Gravity field of the southern Colima graben, Mexico

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RESUMEN
El graben de Colima consiste en dos distintas provincias estructurales separadas por la zona de falla La Cumbre. Los resultados de un estudio gravimétrico en las áreas costa y en el océano de la provincia del sur sugiere que la porción sur del graben de Colima tiene unos 100 km de ancho y está formado por dos grábenes mayores con orientaciones NE-SW. Estos grábenes están separados por un alto angosto con también orientación NE-SW y constituido por magma inyectado a lo largo de una zona de fractura pre-existente. El graben del noroeste tiene unos 35 km de ancho y contiene alrededor de 8 km de espesor de sedimentos y presenta los valores máximos de adelgazamiento cortical. El graben al sureste tiene unos 60 km de ancho y contiene alrededor de 6 km de sedimentos.

PALABRAS CLAVE: Gravimetría, tectónica, estructura cortical, graben de Colima, occidente de México.

ABSTRACT
The Colima Graben consists of two distinct structural provinces separated by the La Cumbre fault zone. The results of a gravity survey conducted within the coastal and offshore areas of the southern province suggests that the Southern Colima Graben is over 100 km wide and is comprised of two major NE-SW trending grabens. These grabens are separated by a narrow NE-SW trending ridge possibly formed by magma injection along a pre-existing fault. The northwesternmost of these two grabens is 35 km wide and contains 8 km of sediments and the maximum amount of crustal thinning and a shoaling of the Moho occurs under this graben. The southeasternmost graben is 60 km wide and contains 6 km of sediments.

KEY WORDS: Gravity, tectonics, crustal structure, Colima graben, western Mexico.

INTRODUCTION

The Colima graben of western Mexico (Figure 1), extending from the intersection of the Chapala and Zacoalco grabens south of Guadalajara to the Middle America Trench south of Manzanillo, is thought to be an incipient rift between the Jalisco Block to the NW and the North American plate to the SE (Luhr *et al.*, 1985).

The structural character of the Colima graben differs north and south of the NW trending La Cumbre fault zone (LCFZ) located just south of the city of Colima. North of Volcán Colima, the northern graben is a narrow, well defined, north-south trending graben containing about 1 km of sediment infill (Allan, 1985). Vertical offsets on the bounding faults in this area are around 2.5 km (Allan *et al.*, in press). South of Volcán Colima, the northern graben widens until it terminates against the LCFZ (Serpa *et al.*, 1992). The Southern Colima graben extends in a SW direction from the LCFZ to the Middle America Trench. The onshore part of the Southern Colima graben is proposed to be a 50 to 65 km wide zone of block faulting, the main part of which is characterized by a broad alluvial plain (Allan, 1986). Offshore, the graben is a broad depression containing several submarine canyons. Single channel seismic reflection data (Bourgois *et al.*, 1988) indicate that these canyons are fault controlled, the major faults exhibiting vertical offsets of at least 1 km.

At present, published gravity surveys exist only in the northern Colima graben (Allan, 1985; Serpa, *et al.*, 1992) and in the offshore region of the Southern Colima graben (Couch *et al.*, 1991). No detailed survey has been published within the onshore area of the Southern Colima graben. The purpose of this study is to infer from gravity data the following characteristics of the southern province of the Colima graben: (1) graben geometry, (2) orientation of major structural trends, (3) sediment thickness within the graben and (4) deep crustal structure.

DATA COLLECTION AND REDUCTION

This study is based on a land gravity survey conducted along the western coast of Mexico during March, 1990. During this survey gravity measurements were made at 167 stations using the Lacoste-Romburg model G geodetic gravity meter #135. These data were collected both along a coastal profile extending from Barra de Navidad to Playa Azul and within the coastal plain of the Southern Colima graben south of the city of Tecoman (herein referred to as the 3-D grid). Station spacing within the 3-D grid is 2 to 5 km. Station spacing along the coastal profile is variable; the spacing is 2 km for stations located within 80 km of Tecoman, 5 km for stations located within 80 to 125 km of Tecoman, and 10 km for stations located at distances greater than 125 km from Tecoman. Station locations were determined from 1:50,000 topographic maps compiled by Mexico's mapping agency, INEGI, and we estimate the maximum error in station location to be ±200 meters. The survey consists of 23 loops of generally less than 3 hours duration. Misclosures around the loops average 0.08 mgals with a maximum misclosure of 0.29 mgals. Misclosures

