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A gravity model of the Colima, Mexico region

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RESUMEN

Se presenta la información gravimétrica de una red de estaciones en el área comprendida entre los 104° y 103° 20' de longitud y los 18°33' y 19°45' de latitud norte. Esta área comprende la parte central del graben de Colima con los grandes estratovolcanes Nevado de Colima y Colima al norte y el "rift" de Colima en el sur. Se elaboraron mapas de anomalía de Bouguer completa así como regional y residual por ajuste de una Serie de Fourier en dos dimensiones. El análisis de esta información permite estimar las dimensiones de algunas de las estructuras más importantes del área y permite concluir que los dos volcanes se levantan sobre una estructura de extensión limitada que no continúa hacia el sur.

PALABRAS CLAVE: Gravimetría, vulcanología, Colima, México.

ABSTRACT

We analyzed gravity data from a quadrangle located between longitudes 104° to 103° 20' W, and latitudes 18° 33' to 19°45' N. This area includes the central Colima graben with the large stratovolcanoes Nevado de Colima and Colima to the north, and the southern Colima rift to the south. We present complete Bouguer as well as regional and residual anomaly maps which show that both volcanoes rise over a graben with no continuation to the south. We also constructed gravity models for the most important structures in the area including the feeding system located beneath the volcanic edifices.

KEY WORDS: Gravity, volcanology, Colima, Mexico.

INTRODUCTION

The Colima rift has attracted the attention of several researchers, among other reasons, because of its significance as the eastern margin of the Jalisco block (e.g. Allan, 1986; Stock, 1993). The central graben structure has a N-S orientation and continues to the north into what Allan (1991) calls the northern Colima graben. This nomenclature however is not universally followed and some authors refer to it as the Sayula graben (Quintero, 1995).

Demant (1979) and Nixon (1982) suggested early that the Colima rift was related to the subduction of the Rivera Plate. More recent work suggests that it is due to the oblique subduction of one of the plates that converge in the area, causing continental tearing from the coast to the Zacoalco region (Serpa, 1989; De Mets and Stein, 1990). Based on geochemical evidence, Luhr *et al.* (1985) proposed that the graben marks an incipient zone of spreading of the East Pacific Rise. From chemical analyses of lavas in the region, Moore *et al.* (1994) suggested the presence of a hot spot south of the city of Guadalajara. Additional interest in this structure derives from the presence at its borders of important volcanic activity whose more recent example is that from the Colima volcano, also known as Volcán del Fuego (Figure 1).

In spite of this, there are still few geophysical studies in the area. Serpa *et al.* (1992) carried out a gravity and magnetic survey within the southern portion of the area and pointed out that there is no evidence of active tensional tectonics south of Colima city. Towards the north the gravity is interpreted as produced by an extensional basin existing some 4000 years ago when an explosive eruption of Colima volcano took place. Bandy *et al.* (1993) combined a land gravity survey of the coastal area with available marine gravity data finding a basin of more than 100 km length composed of two small grabens separated by a narrow horst. More recently, Bandy *et al.* (1995) found a low density zone at a depth between 30 and 100 km north of the Colima and Nevado volcanoes on the Central Colima graben. This feature is attributed to heating by thermal convection in response to divergence along the subducted Rivera-Cocos plate boundary.

In this work we present detailed gravity information which includes the areas studied by those researchers and is further extended north of Colima city to include Nevado and Colima volcanoes and their surroundings.

TECTONIC SETTING

The study area includes the Central Colima graben (CCG) and the Southern Colima rift (SCR) of Allan *et al.* (1991). The great stratovolcanoes Nevado and Colima and a number of cinder cones are found to the north. According to Allan *et al.* (1991), the Northern Colima graben (NCG), the Central Colima graben and the Southern Colima rift are parts of a single structure that extends southward from the Trans-Mexican volcanic belt. The CCG trends N-S and the SCR in a NE-SW direction (Figure 2).

