Analysing the enhancement edges of the Bouguer gravity anomaly map using sunshading method (area of the Tangier-Tetuan, Morocco)

Saad Bakkali, Mahacine Amrani*

Earth Sciences Deparment, Faculty of Sciences and Techniques, Tangier, Morocco.

(Recibido el 23 de noviembre de 2005. Aceptado el 28 de agosto de 2006)

Abstract

Sunshading is a powerful tool for the enhancement of edges in images. Given the azimuth and elevation of a source of illumination, it calculates the reflectance from a surface which is composed of the data to be interpreted. It is a standard tool used in the interpretation of geophysical potential field data. Aerial and terrestrial gravimetric surveys were carried out in the region of Tangier-Tetuan. From the observed and measured data of gravity Bouguer a gravity anomaly map was prepared. This paper reports the results and interpretations of the sunshaded maps of Bouguer gravity anomaly of the Tangier-Tetuan area using image processing. Filtering analysis based on classical image process. Operator image process, such as contrast enhancement, is used as well. This paper also presents the results obtained from this image processing analysis of the enhancement edges of the Bouguer gravity anomaly map of the Tangier-Tetuan zone.

----------*Key words*: gravity, Bouguer, Tangier, filtering, sunshading, enhancement edges.

Análisis de las anomalías de la gravedad de Bouguer usando el método de sombreado (área de Tangier, Tetuan, Marruecos)

Resumen

El sombreado es una poderosa herramienta para destacar los bordes de un objeto presente en una imagen. Conociendo la dirección y la elevación de la fuente de

* Autor de correspondencia. Teléfono: +212+3939 39 54, fax: +212+3 939 39 53, correo electrónico: saad.bakkali@menara.ma.

iluminación, se puede calcular la reflectancia de las distintas superficies representadas por los datos y así facilitar la interpretación de los mismos. El sombreado se ha convertido en una herramienta universal a la hora de interpretar datos geofísicos de campo de tipo potencial. Datos gravimétricos aéreos y terrestres se obtuvieron en la región de Tanger-Tetuan. A partir de los datos observados y medidos se elaboró el mapa de las anomalías de gravedad de Bouguer. En este artículo se presentan los resultados obtenidos, y su interpretación, al aplicar el método del sombreado aplicado a los mapas de las anomalías de la gravedad de Bouguer del área de Tanger-Tetuan usando técnicas de procesamiento de imágenes.

----------*Palabras clave*: gravedad, Bouguer, Tanger, filtración, sombreado.

Geography

The area of Tanger-Tetuan (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 Tetuan 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.

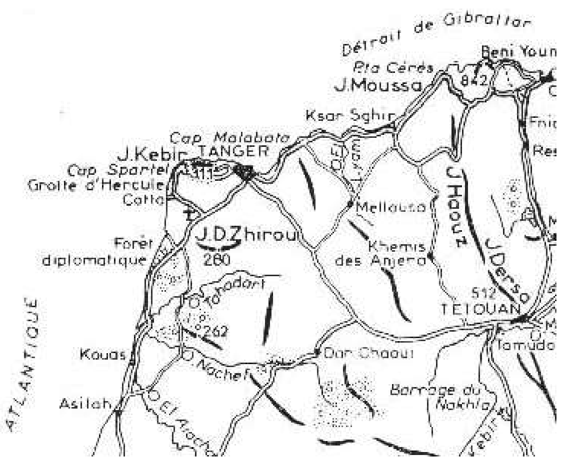

Figure 1 Situation of the studied area

It is a plain open on the strait, strewn by hillocks and hills and limited by two solid masses with unequal importance: solid mass of Anjera and solid mass of Jbel El Kebir.