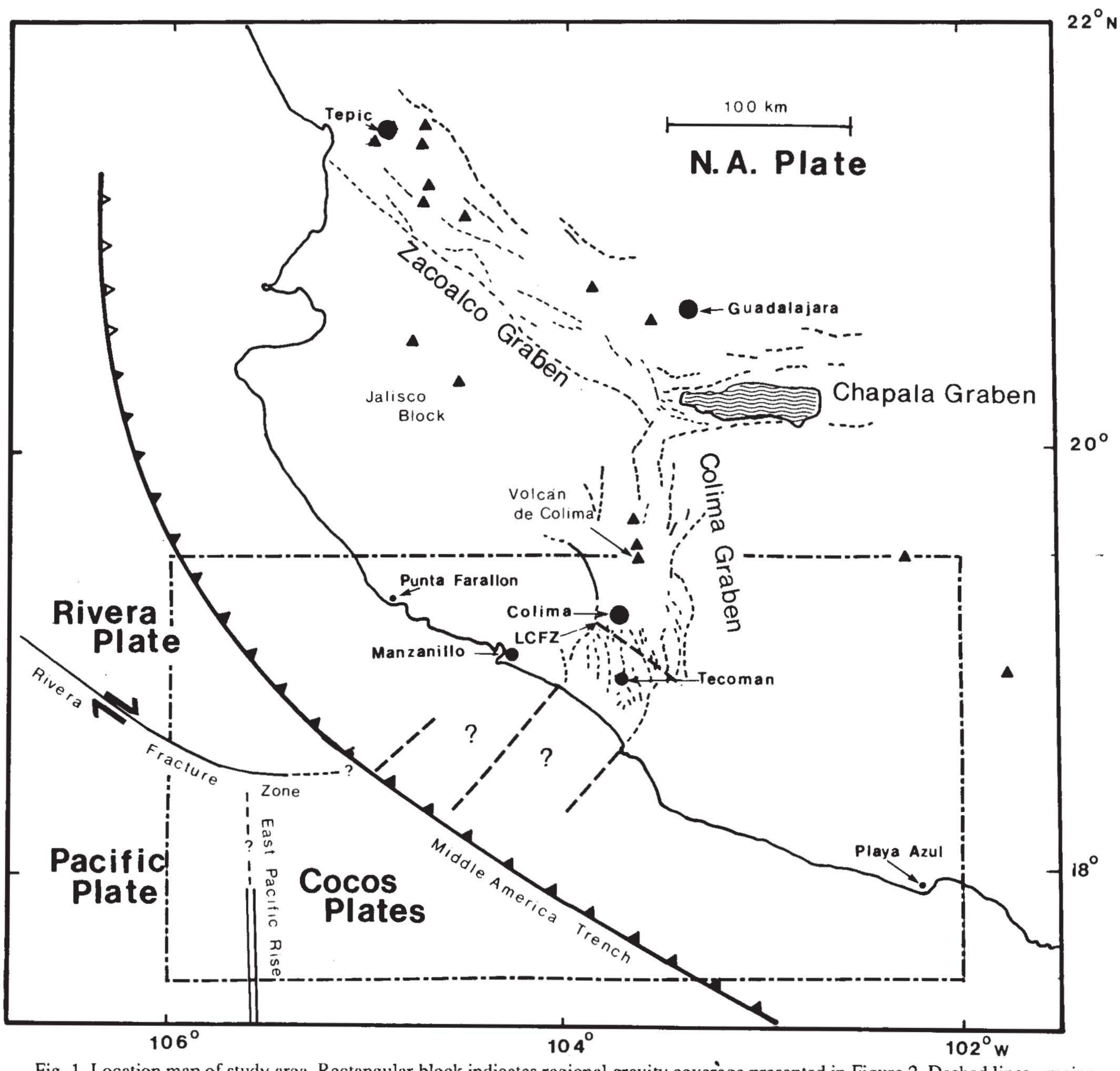

Fig. 1. Location map of study area. Rectangular block indicates regional gravity coverage presented in Figure 2. Dashed lines= major faults; triangles= volcanoes; solid circles= major cities; LCFZ= La Cumbre fault zone.

are attributed to the effects of instrument drift and earth tides. These effects are assumed to vary linearly over each loop and the gravity readings are adjusted accordingly.

