vertical derivative signal)



Source: the authors.

4.2. Horizontal gravity gradient

The magnitude of the horizontal gravity gradient $|g'(x,y)|$ is usually estimated by finite difference methods from values measured at gridded points on the Bouguer gravity anomaly map. The magnitude is determined by using the following equations:

$$|g'(x,y)| = \sqrt{\frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2}} \tag{4}$$

with

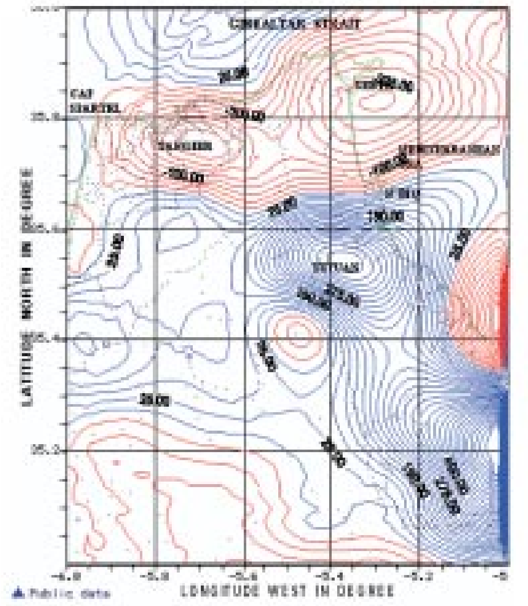
$$\frac{\partial g(x,y)}{\partial x} = \frac{g_{i+1,j} - g_{i-1,j}(x,y)}{2\delta x} \tag{5}$$

and

$$\frac{\partial g(x,y)}{\partial y} = \frac{g_{i,j+1} - g_{i-1-j}}{2\delta y} \tag{6}$$

where x is the longitudinal coordinate and y the latitude coordinate. $g_{i,j}$ is the pseudo-gravity defined at grid point (i,j). Grid intervals in the x-direction and y-direction are dx and dy, respectively. Maxima gravity gradient occur immediately over steep or vertical boundaries separating rock masses of contrasting densities. On the gravity gradient map, lines drawn along ridges formed by enclosed high horizontal gradient magnitudes correspond to these boundaries. If the boundaries dip or if contributions from adjacent sources are significant, the maximum gradient will be shifted a certain distance from the boundaries (Cordell, 1982). The value of the intensity of the horizontal gradient Bouguer anomalies (Figure 5) was calculated starting from a plan obtained by an adjustment by the method of least squares of a grid of 5 cells out of 5 cells centered on the point to be determined. The filtered data raise the anomalies short wavelength which are the reflection of the existence of contrasts of density close to surface.

Figure 5. Horizontal gravity gradient map of Bouguer anomalies of the Tangier-Tetuan area (interval contour 25 mGal.m^{-1}, blue contours correspond to positive horizontal gravity gradient signal)



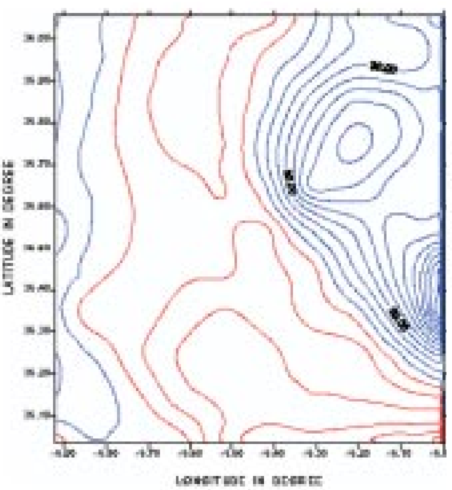
Source: the authors.

4.3. Upward and downward continuation

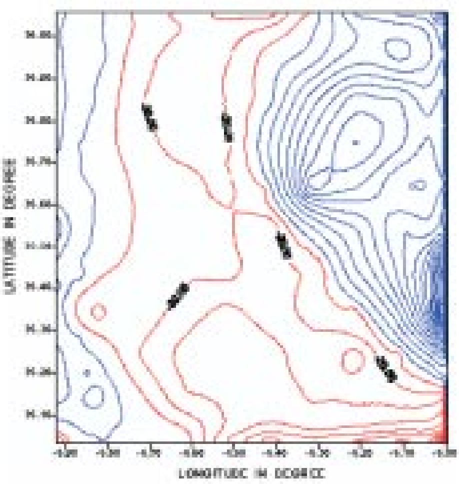
The downward continuation of the Bouguer gravity anomalies map is a low-pass filtering who allows to remove the background noise due to the surface structures; it highlights the underlying structures.

