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SEDIMENT DEPTH IN THE NORTHERN COLIMA GRABEN FROM 3-D INTERPRETATION OF GRAVITY

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RESUMEN

El graben de Colima, con un rumbo N-S, es uno de tres sistemas grandes de graben, los cuales se intersectan a 50 km SSO de Guadalajara, México. Los resultados de una investigación gravimétrica en la parte norte del Graben de Colima indican una anomalía de Bouguer de 20 mgal, asociada con los sedimentos que rellenan el graben. Dicha anomalía se obtiene con respecto a las medidas de gravedad en las planicies en ambos lados del graben. Los modelos usando tres dimensiones y dos cuerpos indican que la profundidad de los sedimentos es tanto como 900 m. Se obtiene una estimación de 2.5 km de cambio aparente de posición vertical dentro de la parte norte del Graben de Colima, cuando se combina la profundidad de los sedimentos con el relieve topográfico.

ABSTRACT

The N-S trending Colima Graben is one of three large graben systems which intersect 50 km SSW of Guadalajara, Mexico. Results from a gravity survey conducted within the northern part of the Colima Graben indicate that a 20 mgal Bouguer gravity anomaly is associated with graben infilling sediments, relative to gravity measured on plateaux on both sides of the graben. Three-dimensional, two-body modeling of the gravity data indicate that the sediment depth is as much as 900 m. An estimate of 2 1/2 km of vertical offset within the northern Colima Graben is obtained from combining the predicted sediment depth with the topographic relief.

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1. INTRODUCTION

The Colima Graben is one of three graben systems that intersect about 50 km SSW of Guadalajara, Mexico to form a graben triple junction (Fig. 1). The Colima Graben overlies the subducting boundary between the Rivera and Cocos Plates, and is a N-S rift of the E-W trending Mexican Volcanic Belt (MVB). The graben may reflect the initiation of rifting of southwestern Mexico away from the mainland (Allan, 1981; Luhr and Carmichael, 1981; Luhr *et al.,* 1983). The Colima Graben consists of a well-defined, 70 km long, 20 km wide inner graben representing the graben's northern extension, and an enveloping, 40-60 km wide outer graben. Normal faulting associated with the graben extends nearly to the southern coast, a distance of over 200 km from the graben triple junction (Demant, 1981).

Previous descriptions of the graben structure have termed the inner graben the Sayula Depression (Diaz and Mooser, 1972) or the Sayula Graben (Herrera, 1967). The inner graben is defined here as extending from the graben triple junction south to the Colima Volcanoes (Fig. 1). Fault scarps within the inner graben run predominantly N-S or NNE-SSW; fault scarplets developed within colluvium or volcanic ash indicate that faulting has continued into the Holocene or Late Pleistocene (Allan, 1981). The inner graben relief is substantial; the western wall averages about 1000 m in height but reaches nearly 1500 m locally. The eastern side of the graben is less imposing; the maximum relief is about 650 m and is often considerably less. Rocks exposed in the inner graben walls are predominantly Miocene-Pleistocene lavas (Allan and Carmichael, 1985; Allan and Luhr, 1982), underlain by volcanic conglomerates, sandstones, shales, and limestones of probable Cretaceous age (Pantoja-Alor *et al.,* 1978; Estela *et al.,* 1978), and by a 70 m.y. old granodiorite (Allan and Carmichael, 1985). The graben is flanked on either side by high plateaux underlain by volcanics. The inner graben is floored predominantly by lacustrine clays, volcanic ash, and ephemeral shallow lakes. The absolute age of the graben is unknown, although estimates of Pliocene (Diaz and Mooser, 1972) and Early Pliocene (Allan and Luhr, 1982) age have been proposed, the latter on the basis of the age of associated alkaline lavas.

