GEOFISICA INTERNACIONAL

REGIONAL GRAVITY OF LOS HUMEROS VOLCANIC AREA

M. MENA* and T. GONZÁLEZ-MORÁN*

RESUMEN

En el extremo este del Eje Volcánico Transmexicano se encontró una anomalía gravimétrica negativa. Tectónicamente, dicha anomalía parece corresponder a un hundimiento en el que han tenido lugar varias series de episodios volcánicos: el área considerada es un campo geotérmico potencial, limitada al Norte, por el complejo litológico de Teziutlán, hacia el Sur, por las llanuras de Tepeyehualco, al Oeste por la Sierra Madre Oriental y al Este por la cadena del Pico de Orizaba-Cofre de Perote.

El estudio realizado incluye el mapa gravimétrico de las anomalías de Bouguer completa, los mapas obtenidos de la separación regional-residual y un modelo bi-dimensional de la porción central de la caldera de Los Humeros que contiene una anomalía central, positiva, aparentemente correspondiente a una obturación central masiva. Además de una discusión esquemática de la evolución del área volcánica, se propone la existencia de una caldera localizada entre la de Los Humeros y la montaña Cofre de Perote, que está totalmente rellena de material volcánico.

* *Instituto de Geofísica, UNAM.*

ABSTRACT

A negative gravity anomaly has been obtained on the eastern end of the Transmexican Neovolcanic Axis. Tectonically the anomaly appears to correspond to a sinking in which a series of volcanic episodes have taken place; the area is considered a potentially producing geothermal field. The area is limited to the North by the lithological complex of Teziutlán, to the South by the Tepeyehualco plains, to the West by the Sierra Madre Oriental and to the East by the Pico de Orizaba-Cofre de Perote range.

The study includes the gravimetric map of complete Bouguer anomalies, the maps resulting from the regional-residual separation, and a two-dimensional model through the central portion of Los Humeros caldera which contains a central, positive anomaly apparently corresponding to a massive central plug. In addition to a schematic discussion of the evolution of the volcanic area, the existence is proposed of a caldera located between Los Humeros caldera and Cofre de Perote mountain, which is completely filled by volcanic materials.

INTRODUCTION

The marked differences of internal mass distribution make the gravimetric method useful for regional studies in volcanic areas (Malahoff, 1969). The present study covers an area located between 19°15' and 19°55'N, and 97°08' and 97°45'W on the eastern end of the Transmexican Neovolcanic Axis (TNA). The TNA shows sharp, negative gravimetric gradients, characteristic of regions with deep mountain roots (Monges, 1973). Figure 1 shows that the studied area is located at the end of a regional alignment of simple Bouguer anomalies that decrease in magnitude in the NE direction; such anomalies are associated with the orographic system of the Sierra Madre Oriental and the Teziutlán granitic massif. Such an alignment bends over towards the South owing to the presence of the Pico de Orizaba-Cofre de Perote range and the calcareous Mesozoic complex that limits the SE portion of the TNA (Demant *et al.*, 1976).

Field data were obtained with a Lacoste Romberg gravimeter, Model G, aiming at a uniform distribution of stations; however, it was not always possible to reach the best locations owing to access difficulties. Observed gravity was computed for each station after conversions and instumental corrections, linking the observations to the National Network of Gravity Stations through station K-10 in Perote City. Since available topographic charts are inadequate for this type of work (i.e., 50 m contour interval), station altitudes were obtained through barometric measurements with two Wallace and Tierman altimeters, making continuous closures on the available level benches of the Secretaría de la Defensa Nacional, and on the nearby railrod stations whose altitudes are well established. The coordinates of the observed stations were obtained from the 1:100000 charts of the Secretaría de la Defensa Nacional; the theoretical gravity values were obtained with such coordinates and the model described by the International Gravity Formula (Postdam System, 1930).

A density value of 2.67 g/cm^3 was used in the calculation of the Bouguer anomalies; such a value is internationally accepted as the average density of crustal rocks. This density choice will allow the new observations to be linked to those previously obtained for the elaboration of the gravimetric map of the TNA (Monges, 1973). Figure 1 shows the gravimetric map of the portion of TNA corresponding to this study. The standard value of the vertical gravity gradient is –0.3086 mgal/m; terrain corrections were computed with the method of rectangular prisms with a 2.40 gm/cm^3 density (Hernández, 1978). The final values yielded the complete Bouguer anomaly shown in the map of Figure 2 (dots represent stations) with an error of 1.5 mgals.