The downward continuation of the Bouguer gravity anomalies map reveals the limits of the surface structures. This operator allows to determine the depth of the roof of the structures. We can not prolong to the bottom of more than 2 times the step of sampling without filtering (4 times with filtering).The operator of continuation in the spectral domain is $e^{2\pi z\sqrt{u^2+v^2}}$, where z is the depth of continuation. ($z \leq 0$ in the case of upward continuation). We have applied this process to the map of the Bouguer gravity anomalies to determine the depth of the roof of the structures using the GeoGrid software (Cooper, 2000). We evaluated the limit around 3.9km of depth; beyond 3.88km we notice that the transformed map is dominated by the noise; thus, we are probably with the depth limit roof of the structures (Figure 6).

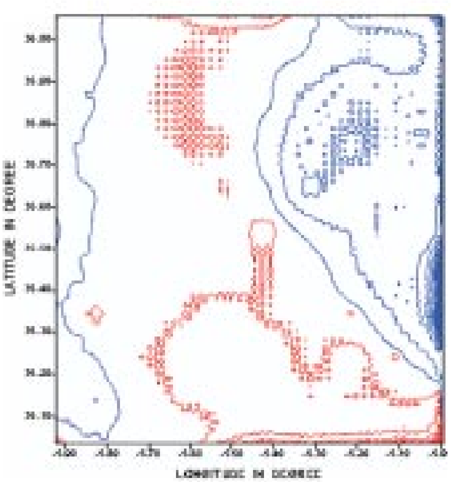
Figure 6. Downward continuation maps of the Bouguer gravity anomalies (blue contours correspond to positive signal)



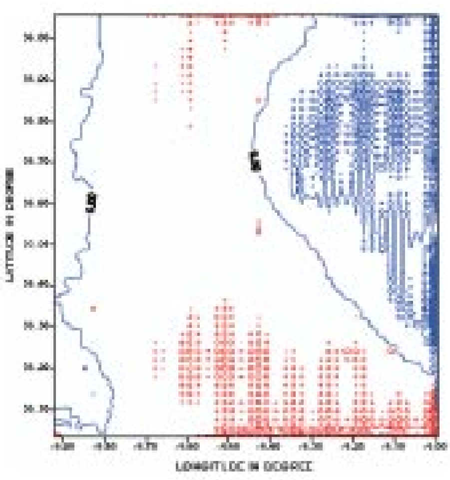
1.11km of downward continuation (interval contour : 10 mgal)



2.22km of downward continuation (interval contour : 10 mgal)



3.33km of downward continuation (interval contour : 25 mgal)



3.885km of downward continuation (interval contour : 25 mgal)

Source: the authors.

5. Discussion and conclusions

The Bouguer gravity anomaly spectral signatures of the area of study were circumscribed easily. The various gravity signatures show an inherent singularity with the Tangier-Tetuan aerial data. This effect is the resultant combined effects of topography and the local tectonic ondulations. On the downward continuation map we determined the limit of the roof of the structures. On the horizontal gradient Bouguer gravity anomaly map, the area is dominated by an unusal zone which represents a particular gravity signal of Tangier-Tetuan's zone. This result is probably explained by strong gradients which materialize the brutal changes of density in the basement. That could be possibly used to locate the points of inflection of the vertical contacts (Cordell, 1982). The influence of the peridotites might be probably considered.

Within sight of these results we propose for further works to consider the study of these strong gradients by means of the multi-scale analysis by wavelet. Indeed, the superposition of maximum values determined by buildings on various scales will make it possible to highlight the various contacts presented on the horizontal gradient map (Hornby, 1999). The linear contacts generally correspond to faults, whereas the contacts of circular form are the limits of intrusive bodies.

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