A line of cinder cones trending NW-SE is found north of Colima volcano. These follow the direction of the

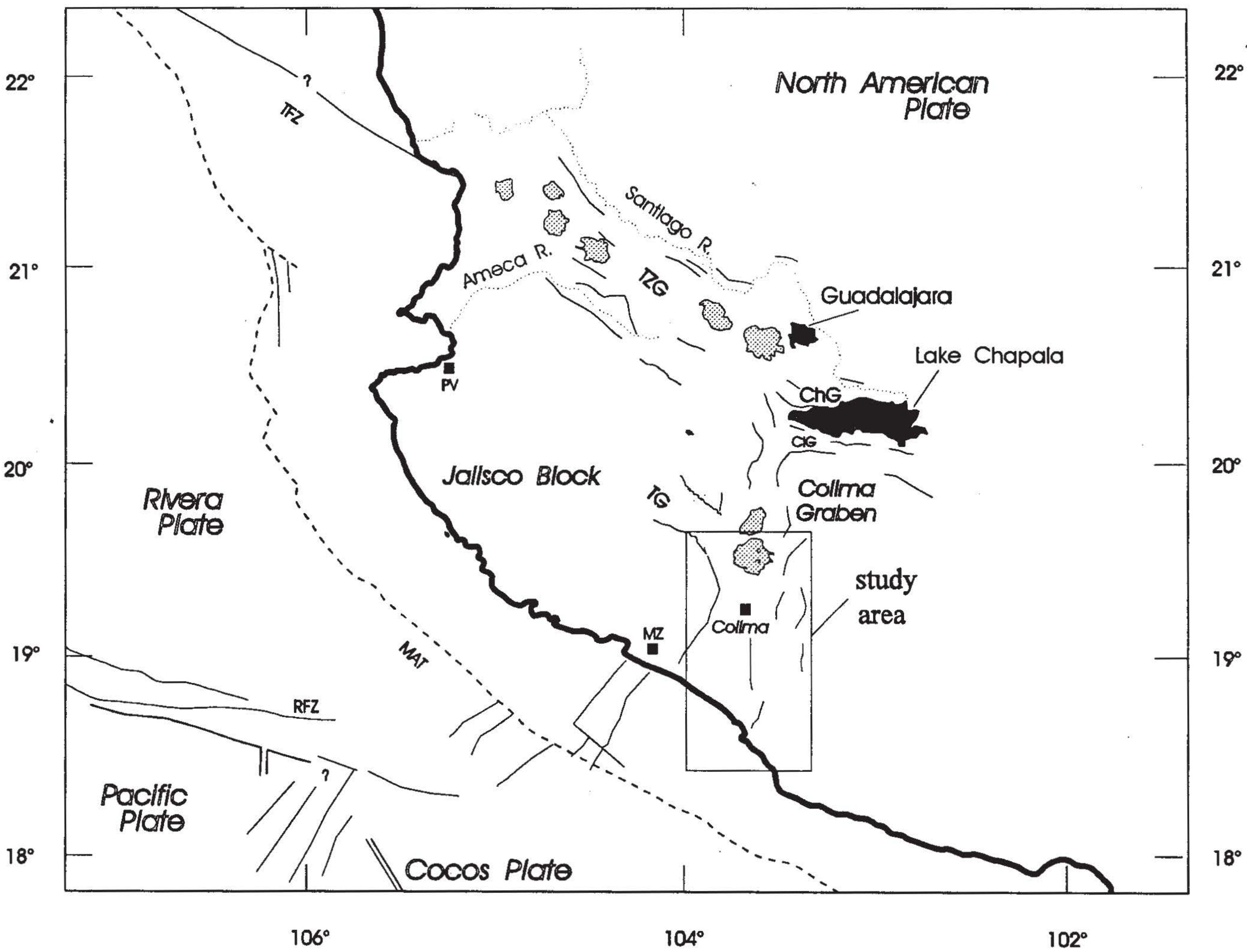

Fig. 1. Tectonic framework of the Colima area with respect to the Jalisco Block and the subduction zones of the Rivera and Cocos plates. Symbols: TZG Tepic-Zacoalco Graben, ChG Chapala Graben, TG Toliman Graben (modified after Macías *et al.*, 1993)

Toliman graben. La Erita, Telcampana, and Comal Chico volcanoes, with ages ranging between 12,000 and 1,500 years BP, are part of this series (Luhr and Carmichael, 1980). Farther north from Nevado and Colima volcanoes lie the eroded remains of Volcán Cántaro. These three volcanoes are evidence of a southward migration of volcanism (Luhr, 1993). The history of the Nevado and Colima volcanoes is complex. For our purposes, however, it is important to point out that frequent episodes of collapse at Colima volcano have generated massive avalanche deposits towards the south, as shown in Figure 2 (Stoopes and Sheridan, 1992).