GRAVIMETRIC ANOMALIES

The gravimetric map of complete Bouguer anomalies of the area (Figure 2) partially shows the alignments previously mentioned in relation to Figure 1. Such alignments begin to be disturbed along longitude 97°35'W, which corresponds to the end of the Sierra Madre Oriental and the beginning of the anomalous area reported herein. In the central portion of such an area there is a complex distribution of maxima and minima that shall be discussed in detail subsequently.

Field data contain the effect of all sources producing the observed anomaly; in order to enhance features of geological interest it is necessary to separate the deep and superficial contributions to the anomaly. There are many methods to determine the regional contribution, from which the residual is then computed (e. g., Agocs, 1951; Simpson, 1953). We have observed that the best fit of the regional to the measured data is obtained with least squares fitting, assuming that the regional tendency can be approximated by a 1st order polynomial. In the present work 292 observations are considered, localized in an approximate area of 4700 km^2. The equation

$$Y = a_O \, a_1 x_1 + a_2 x_2 \qquad (1)$$

with x_1 and x_2 as geographical orthogonal coordinates, represents the 1st order polynomial for which optimum values of the coefficients a_O,

a_1, and a_2 were computed. These are $a_0 = -195.49$, $a_1 = 0.0686$, $a_2 = 1.1503$. The Y-value for each one of the 292 observations was calculated and the residual obtained as the difference $\overline{Y}_i - Y_i$ where $\overline{Y}_i$ is the gravity value observed for each station and Y_i is the computed gravity value for the same station. Figure 3 shows the residual anomaly map; the percent adjustment for the regional tendency is of 80.6% with a multiple correlation coefficient R = 0.898; we are thus dealing with a smoothly varying regional tendency (approximately 1.2 mgal/km in the N-S direction), otherwise a higher order polynomial would be required to provide the same fitting.

DISCUSSION

The residual anomaly map (Figure 3) enhances the gravimetric effect produced by the main tectonic and volcanic structures of the area. Figure 5 shows the main tectonic and geologic structures; the intersection between Los Humeros graben of direction NW (1-1), and the Oriental graben of direction NE (2-2) encloses the area of main volcanic activity which contains Los Humeros caldera, Tepeyehualco volcano, the intrusive and explosion crater Pizarro and the inferred structure of La Gata caldera. SW of the area a horst is defined by Alchichica fault and Pico de Orizaba-Pachuca fault; in this horst one finds the Sierra Blanca and Las Derrumbadas intrusives. A clearly defined mass deficiency is observed in the eastern portion of Figure 3, produced by the low density rock of Cofre de Perote volcano (19°30'N, 97°10'W); to the southwest the main maximum is probable due to the Sierra Blanca formation (19°25'N, 97°32'W); to the West and North, the effects produced by the mountain roots of the Sierra Madre Oriental and the Teziutlán granitic massif are maintained as in the complete Bouguer anomaly map. In the central part (Figure 3) the zero contour delimits a negative anomaly of elliptical shape, suggesting the existence of an area of low density probably originating in the intersection of the Los Humeros graben and the Oriental graben (Figure 5).

Within the limits of such a low density area it is possible to differentiate four anomalies of annular shape (Figure 3): (1) Los Humeros anomaly (19°36' to 19°47'N and 97°22' to 97°30'W), with a relative maximum at coordinates (19°42'N, 97°26'W), which is probably produced by the extrusive body that constituted the base and chimney of the original volcano. Although the gravimetric station density is low in the area, the existence of this maximum is confirmed by the magnetometric data (C. Flores *et al.*, this issue) which indicate the presence of a magnetized body in the same region. Secondary vulcanism, internal to the caldera, produces a series of gravity minima in the southern caldera rim; the most important is associated to the Calderita volcano (19°38'N, 97°27'W. (2) The existence of a buried caldera (La Gata) is suggested by the second anomaly (19°34' to 19°41'N and 97°10' to 97°22'W), with possibly the remaining structure of a volcano chimney, as suggested by the relative maximum observed at 19°37'N, 97°18'W. Although such a caldera is completely covered, gravimetry and LANDSAT satellite images (e.g., E-1306-16224-7 01; E-1180-16225-7 01) suggest its existence. (3) Anomaly (19°38'N and 97°21'W) associated with the intrusive body and explosion crater known as Cerro Pizarro (Alvarez *et al.*, 1976), and (4) anomaly associated with Tepeyehualco volcano (19°31'N, 97°30'W, Figure 3), located between 19°33' to 19°36' and 97°27'-97°32'.