The Colima Graben is the dominant structural feature of the western MVB (Mooser, 1971; Demant, 1981), yet little about its structure and

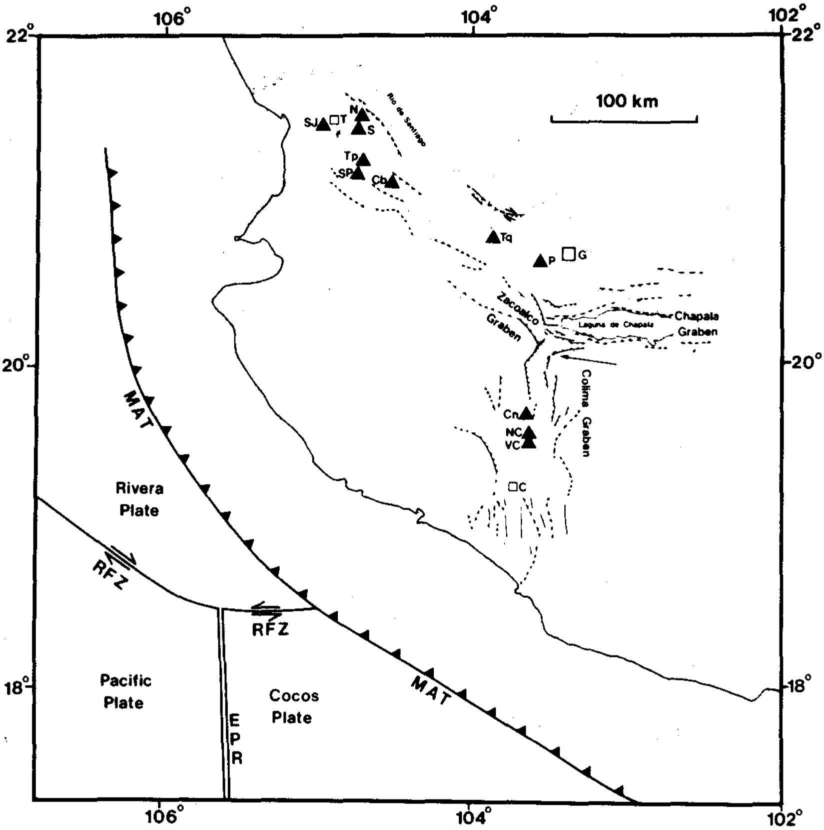

Fig. 1. Location map showing normal faults (solid lines with hachures on the downthrown sides), inferred normal faults (dashed lines with hachures), and lineaments (solid lines) of the three graben systems in SW Mexico. Area of gravity survey is shown by stippled region pointed to by the arrow. Open squares refer to cities: G = Guadalajara, C = Colima, and T = Tepic. Closed triangles refer to volcanoes: SJ = San Juan, N = Nevajas, S = Sanganguay, Tp = Tepitiltic, SP = San Pedro, Cb = Ceboruco, Tq = Tequila, P = Primavera, Cn = Cantaro, NC = Nevado de Colima, and VC = Volcán de Colima (Fuego). Plate boundaries are from Klitgord and Mammerickx (1982).

geology have been published. In order to estimate sediment depth within the inner Colima Graben and to help obtain an estimate of graben downfaulting, a gravity survey was conducted across the northern portion of the graben. This survey was completed in conjunction with geological field mapping of the inner graben. The results of the survey are presented here.

2. DATA ACQUISITION METHODS

The area that the gravity survey covers is shown schematically in Figure 1. The bulk of the survey was conducted in three traverses across the graben floor, with single traverses extending onto adjacent plateaux at least 5 km away from the rims of the major scarps (Fig. 2). Field conditions during the survey (winter, 1981) made impossible the extension of the survey further south; the lakebed constituting the graben floor was impassable by vehicles and so was traversed primarily on foot. Gravity was measured on a Worden-type Worldwide gravimeter, and elevation control was by altimeter and topographic map. The overall precision of the data acquisition is estimated to be about 1 mgal, based upon an elevation uncertainty of 3 meters and an overall instrumental precision of 0.3 mgal. The raw data were processed using free-air, topographic, Bouguer, latitudinal, and instrumental drift corrections. Earth-tide cor-