Geology

The area of Tangier-Tetuan belongs to the Riffian field (figure 2). It can be divided into three great morphological units [1]:

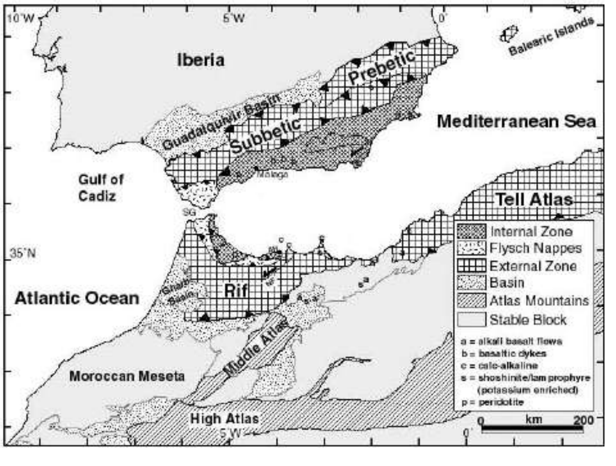

Figure 2 Principal geological features of the Riffian field

- In the western side a mountainous and coastal solid mass sandy (Jbel El Kebir), parallel with the Straits of Gibraltar and morphology of plate. Average altitude is 150 with 200 m there. It is an independent coastal solid mass, parallel at the coast which finishes in a very abrupt way on the strait. It forms the "Numidienne" tablecloth made up of siliceous sandstone, in massive and thick benches pertaining to the Oligocene.

- In the center, the undulating plain of Fahs emerging in the Straits of Gibraltar by bay of Tangier. The hills which strew it have an average altitude of 100 m and dominate a whole of broad valleys succeed either to the ocean or in the Straits of Gibraltar by the means of various wadis.

- In the eastern zone, the solid mass of Anjera, Western northern spur of the chain of Rif, finishing on the littoral in the Cap Malabata. The reliefs marked and are separated by deep valleys. The tops have altitudes varying from 194 m to 376 m. The solid mass of Anjera is a formed compact solid mass of marno-sandy grounds constituting the unit of Beni Ider. The reliefs are very broken and are separated by deep valleys.

The back coast constitutes a low sablo-muddy plain strewn by marly and argillaceous outcrops towards the east and the south. It is lower and seldom exceeds 50 m. The littoral has a layout close to an arc of circle having a radius of curvature from approximately 1500 m. Its orientation is between the North-West and the North-East.

Bouguer Gravity Anomaly

The field area lies between latitudes 35.035° N and 36.057° 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" [2] (figure 3) and were supplemented by aerial gravity data.

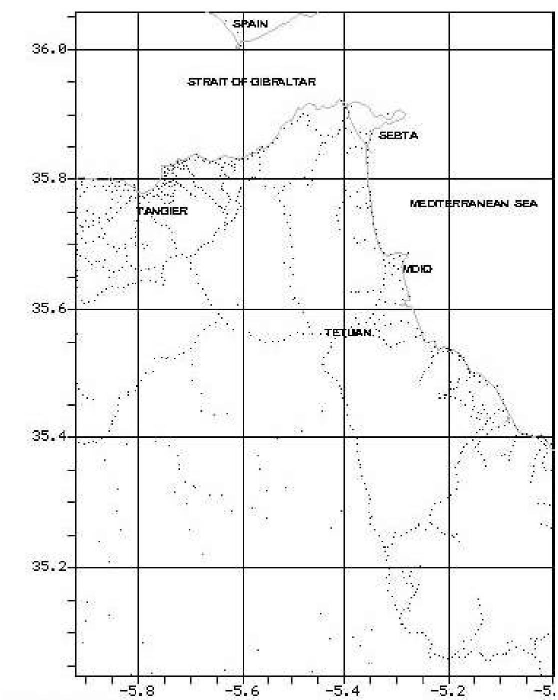

Figure 3 Gravity data, reference map (BGI, 2005)

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 [2]. The Bouguer anomaly was calculated by employing a vertical gradient of the gravity of 0.3086 $mGal \cdot m^{-1}$ [3] 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:

$$g_T = 978031.85(1+0.005278895\ \sin^2(\vartheta) + 0.000023462\ \sin^4(2\vartheta))mGal$$

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

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

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 6.673×10^{-11} $N.m^2.Kg^{-2}$. We applied this method to the gravimetric map of the area. The corresponding map (figure 4) has been 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 also with about 1 mGal of precision. The Bouguer gravity anomalous zones (figure 5) is obtained using Golden Surfer software [4], [5]. The Bouguer anomaly reflects the lateral variations of the density of the rocks [6].