In order to model the main features of the anomalies associated to Los Humeros caldera a section going through the relative maximum was chosen, his is section AA' in Figure 3. Values for this section were taken from the contoure Residual Anomaly map but still provide an estimate of the subsurface structure that can be correlated with other geophysical data (Alvarez, this issue; Flores *et al.*, this issue). Calculations were made with the algorithm of Talwani *et al.* (1959) with the following densities: 2.67 g/cm^3 for the surrounding rocks, 2.35 g/cm^3 for pyroclastics, 2.52 g/cm^3 for the central body. The proposed model is shown in Figure 5, where it can be seen that departures between observed and computed anomalies do not exceed 1 mgal.

The residual anomaly map coincides rather well with the tectonics of the area proposed by Mooser and Soto (1979) (Figure 4), in which Los Humeros graben of NW direction intersects the Oriental graben of NE direction, producing an area of extreme weakness that favors the appearance of volcanic activity. In the SE portion of the area, the Alchichica fault and the Pico de Orizaba-Pachuca fault delimit a horst within which are contained the structures of Sierra Blanca and Las Derrumbadas.

Since no dating is yet available for the rocks of the area, it is not possible to precisely establish the sequence of events that yielded the present day features. However, we offer tentatively the following broad scheme:

1) The sinking was produced by the intersection of Los Humeros graben and the Oriental graben (Figure 4), probably in the Upper Miocene.
2) Within the area of this intersection a volcano was formed, which after collapsing gave rise to La Gata caldera; the neck of the volcano collapsed as well and in such a process it was displaced from the center along the NE direction.
3) The process of volcano formation was subsequently reactivated at a new, neighboring volcano formed to the West of La Gata. Alfter the magma chamber was partially depleted the new volcano structure collapsed forming Los Humeros caldera; the neck of the volcano was about 1.25 km wide and sunk to a depth of about 500 m (Figure 5).
4) In the rim, and within Los Humeros caldera a series of secondary volcanic structures erupted lavas and pyroclastics, which covered the caldera and its surroundings with tuffs and ashes (Pérez-Reynoso, 1978), producing the present day structure.

CONCLUSIONS

The schematic sequence of events described above suggests that volcanic activity could have taken place possibly since upper Miocene and that migration of vulcanism would be a common feature in the area. The existence of a major, buried structure has been inferred on the basis of gravimetric results (La Gata caldera); its presence should be corroborated by other geophysical means. The present results cannot, in its own, decide on the viability of Los Humeros caldera as a geothermal area; however, we think that the purpose of this work has been fulfilled inasmuch as it has identified and delimited the main structures in the area.