The Colima region is also very active seismically. Most of the seismicity is related to the processes of subduction; but there is also a great deal of shallow activity occurring in the upper crust, some of which can be correlated with faults running E-W on the west side of the SCR (Reyes y Jiménez, 1996).

GRAVITY

We used gravity data from PEMEX (De la Fuente *et al*, 1995). Figure 3 shows the network of gravimetric stations. Altitudes were obtained by leveling; a reference density of 2.67 gr/cm^3 was assumed for computing Bouguer anomalies. Terrain corrections were carried out by hand using Hammer's chart and tables up to zone M. Figure 4 shows the complete Bouguer anomaly inland. The anomaly shows the decreasing regional tendency towards the NE pointed out by Serpa *et al.* (1992); in our area the difference is about 170 mGal. The conspicuous structure to the north is related to the Nevado de Colima and Colima volcanoes.

A regional residual separation was made by using a bidimensional Fourier fit (Aiken, 1976). Figures 5 and 6 show the residual and the regional as obtained when using 25 Fourier coefficients. This should adequately separate structures with depths of some 10 km; however, using as few as 9 coefficients makes no significant difference.

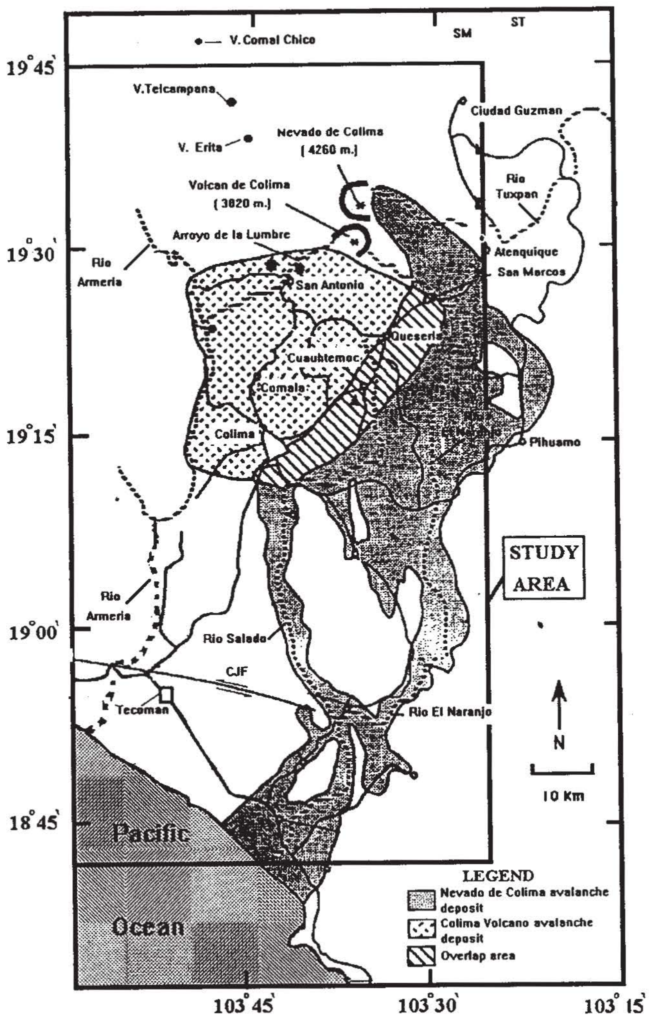

Fig. 2. Tectonic features within the Colima rift and surrounding areas. Symbols: ST Sierra del Tigre, SM Sierra los Manzanillos, SJP San Juan Plains, CJF Cofradía de Juárez Fault (modified after Stoopes and Sheridan, 1992)

The residual anomaly map (Figure 5) shows no evidence of deep faulting on the eastern margin of the Colima rift in agreement with Serpa *et al.* (1992). Towards the north, the anomalies of the CCG and NCG are clearly seen as closely related. The Central Colima graben forms a square depression of width of 18 to 20 km with the Nevado and Colima volcanoes in the center. The anomaly due to the Cofradía de Juárez fault at about 19° N. (Ortíz *et al.*, 1993) is parallel to the coast and seems to represent a contact between different lithologic units. The fault is right lateral and is reported to show recent displacements greater than 3 km.