In order to maintain reliable station elevations, stations were located at benchmarks whenever possible. In addition, several elevation control points were established by determining elevation differences between the control points and sea level employing barometric measurements. The elevations of stations not at these control points or benchmarks are determined using a Paulin survey microbarometer. In general, the time difference between measurements made at these intervening stations and those made at control points is less than 1 hour. Average accuracy of the elevations determined in this manner is estimated to be within ±1.5 meters for stations elevations less than 25 meters and within ±3.0 meters for station elevations between 25 and 50 meters. Station elevations in the 3-D grid and along the coastal profile are generally less than 25 and 50 meters, respectively. Therefore, the overall accuracy at stations along the coastal profile is estimated to be ±0.6 mgals and ±1.0 mgals for Bouguer and free-air anomaly values, respectively. At stations within the 3-D grid, the overall accuracy is estimated to be ±0.3 mgals and ±0.5

mgals for Bouguer and free-air anomaly values, respectively.

The base station for this survey is located at the Instituto Oceanográfico in Manzanillo. This station is located at 19°03'45.545"N ± 0.017", 104°18'08.800"W ± 0.023", and the elevation with respect to the WGS-77 ellipsoid is-11.15 meters (approximately 2.5 meters above mean sea level). The observed gravity at the base station is 978581.46 ± 0.07 mgals. The Manzanillo base is tied to LAGSN77 gravity station #9712-62 in Puerto Vallarta (Ness, 1984).

Additional land gravity measurements at 125 stations were provided by the United States Defense Mapping Agency (US-DMA). Marine free-air gravity measurements were obtained from the National Geophysical Data Center, Boulder, Colorado, USA.

Gravity anomalies for all the land data have been computed with reference to the WGS-84 ellipsoidal Gravity Formula (US-DMA Technical Report, 1987). Bouguer corrections are based on slab densities of 2.67 g/cm^3. Complete Bouguer anomalies are determined by correcting the simple Bouguer values for terrain effects out to 22 km using a density of 2.67 g/cm^3, and a correction for the earth's curvature (LaFehr, 1991) has also been applied.

REGIONAL GRAVITY FIELD

The regional gravity field along the coast and seaward of western Mexico is illustrated by the contour map shown in Figure 2. The contours represent free-air anomaly values in the offshore area and complete Bouguer anomaly values onshore. The dominant trend exhibited by the contours is NW-SE, parallel to the trend of the Middle America Trench. Here, the trench is associated with an elongate, NW-SE trending gravity low within which free-air values less than -130 mgals are observed. Along the coast, an elongate, NW-SE trending gravity high (henceforth termed the 'Coastal Gravity High') is observed along which both Bouguer and free-air values in excess of 50 mgals are observed.

The Coastal Gravity High (see Figure 2) extends unbroken from just NW of Playa Azul to the area south of Tecoman at which point free-air values decrease rapidly from 50 mgals to around 0.0 mgals. This break in the Coastal Gravity High lies adjacent to the broad alluvial plain of the Southern Colima graben. Two other breaks occur along the Coastal Gravity High to the NW. The first is located just west of Manzanillo where free-air values decrease to around 10 mgals. The second break is only partially revealed in the NW corner of the map near Punta Farallon where free-air values along the Coastal Gravity High decrease to around 0.0 mgals. All three breaks are located adjacent to NE-SW trending gravity lows in the offshore continental shelf and slope areas, the most prominent of which (henceforth termed the 'Tecoman Offshore Gravity Low' or TOGL) is located SW of Tecoman. The gravity low just west of Manzanillo is henceforth termed the 'Manzanillo Offshore Gravity Low' or MOGL. These gravity lows extend onshore but are not as pronounced as in the offshore area.