ACKNOWLEDGMENTS

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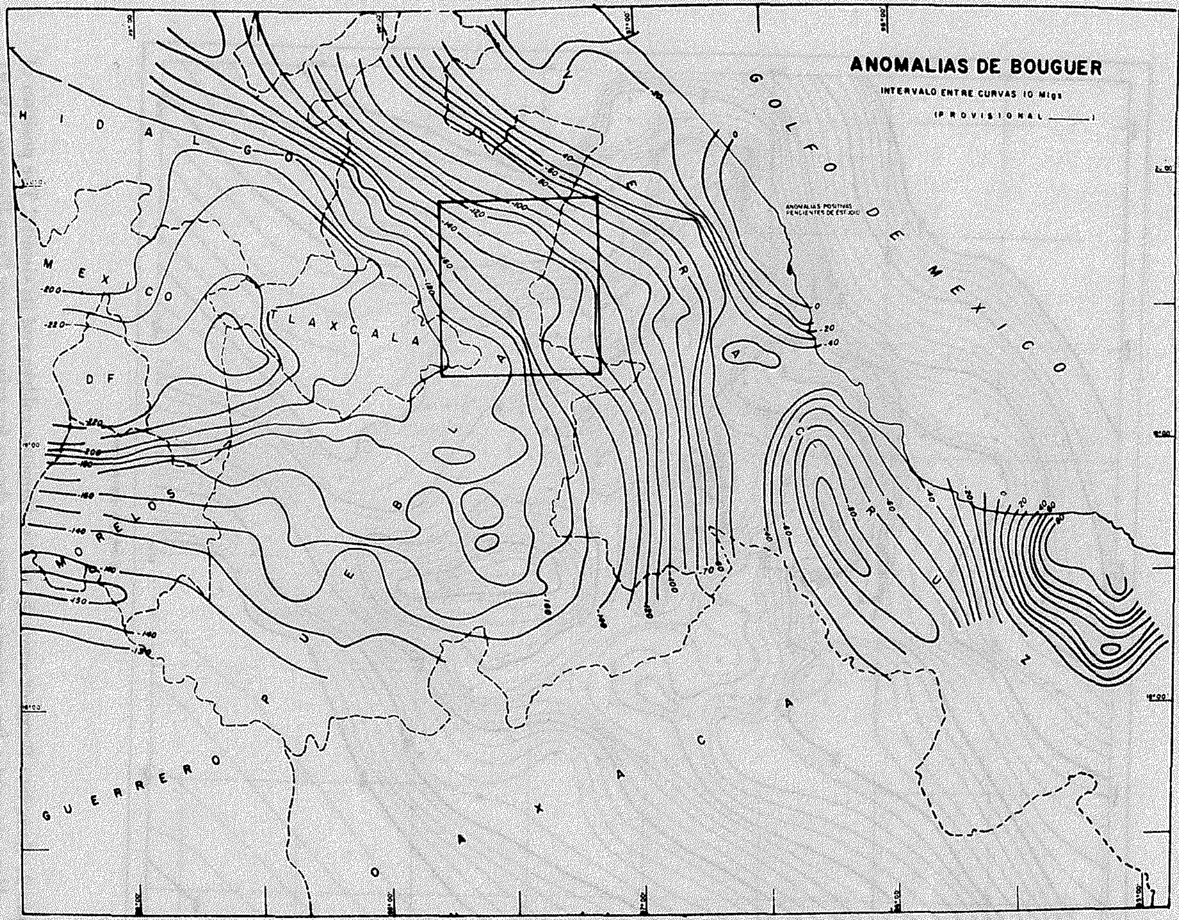


Figure 1. Bouguer anomaly map of the eastern portion of the Transmexican Neovolcanic Axis (after Monges, 1972), showing the NW trend of gravity values that decrease in magnitude in the NE direction as the TNA is approached. The rectangle shows the location of the studied area, detailed gravity surveys are not available at this time in such an area.