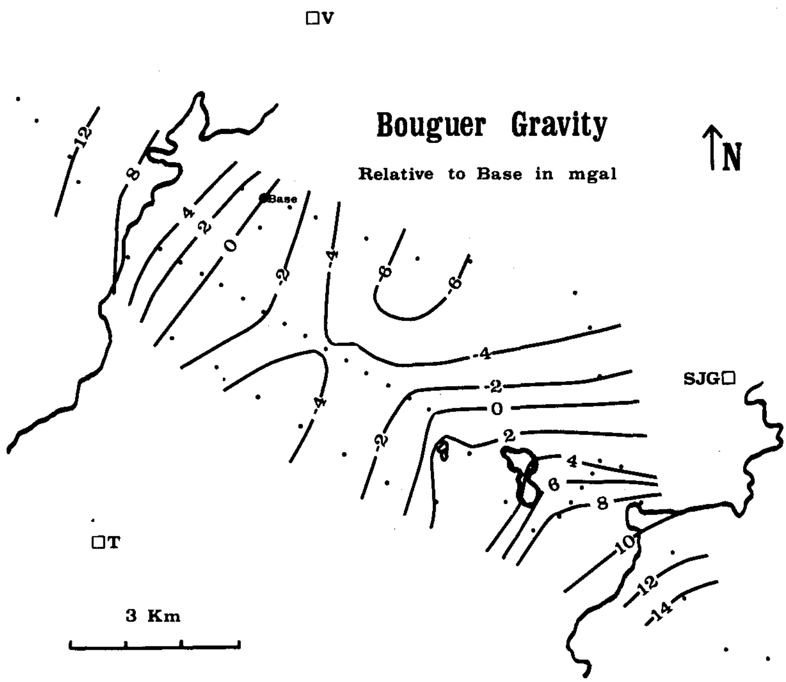

Fig. 2. Bouguer gravity anomaly map of the area surveyed. Contours are in mgal and represent anomalies relative to the base station on the graben floor. Dots represent the locations of gravity stations. The heavy lines represent the limits of bedrock outcrop. T = Techaluta, V = Verdia, SJG = San José de García.

rections were assumed to be included within the instrumental drift corrections. The results of the survey are shown graphically in Figure 2, and represent Bouguer gravity anomalies relative to a base station located on the graben floor. Individual station locations with their actual Bouguer gravity values are available from the author as an appendix.

No attempt was made to construct a residuals map for the area of the survey. A country-wide survey of Mexico has been published (Woolard *et al.,* 1969), but the data as presented are too general to be used to construct a regional gravity correction for the Colima Graben area. Instead, the gravity anomalies for the plateau regions flanking the graben were averaged, and this value was substracted from all other gravity station data, thereby establishing an absolute reference frame representing the regions underlain by crystalline rock on either side of the graben. The Bouguer gravity values, corrected to this reference frame, were used for the modeling of the graben sediment depth.

3. DATA MODELING METHODS

The graben sediment depth was estimated by the construction of a three-dimensional, two-body model, using a computer program written by Bruce D. Smith based on the method of Talwani and Ewing(1960). In this modeling procedure, the inner body is defined by a sequence of closed polygonal contours at a succession of increasing depths, with intervals ranging from 100 - 200 m. The anomaly caused by a polygonal lamina defined by a contour can be calculated for any external point (i.e., a gravity station). Therefore, by interpolating between contours and by numerical integration, the gravity anomaly caused by the inner body (the graben-infilling sediments) can be calculated for different models of varying sediment depth and dimensions.

The model considered the most successful at fitting the observed data is shown in Figure 3. The two-body model used for these calculations is shown by Figure 4, which shows a cross-section of the model constructed between the two southernmost survey traverses. The model is constructed of an outer body of rock of density 2.67 g/cc. and an inner body of clayey lacustrine sediments that have a density range of 1.5 - 2.24 g/cc. The density used for the outer body was chosen because the calculated Bouguer gravity anomalies for adjacent stations well away from the graben floor were within 0.4 mgal of each other when this density was used for the Bouguer corrections.