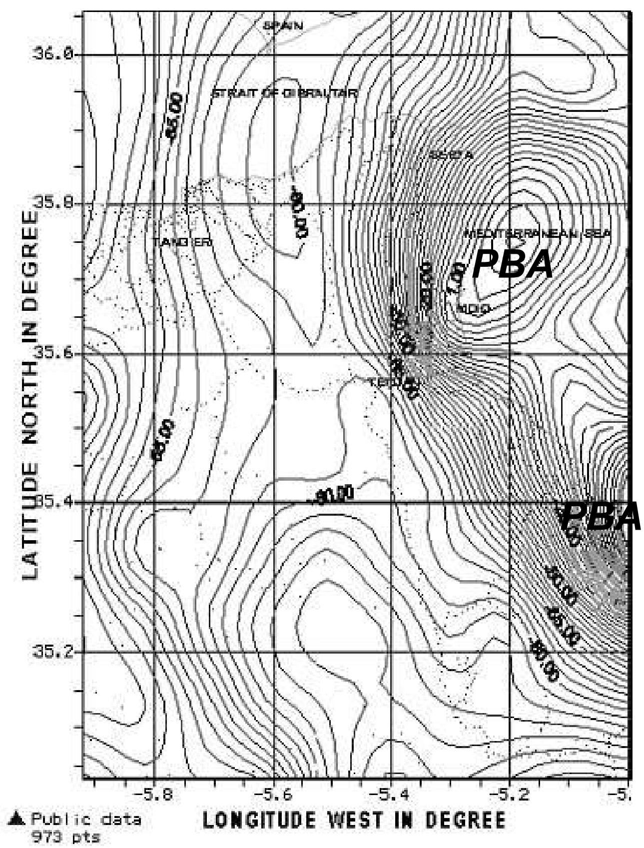

Figure 4 Bouguer anomaly map of the area of Tangier-Tetuan (interval contour 3 mGal, PBA for positive Bouguer anomalies)