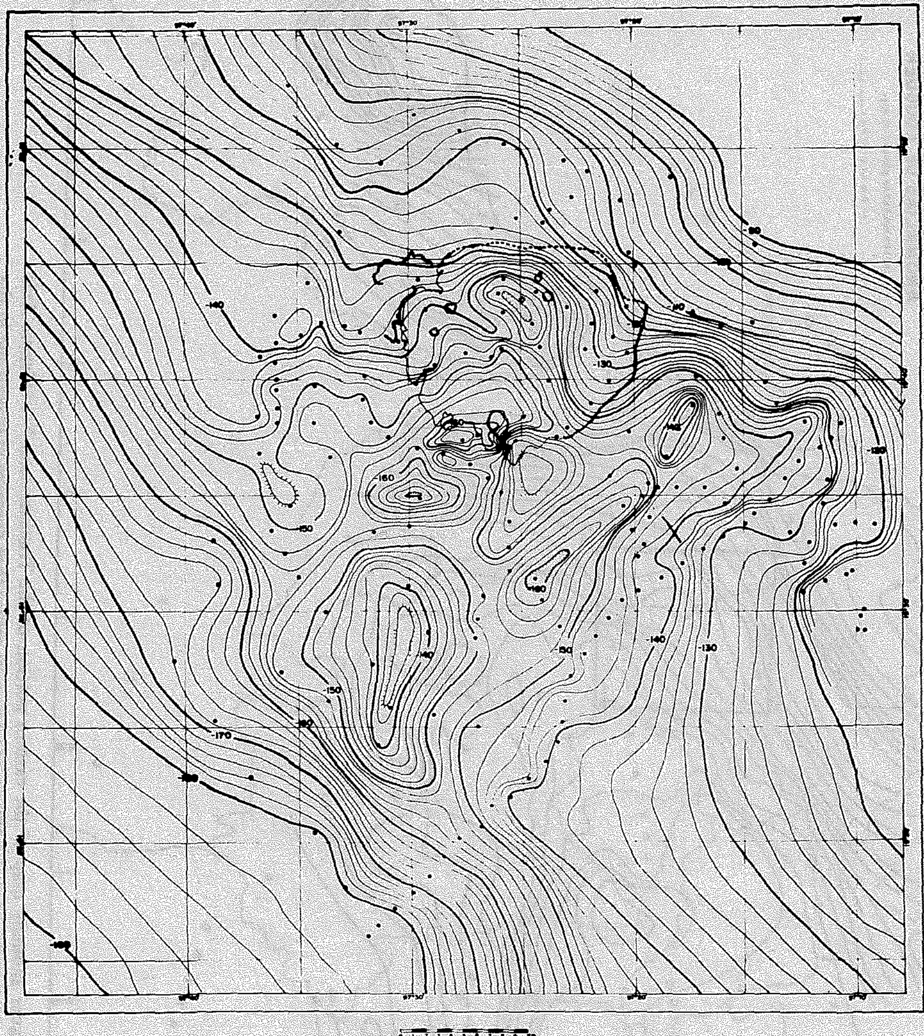


Figure 2. Complete Bouguer anomaly of Los Humeros caldera and its vicinity. The position of the caldera rim and a few volcanic centers are shown for reference (see Pérez-Reynoso, 1979). Gravity values are in mgals.