The shape of the gravity anomaly across the TOGL is highly asymmetric, with the lowest values located in the NW (see Figure 2). The TOGL is bounded on the SE by an NE-SW trending elongate gravity high extending from the Coastal Gravity High to the seaward edge of the continental shelf near 104°W. This high lies along the offshore projection of the SE margin of the broad alluvial plain of the onshore part of the Southern Colima Graben. The TOGL is bounded on the NW by a prominent isolated gravity high exhibiting 30 mgals of closure. This gravity high correlates with a bathymetric dome exhibiting 300 meters of relief. The gradient of the anomaly across the TOGL is greatest along the NW margin (see Figure 3). To the SE the anomaly exhibits two abrupt changes in gradient between which the gradient is nearly zero. Single channel seismic reflection data (Bourgois *et al.*, 1988) indicate that the closed low within the NW half of the TOGL correlates with a fault bounded depression containing two prominent submarine canyons. Throws on the bounding faults are in excess of 1 km.

The MOGL is narrower (35 km wide) and less distinct than the TOGL. It is separated from the TOGL by a NE-SW oriented ridge along which lies both the bathymetric dome mentioned previously and an isolated gravity high situated on the Coastal Gravity High just south of Manzanillo. Since the alignment of these two gravity highs is parallel to the trend of the fault bounding the TOGL to the NW, they may be indicative of igneous intrusions formed by magma rising along this fault. Thus the Colima Graben in this area may consist of two grabens separated by a ridge of igneous intrusives.

GRAVITY FIELD OF THE ALLUVIAL PLAIN, SOUTHERN COLIMA GRABEN

The contour map presented in Figure 4 illustrates the gravity field within the alluvial plain and adjacent offshore area of the Southern Colima graben. Contours represent free-air anomaly values offshore and simple Bouguer anomaly values onshore.

Two prominent NE-SW trending features are observed onshore. The first is an elongate, 6 to 8 mgal gravity low located west of Tecoman. No surface features are observed which can account for this low, however, it is coincident with the Rio Armería at the coastline, suggesting that it may correspond to a buried, abandoned channel of the Rio Armería. Alternatively, since this low lies along the projection of one of the fault controlled submarine canyons observed offshore, the gravity low may represent the onshore extension of this fault. The second feature consists of two closed gravity highs which are aligned in a NE-SW direction situated near the SE margin of the alluvial plain. The southernmost high corresponds to a syenite outcrop, the exact age of which has not been determined. It is likely that the closed high to the NE is also produced by an ig-