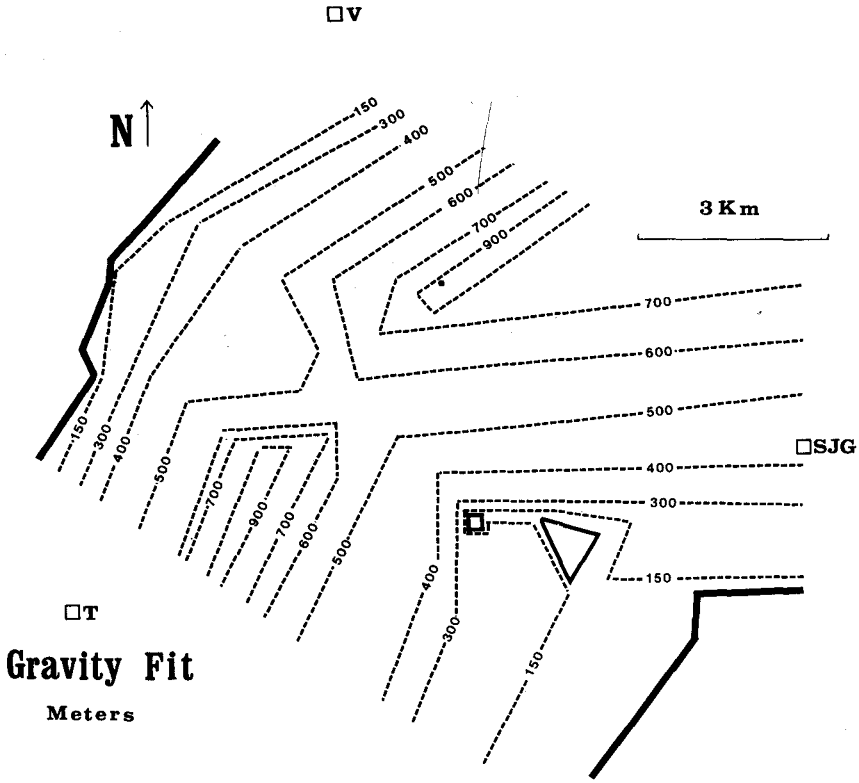

Fig. 3. Three-dimensional, two-body fit to gravity data using methods of Talwani and Ewing (1960). Contours are in meters depth. The heavy line represents bedrock outcrop or the 0 m contour. Geographic symbols same as in Figure 2.

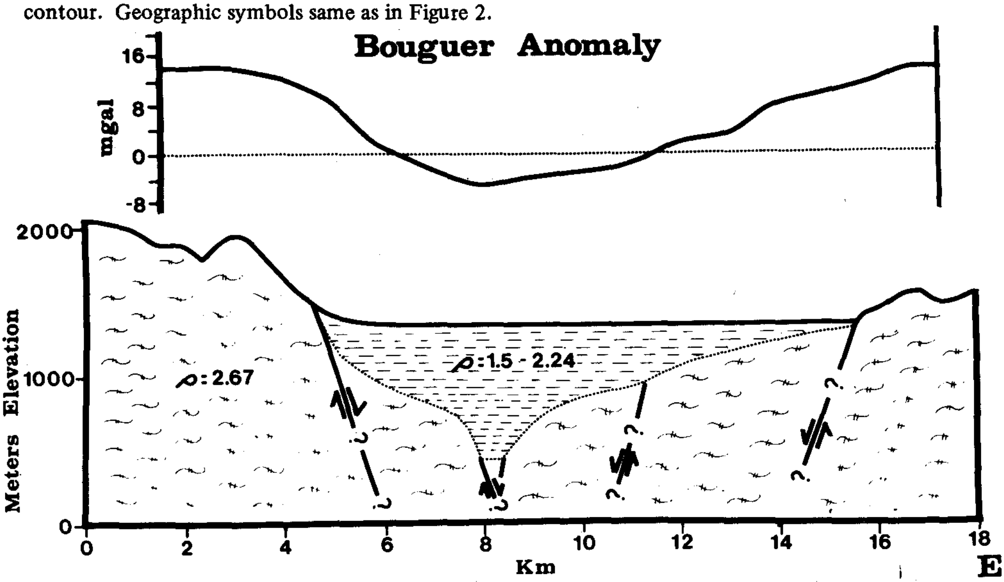

Fig. 4. Cross-section through the two-body model showing body densities. Vertical exaggeration is 3X. The Bouguer gravity anomaly curve for this cross-section is relative to the graben floor base-station.