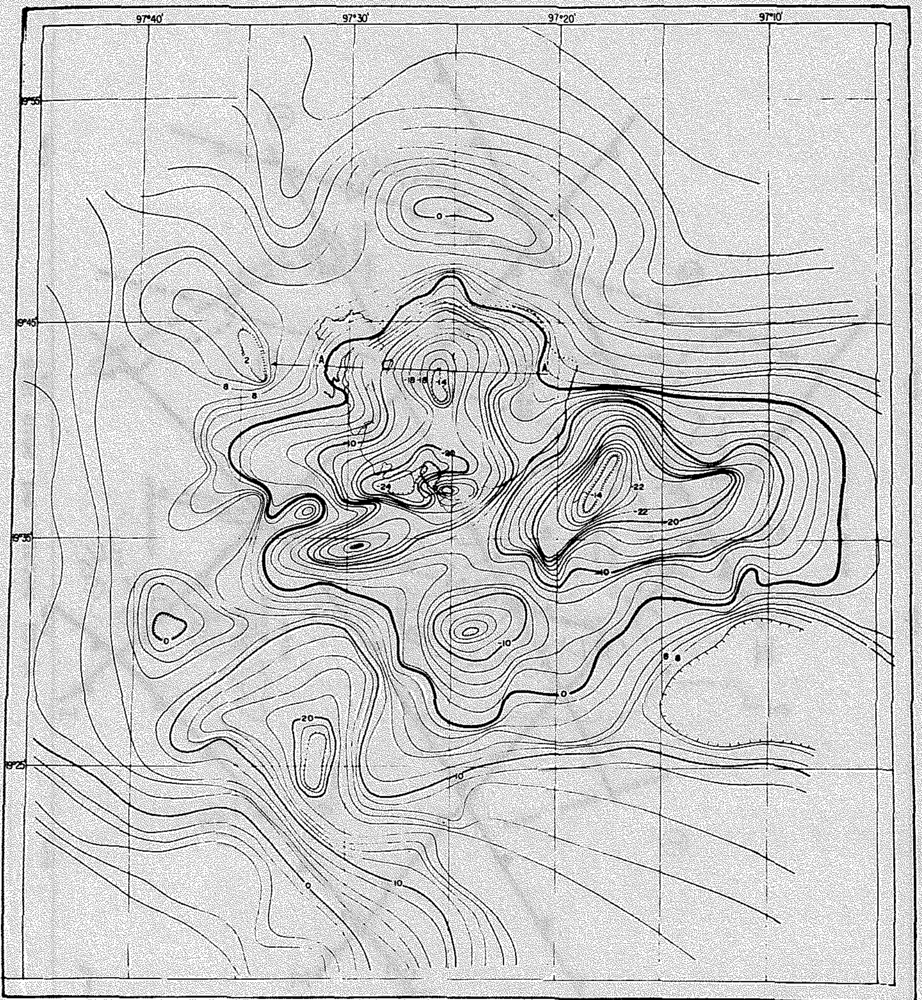
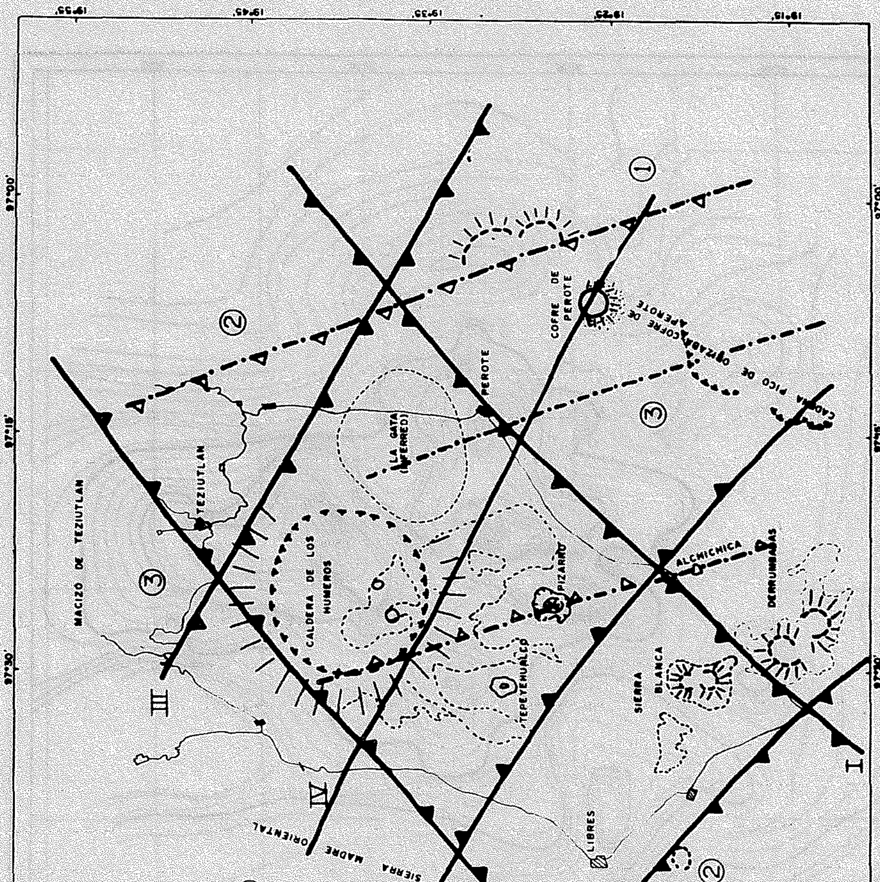


Figure 3. Residual anomaly map of the anomalous area shown in Figure 2. Gravity values are in mgals. Line AA' across Los Humeros caldera corresponds to the modeled cross-section in Figure 5.


AFTER MOOSER and SOTO 1979
MACIZO DE TEZIUTLAN
TEZIUTLAN
CALDERA DE LOS HUMEROS
LA GATA (INFERRED)
PEROTE
COFRE DE PEROTE
PIZARRO
TEPEYEHUALCO
ALCHICHICA
DERRUMBADAS
SIERRA BLANCA
LIBRES
SIERRA MADRE ORIENTAL
I
II
III
IV
V
VI