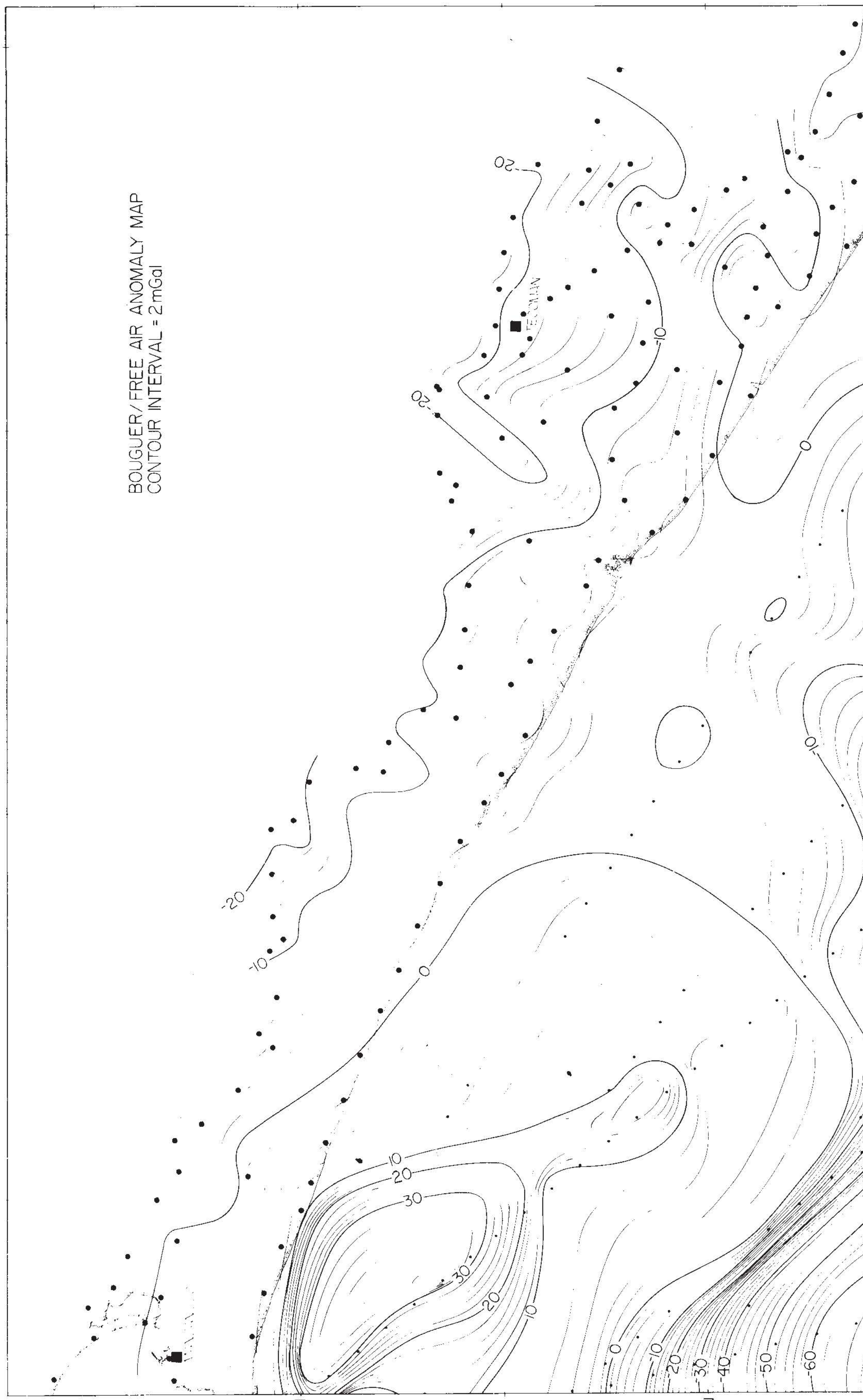

Fig. 2. Regional gravity anomaly map. Contours represent complete Bouguer anomaly values onshore and free-air anomaly values offshore. Also shown are the locations of the gravity profiles shown in Figures 3 and 5. The NE-SW trending dashed lines mark the boundaries of the broad alluvial plain of the southern Colima Graben. CGH=Coastal Gravity High; MAT=Middle America Trench; MOGL=Manzanillo Offshore Gravity Low; TOGL=Tecoman Offshore Gravity Low.

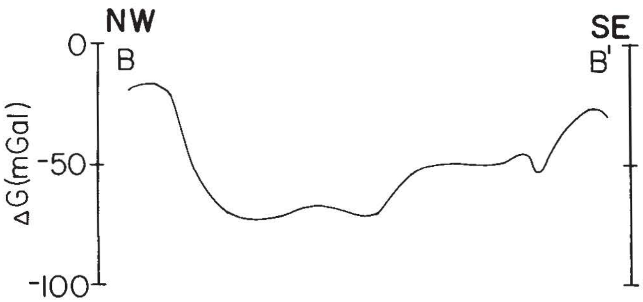

Fig. 3. Gravity profile across the Tecoman Offshore Gravity Low. See Figure 2 for profile location.

neous intrusion. Further, it is probable that these intrusions originated by magma rising along a major NE-SW trending fault which is now buried beneath the sediments of the alluvial plain.

2-D GRAVITY MODEL

A 2-D gravity model (Figure 5) is constructed from the contour map shown in Figure 2 (complete Bouguer anomaly values onshore and FAA values offshore) along a profile running parallel to the regional contours along the crest of the Coastal Gravity High (see Figure 2 for profile location). The modeling method employed is that of Talwani *et al.* (1959). Densities used in the model are assumed densities.

Since no seismic reflection or refraction data or subsurface geologic data is available for this region, the gravity model is highly non-unique. However, the model suggests the following:

(a) The Southern Colima graben is over 100 km wide, extending from just NW of Manzanillo to SE of Tecoman.

(b) The Colima graben is comprised of two smaller grabens, corresponding to the MOGL and TOGL, separated by a narrow ridge.

(c) The graben producing the MOGL is 35 km wide, containing about 8 km of sediments.