The residual anomaly from the volcanoes and the SW avalanche deposits reported by Stoopes and Sheridan (1989) are also observed in Figure 5. The regional anomaly (Figure 6) shows no evidence of a basin buried by the avalanche deposits. There is no evidence of an existing basin previous to deposition in the area as the graben on which the Nevado and Colima volcanoes rise does not extend to that region. A single anomaly for the Nevado and Colima volcanoes supports Demant (1979) who suggested that both volcanoes have the same source in the crust.

Figures 7 and 8 show gravimetric models for sections AA' and BB' in Figure 3, as obtained with the method of Talwani *et al.* (1959). Due to vertical exaggeration the body seen under the volcanic edifice shows a highly prolate geometry. Its dimensions are roughly equal in the vertical and horizontal dimension and corresponds probably to the magma chamber. The seismicity associated with the volcano occurs mostly in this zone as a response to pressure changes in the conduit (Jiménez *et al.*, 1995).

DISCUSSION AND CONCLUSIONS

The origin of the Colima rift is not fully understood. Most researchers agree that it is related to the dynamics of the Jalisco block (Kostoglodov and Bandy, 1995), and particularly to the Rivera-Cocos plate boundary subducting under the North America plate (Bandy *et al.*, 1995). Any tectonic model of the area should take into account the gravity which fails to support normal faulting the eastern margin of the Colima rift. Quintero (1995) carried out a detailed geologic study of the area and found no evidence of normal faulting.To our knowledge there is no other field evidence of normal faulting along the eastern margin of the rift.

Gravity measurements in the Colima area between 104° to 103° 20' W, and 18° 33' to 19°45' N suggest that the thickening of the plate creates a gradient of about 2.6 mGal/Km. North of parallel 19°30' there is a depression that deepens towards the north. This is the easternmost part of the Northern Colima graben with the Nevado and Colima volcanoes marking the end of the structure. Any faulting south of the volcanoes is not evident from gravimetry, probably hidden by volcanic deposits.

The gravity anomaly due to the volcanoes can be modeled by a body of more than 2 km in width and more than 5 km in length with the top about 1.5 km below sea level. This would be the volcanoes' magma chamber. The effect of the vertical exaggeration in the plots of Figures 6 and 7 confers a slender shape to the body; however its dimensions are roughly 2 km by 5 km. The transverse width of the body is only slightly larger than the width along profile B-B' thus, its volume is about 50 km^3. This body has average density contrast of - 0.35 g/cm^3; however it most probably has a density gradient because of the continuous feeding of the volcanic conduit to the surface. Our model further suggests that the avalanche deposits may have buried several small basins; the bottom of the deepest basin would be some 1.5 km below sea level.

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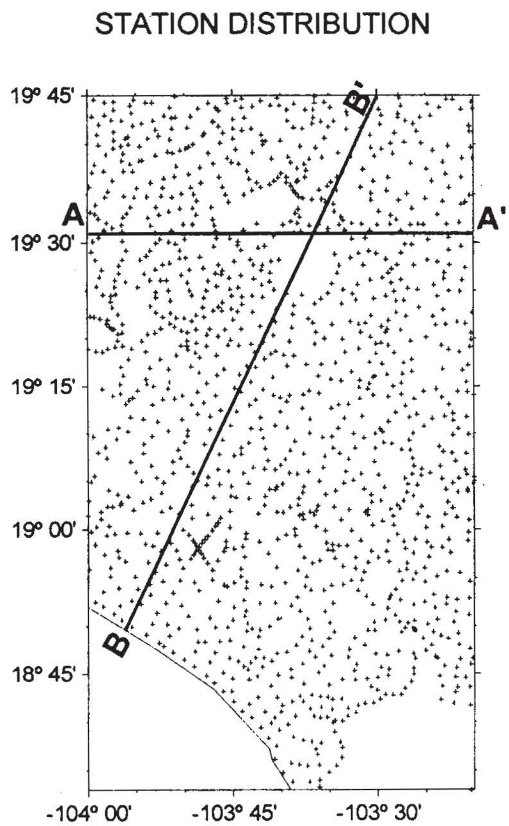

Fig. 3. Network of gravimetric stations. Gravity stations are represented by crosses. Lines AA' and BB' are the profiles modeled and shown in Figures 6 and 7.