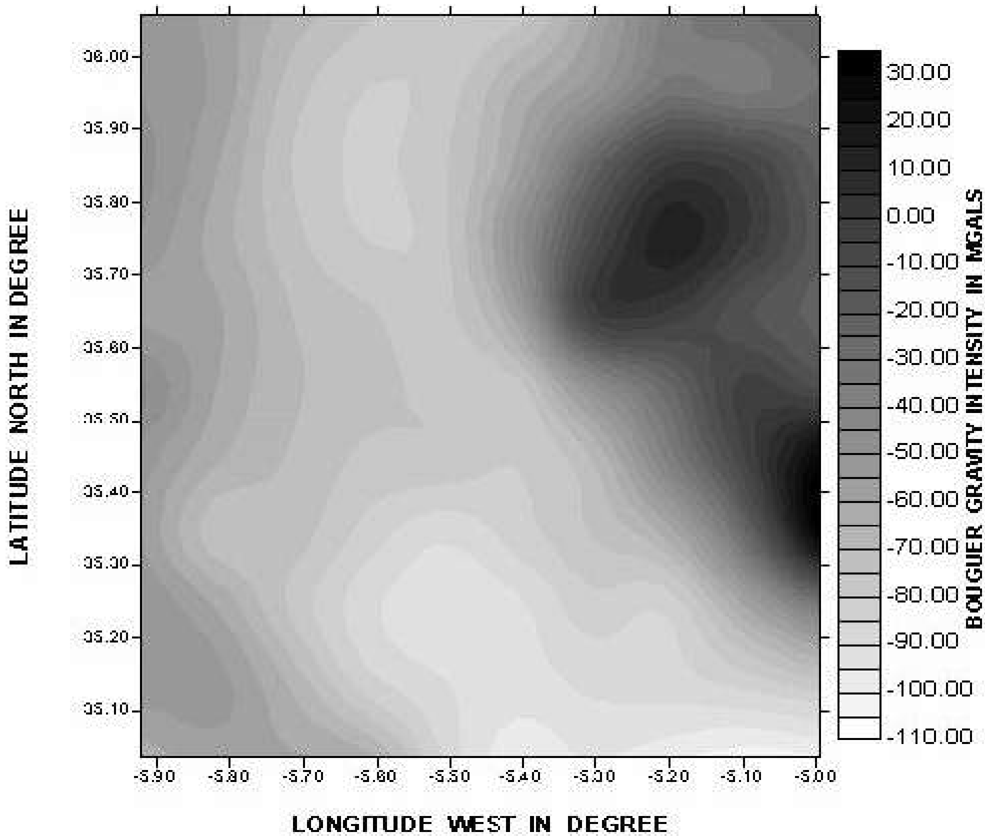

Figure 5 Bouguer gravity anomalous zones of the area of Tangier-Tetuan

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 indicates the limit of the lateral variations of the densities of the base. Positive and negative anomalies also result from the contrasted variations of topographic altitudes [6, 7].

Map of the Bouguer gravity anomaly is assimilated to image where anomalous areas have different levels of reflectance in gray scale. Levels of reflectance were in first approach considered directly linked to the intensities of the Bouguer gravity anomaly. In this particular context anomalous zones will appear disturbed on a scale going from slightly to very strongly in accordance with a scale of levels of gray. As the data of the Bouguer gravity anomaly will induce noise implicitly, contours of anomalous zones, corresponding to positive Bouguer anomaly on the zones of M'diq and Tetuan, present distortions. The image processing operated in these work aims to effectively circumscribe its singular zones of the Bouguer anomaly.

Sunshading method

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 they were a topographic surface illuminated with light from a source at infinity which is specified by its azimuth and elevation [8]. Different reflectance models are available for different types of surface. It is common to assume that the surface is ideal: it reflects all incident light upon it and reflects light equally in all directions. This is termed a Lambertian reflector and its normalized reflectance [9] 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 $p_0=-\cos\phi\tan\vartheta$ and $q_0=-\sin\phi\tan\vartheta$, 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 eastern and northern directions respectively, and may be calculated in the space domain by the following expressions:

$$p=\frac{\partial(\Delta g_B)(x,y)}{\partial x}=\frac{(\Delta g_B)_{i+1,j}-(\Delta g_B)_{i-1,j}}{2\delta x} \text{ and}$$

$$q=\frac{(\Delta g_B)(x,y)}{\partial y}=\frac{(\Delta g_B)_{i,j+1}-(\Delta g_B)_{i,j-1}}{2\delta y}$$

Where *x* is the eastern coordinate and *y* the northern coordinate. $(\Delta g_B)_{i,j}$ is the pseudo Bouguer gravity defined at grid point *(i, j)*. Grid intervals in the *x*-direction and *y*-direction are *δx* and *δy* 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 [9].

Results

The data process was executed using the Geogrid software [10]. The sunshading tool is basically a spatial filter which enhances 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.

We have applied to the Bouguer gravity anomaly map a vertical gradient operator to filter the gravity corresponding data: this process allows to better constrain the anomalous contours zones. The various Bouguer gravity maps obtained from the survey had been considered as maps of discrete potentials on the free surface, and any major singularity in the Bouguer gravity due to the presence of a perturbation would be due to the crossing from a "normal" into a "perturbed" area or vice versa [11]. The Bouguer gravity maps obtained and based under those hypothesis, had allowed us direct images for an interpretation of the gravity survey. The various sunshaded Bouguer gravity maps (figure 6) obtained starting from this process allowed us to optimize the edges of the anomalous zones [12]. We were, in first approach, able to identify the anomalous zones which turned out to be strongly correlated with the microtectonics. The degree of correlation is directly connected to the level of reflectance.