(d) The graben producing the TOGL is about 60 km wide and contains about 6 km of sediments.

(e) The Moho shoals under the NW graben.

(f) The maximum amount of crustal thinning occurs under the NW graben.

SUMMARY

The results of this study suggest that the Southern Colima graben along the Pacific coast is over 100 km wide. Prominent gravity trends within the graben are NE-SW, parallel to the overall strike of the graben. Offshore, the Southern Colima graben consists of two NE-SW trending grabens (which produce the TOGL and the MOGL) separated by a narrow ridge which was probably formed by magma injection along a pre-existing NE-SW trending fault.

The southwesternmost of these two grabens (the one which produces the TOGL) in the offshore region is 60 km wide and contains about 6 km of sediments. The steep gravity gradient on the NW margin of this graben suggests that the total displacement there occurs across a single boundary fault, whereas the displacement on the SE margin appears to primarily occur across two widely separated faults. The prominent trough in the NW part of this graben is fault bounded, the southeasternmost boundary fault may extend onshore just west of Tecoman.

The northwesternmost graben, under which crustal thinning is a maximum, is 35 km wide and contains about 8 km of sediment. Further, the Moho shoals under this graben.

The sediment thickness within the grabens and the shoaling of the Moho are uncertain due to the non-uniqueness inherent in gravity modeling. It is strongly recommended that seismic refraction data be collected in this area to better constrain the gravity modeling.

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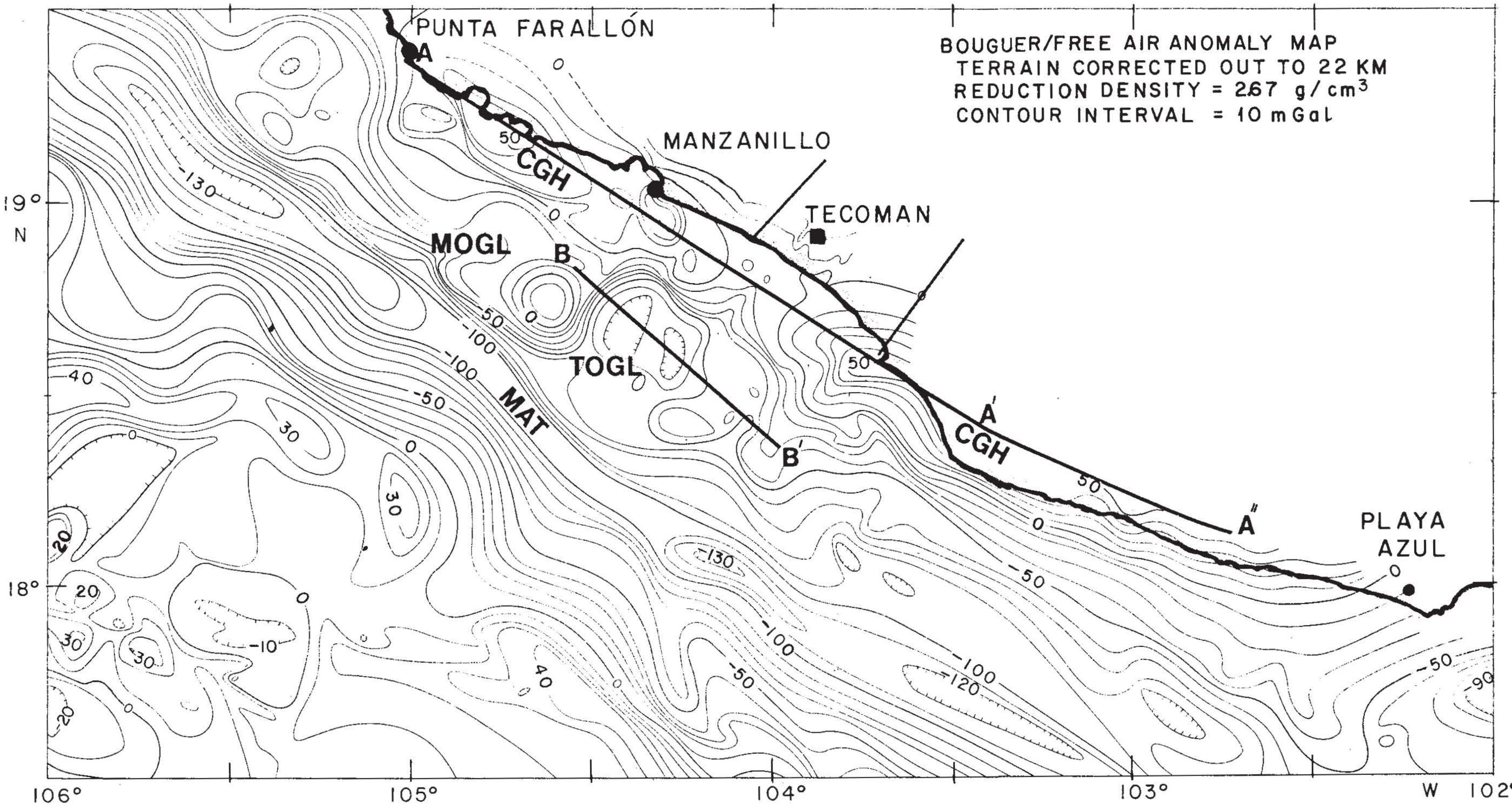