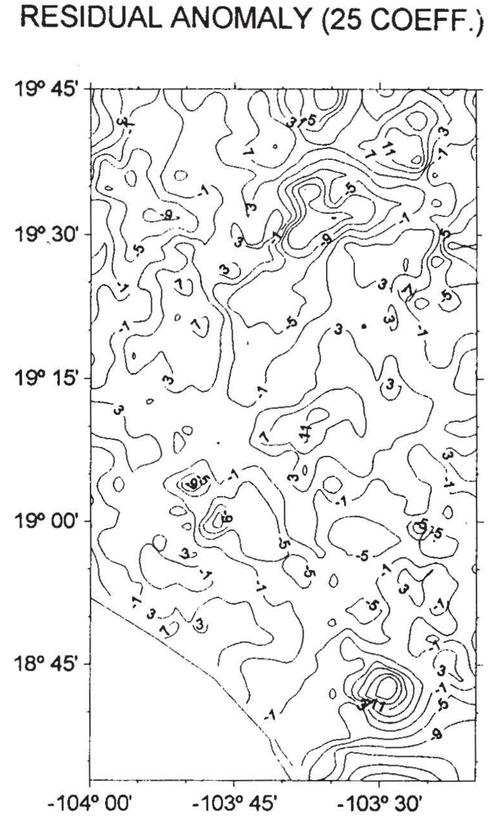

Fig. 5. Residual anomaly after substraction of a 25 coefficient Fourier fit to data.

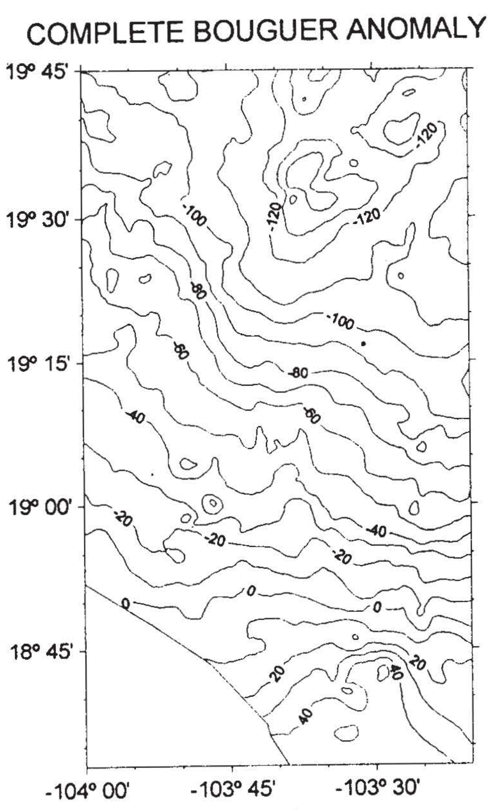

Fig. 4. Complete Bouguer anomaly contoured at 10 mGal.

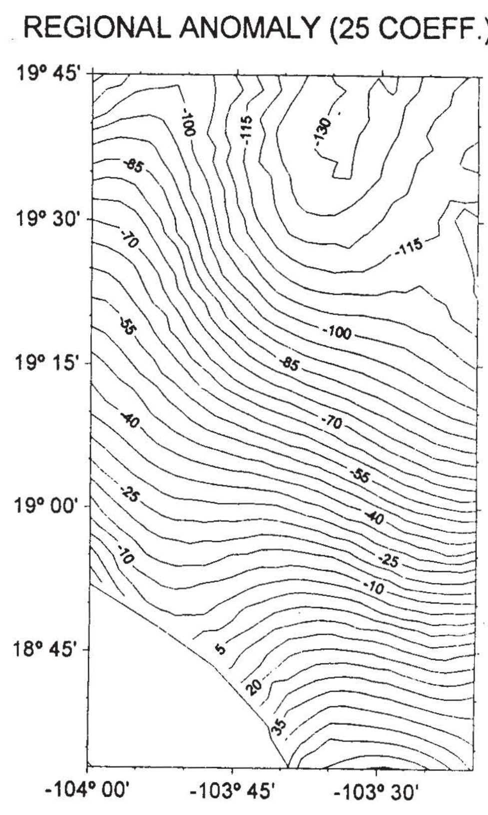

Fig. 6. Regional anomaly from a 25 coefficient Fourier fit to data.