These zones correspond to the disturbances of peridotic origin of the areas of Tetuan and M'diq. Theses results were corroborated by the filtered sunshaded Bouguer gravity maps (figure 7) using the optimization contrast tool of Image Enhancement software [13].

The sunshaded maps represent an effective indicator of the level of disturbance measured on the topographic surface corresponding to the studied area. The maximum reflectance would 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. A high reflectance ratio will represent a strong level of contrasting densities. In our case, the anomalous areas edges were better enhanced. According to the appreciation of the geologists 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.

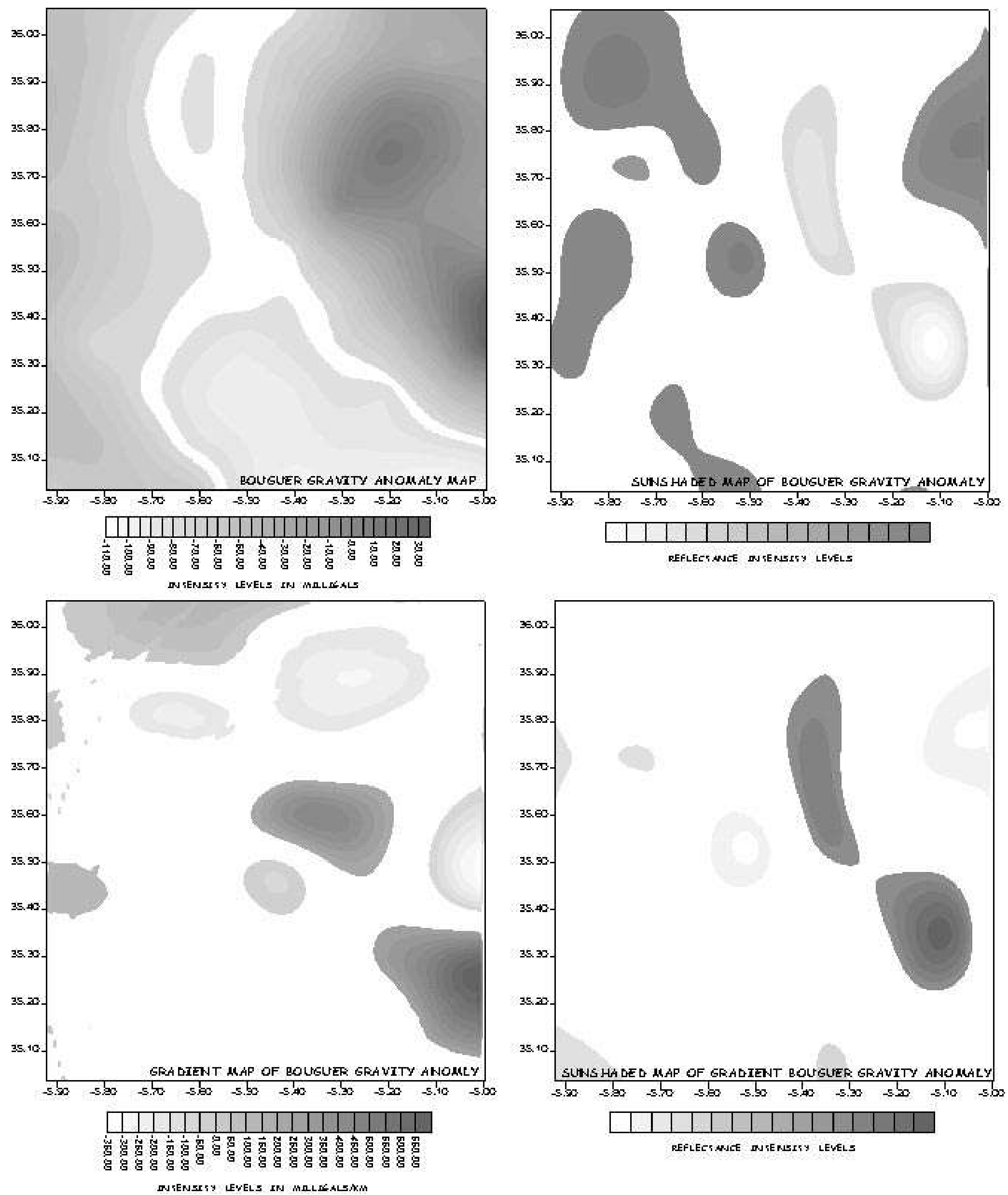

Figure 6 Sunshaded Bouguer gravity maps of the area of Tangier-Tetuan

Conclusions

We found that the image processing approach using contrast stretching spatial operator 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 geosciences image processing. The results are satisfactory. Data processing procedures as image processing were found to be consistently useful and may be used as auxiliary tool for decision making under field conditions.

We found that the sunshading approach helps to better constrain the location of Bouguer gravity