Fig. 4. Local gravity anomaly map of the coastal region of the southern Colima graben. Contours represent simple Bouguer anomaly values onshore and free-air anomaly values offshore. Large solid circles= locations of gravity stations onshore; smaller solid circles= locations of marine gravity data.

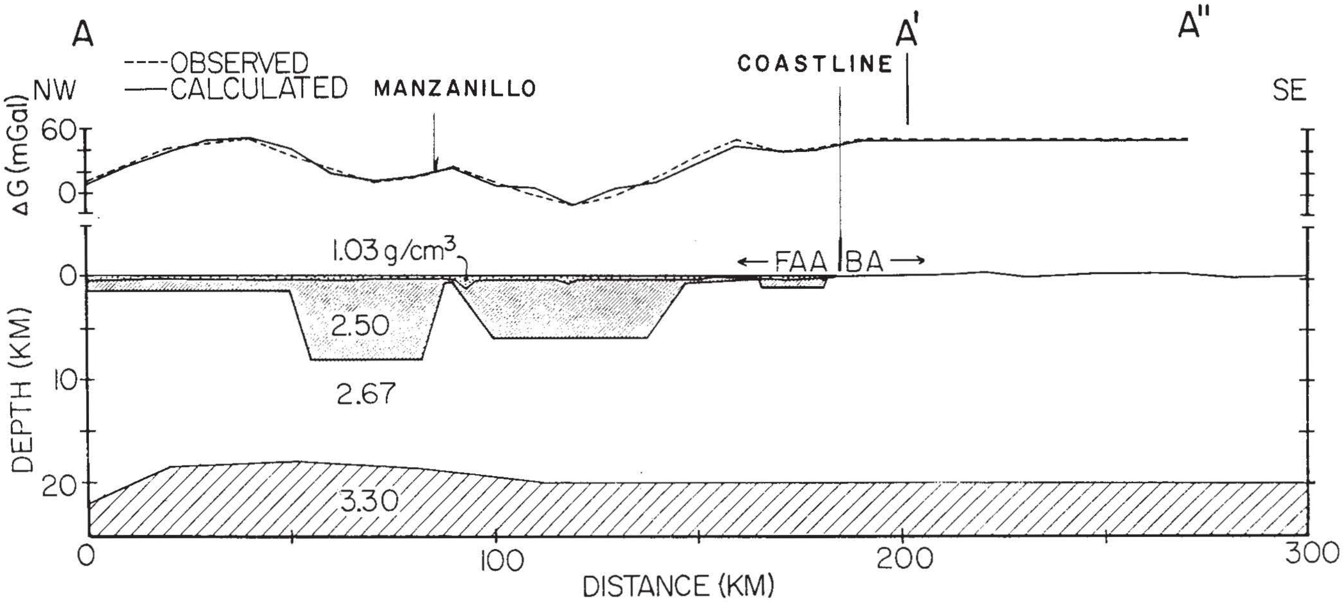

Fig. 5. 2-D gravity model along the Coastal Gravity High. See Figure 2 for profile location.

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