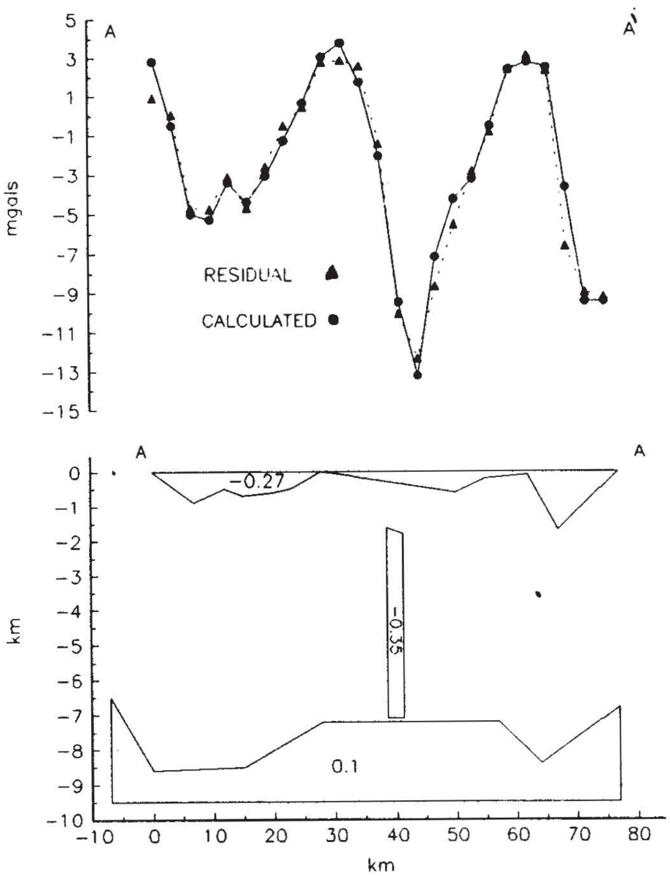

Fig. 7. Gravity profile AA' (upper plot) together with calculated anomaly from density model (below). Numbers are density contrast in g/cm³

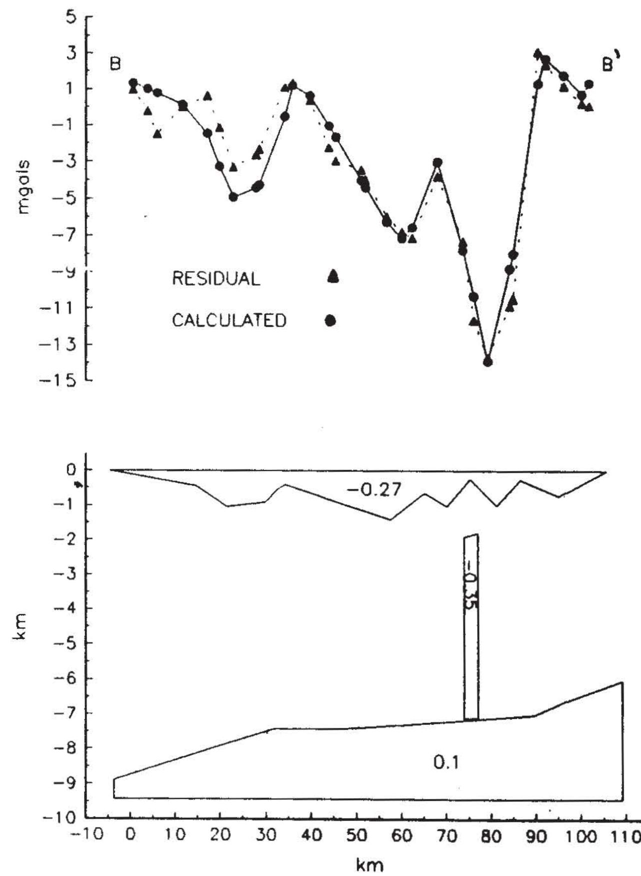

Fig. 8. Gravity profile BB' (upper plot) together with calculated anomaly from density model (below). Numbers are density contrast in g/cm³.

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