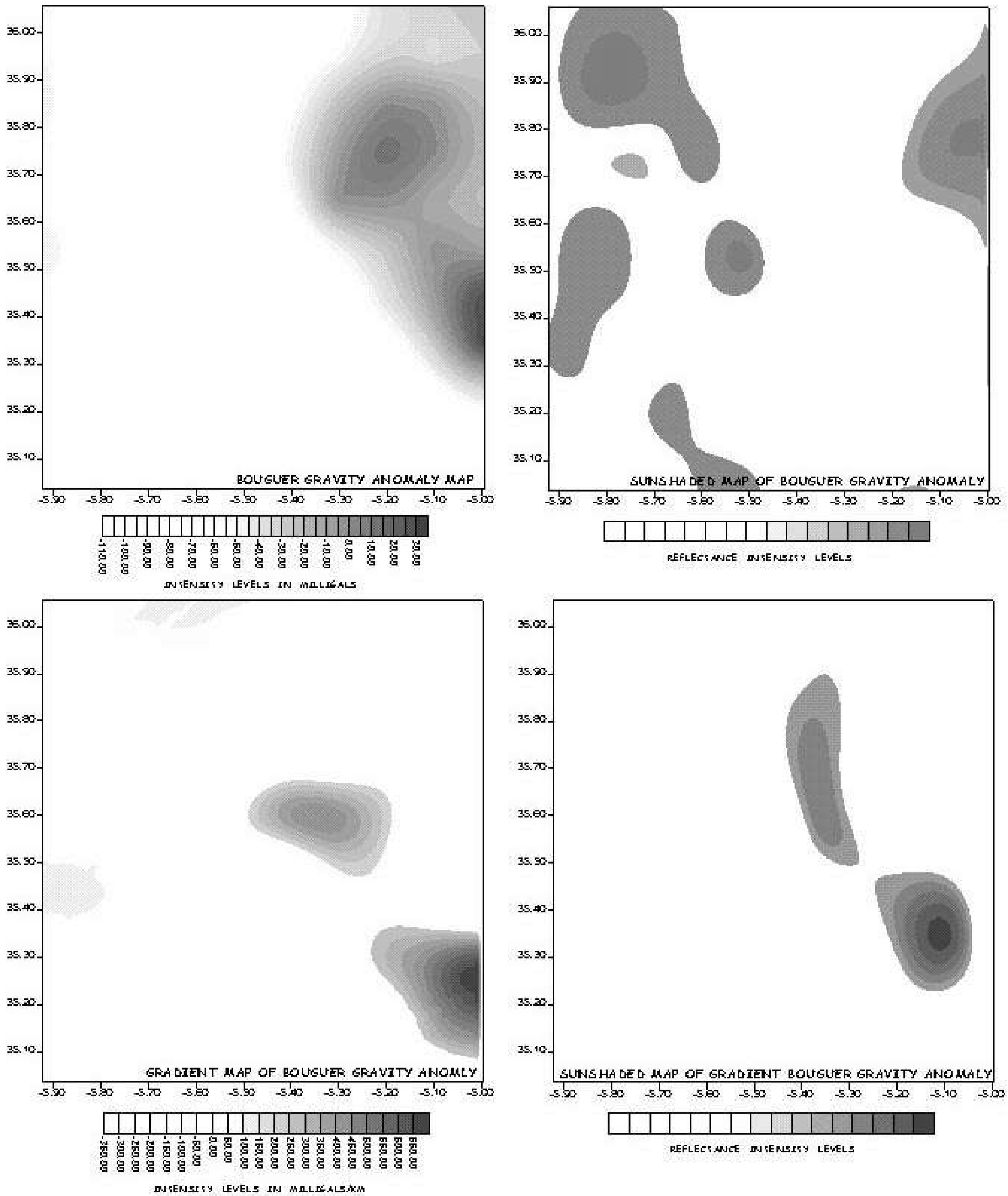

Figure 7 Filtered sunshaded Bouguer gravity maps of the area of Tangier-Tetuan

anomalous areas on the surface. It was also found that the sunshaded images with 180° of an azimuth sun were particular useful to the geologists for improving and constraining their basic interpretations. While assimilating the reflectance level to disturbances of densities the sunshading tool appears to be an interesting technique of optimization of enhancement edges on the Bouguer gravity anomaly map. While assimilating the grey scale level to level of anomalous zones of Bouguer gravity, this singular study appears to be an interesting technique of geological interpretation.

References

1. B. Biju-Duval, L. Montadert. *Structural history of the mediterranean basins*. Editions Technip. Paris. 1977. pp. 143-164.
2. I. A. G (International Association of Geodesy). "Geodetic Reference System 1967". *Special Publication of Bulletin Géodésique,* Vol. 3. 1971. p. 115.
3. C. H.Swick. "Recent Progress in Gravity Determinations at Sea" *Geographical Review*, Vol. 20. 1930. pp. 278-282.
4. Golden Surfer (Win32) software, version 6.04, Surface Mapping System, Copyright 1993-97 Golden Software Inc, Golden Colorado, USA, 1997.