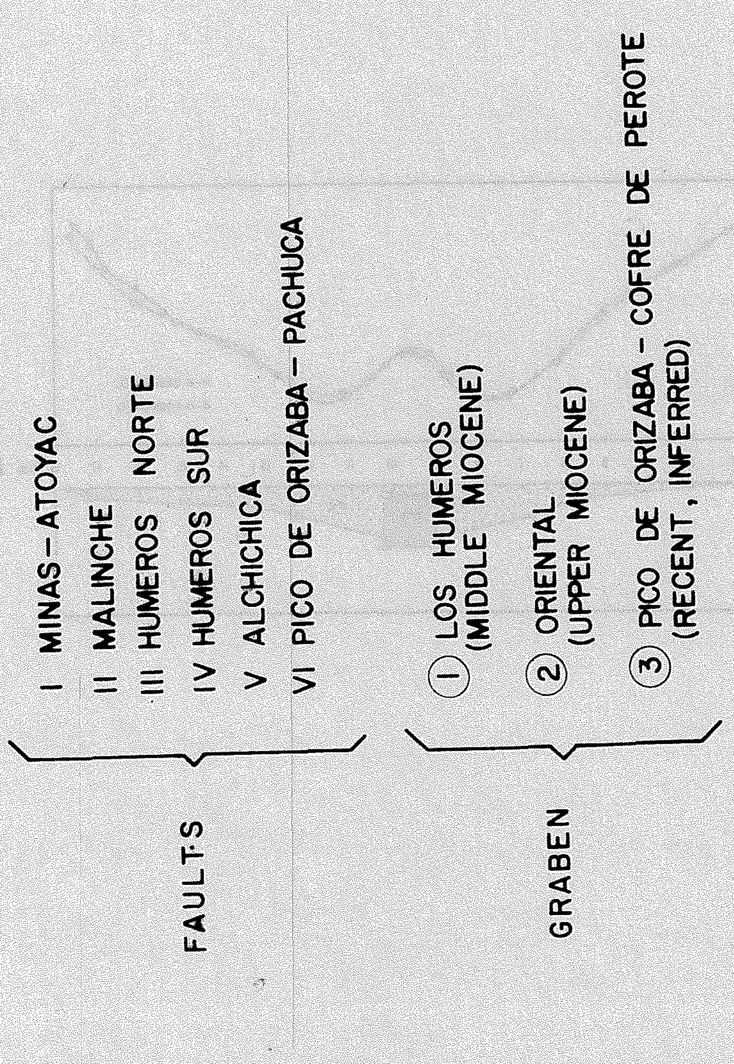


Figure 4. Main tectonic features of the surveyed area (after Mooser and Soto, 1979). Notice the correlation between the residual anomalies in Figure 3 and the faulting and tectonic features shown.

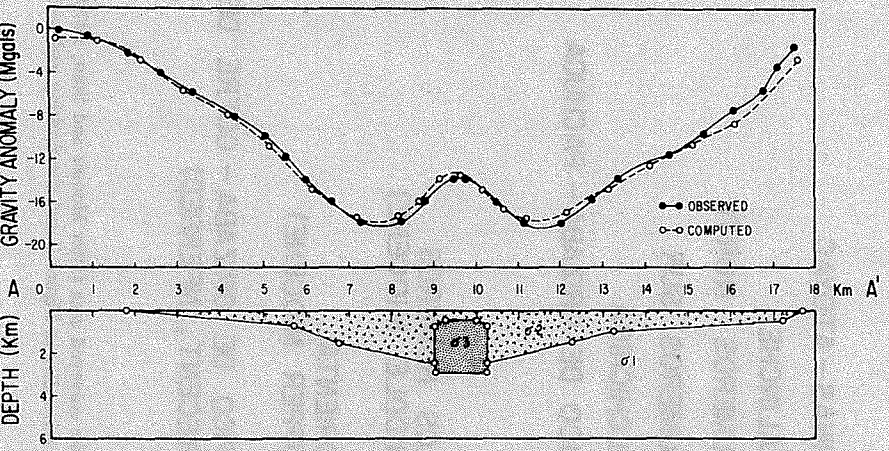


Figure 5. Modeled cross-section along Line AA' in Figure 3. Crosses represent values taken from the residual anomaly map and circles represent computed gravity values. A central body of anomalous density is necessary to fit the observations; most of the caldera volume is filled with pyroclastics.

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