Density modeling of the sediments comprising the inner body was more complex. Samples of water-saturated sediment were collected from the base of a 1 m-deep trench and double-sealed in plastic bags. Sediment density was determined on a Jolly balance. Sediment porosity was determined from the density by assuming that all sediment pores were filled with water and that the mineral fragments composing the sediment had an average density of 2.7 g/cc. The sediment depth for each depth contour was derived by varying the sediment porosity with depth, using the same percentage decrease in porosity due to compaction as is observed in the compaction of shales (Pettijohn, 1957 after Athy, 1930). The resulting densities (Table 1) may be regarded as minimum values, as the calculated initial porosity of the lacustrine clays is higher (70% vs. 55%) than the shale of the study, implying that more compaction of the clays probably occurred than is modeled here. As a counter-effect, the clay porosity would be lower than calculated if the pores were not entirely filled with water.

Table 1

Model Sediment Densities

Depth (meters)	Porosity (volume %)	Density (g/cc)
0	70	1.5
150	49	1.78
300	42	1.99
400	38	2.05
500	34	2.12
600	32	2.16
700	30	2.19
800	28	2.22
900	27	2.24

Figure 5 compares the observed gravity values for stations within the three traverses across the graben floor with values predicted by the model. Predicted gravity anomalies are typically within 0.5 mgal of the observed anomalies; significant deviations are observed only at the eastern end of the middle traverse, where there is complex faulting.

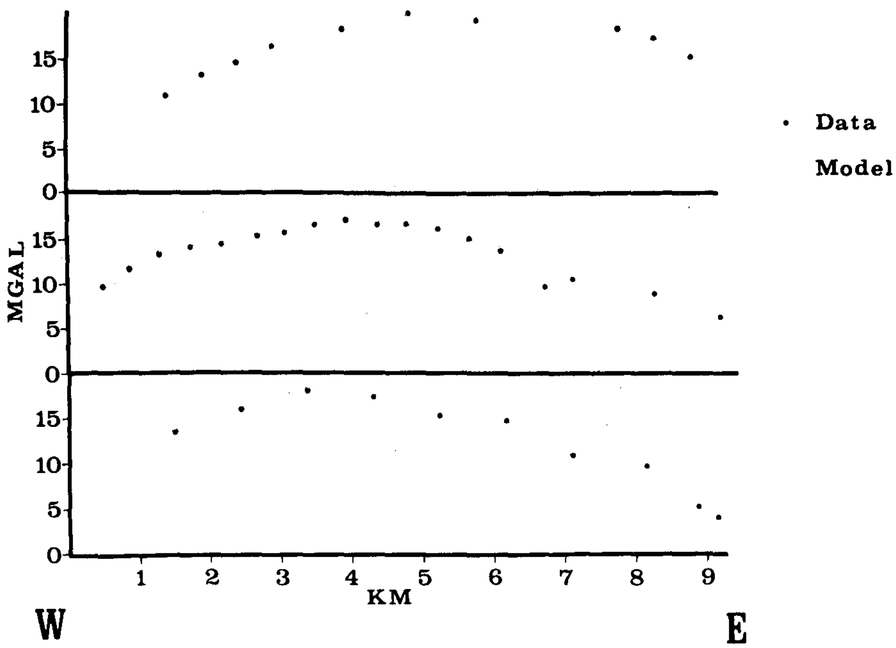

Fig. 5. Comparison of predicted gravity values (open circles) with observed gravity values (closed circles) for the three traverses across the graben floor. Traverses are arranged north to south going from top to bottom. Gravity values represented are Bouguer gravity anomalies relative to the plateaux flanking the graben.

4. DISCUSSION

The results of the survey indicate that in the northern Colima Graben there is a 20 mgal negative Bouguer gravity anomaly associated with the graben infilling sediments, relative to the plateaux on either side of the graben (Fig. 2). Modeling of the data predicts that the graben sediment depth is at least 900 m (Fig. 3). Both the Bouguer anomaly contours and the predicted sediment depth contours reflect the intersection of the Colima and Chapala graben fault systems; the sediment depth contours follow the NNE-SSW and N-S trends of the grabens.

The relief of the western wall of the Colima Graben rises sharply away from its northern terminus, from 350 - 700 m in the survey vicinity to 1500 m several km south of the survey, where the graben walls are capped by horizontal, 4.9 m.y. old lavas (Allan and Luhr, 1982). By assuming that the depth of graben infilling sediments within this area of higher relief is 900 m or more, an estimate of 2 1/2 km of vertical fault offset within the graben over the last 4.9 m.y. is obtained by adding the topographic relief to the predicted sediment depth.

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