5. G. R. J.Cooper. "Gridding gravity data using an equivalent layer". *Computers & Geosciences*. Vol. 26. 2000. pp. 227-233.
6. H. Lutz. *Cartographie, traitement et interprétation des données gravimétriques du fossé rhénan méridional (projet Geofrance 3D)*. Université Louis Strasbourg I. Diplôme d'Ingénieur de l'Ecole de Physique du Globe. 1999. p. 83
7. S. Bakkali, M. Amrani. "Gravity signatures of the Gibraltar strait zone". *Ingenieria.* Vol. 16. 2006. pp. 51-58.
8. S. Bakkali. "Using a shading method to optimize anomalies in a moroccan phosphate deposit". *Stud. Geol. Salmant.* Vol. 42. 2006. pp. 21-32.
9. G. R. J.Cooper. "Feature detection using sunshading". *Computer & Geosciences.* Vol. 29. 2003. pp. 941-948.
10. GeoGrid Software 1.27, Copyright G.R.J Cooper, 1999-2004. School of Geosciences University of the Witwatersrand, Johannesburg, South Africa. www.wits.ac.za/science/geophysics/gc.htm. Consultada el 10 de septiembre de 2005.
11. G. Cooper, D. Cowan. "The application of fractional calculus to potential field data". *Exploration Geophysics.* Vol. 34. 2003. pp. 51-56.
12. B. K. P. Horn. "Hill shading and the reflectance map". *Geoprocessing.* Vol. 2. 1982. pp. 65-146.
13. D. Backström Image Enhance 3.2.4 Drag & Drop, User's Guide, Copyright Daniel Backström, www.baxtrom.com. Consultada el 20 de octubre de 2004.