

CIRCULAR 91

Gravity Survey in Central Socorro County, New Mexico

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Abstract

A detailed gravity survey covering parts of the Rio Grande depression and adjacent areas in central Socorro County, New Mexico, is described. Regional and residual Bouguer anomaly maps are presented and qualitative and quantitative interpretations of the results made.

Principal results are that (1) the Rio Grande valley

is a series of linked structural depressions that can be quite asymmetrical in cross section, (2) other structural lows as significant as the Rio Grande depression exist in the region, and (3) recent earthquake activity near Socorro does not originate along the major normal faults bordering the depressions.

Introduction

About one thousand gravity observations have been made in west-central New Mexico. A majority of the gravity stations lie within or adjacent to the Rio Grande structural depression in the vicinity of Socorro and San Antonio, New Mexico. Quadrangles (fifteen-minute) covered in considerable detail by the gravity data include Magdalena, Socorro, San Antonio, and Carthage (fig. 1).

This circular describes the survey and computational procedures, gives regional and residual Bouguer gravity anomaly maps, and presents a structural interpretation of the results. Included also is a brief discussion of the relation between structures as revealed by the gravity data and seismic activity.

The only previous detailed gravity work in the region was by Anderson (1955). His survey consisted of 61 gravity observations across the Rio Grande depression between 34° 05' N. and 34° 10' N. On the basis of assumptions considerably different from those used in this paper, Anderson found the thickness of Cenozoic rocks in the depression to be between the limits of 2100 and 5800 feet. His gravity observations are included in the data presented herewith.

Most of the field and computational work for the gravity survey was carried out by the following undergraduate students at New Mexico Institute of Mining and Technology: Richard Cole, James Hulsey, Edward Jolly, Kenneth Jones, Bob McMillan, Dennis Stanley, and Richard Zbur. I am also indebted to the National Science Foundation, which provided support for this work through the Undergraduate Research Participation Program and through two Research Grants (GP3089 and GA 601).

BASE STATION AND INSTRUMENTS

The base station for the entire gravity survey was U.S. Geological Survey Bench Mark R 222 on the NMIMT campus. The bench mark monument, originally located at the northwest corner of the Research and Development Building, was destroyed during construction of an addition to the building in 1961. However, the outside sidewalk on the north side of the building opposite Room 24 is at the same elevation

(4636.7 feet) and is within a few feet horizontally of the original monument.

Absolute gravity at the base station is 979185.34 milligals. This value was obtained by making two consecutive runs between the NMIMT station and Woollard's gravity base station at the old Albuquerque Airport (Woollard and Rose, 1963, p. 101).

Two Worden gravity meters with instrument constants of 0.0886 and 0.9385 milligal/division were used. About half the survey was done with each instrument.

COMPUTATION OF BOUGUER ANOMALIES

CORRECTIONS

Datum. All computations were made with respect to a sea-level datum.

Elevation corrections. A combined Free-air and Bouguer plate correction of 0.05998 mg/ft was used. The density adopted for the plate correction was 2.667 gms/cm³.

Terrain corrections. To facilitate application of terrain corrections, two contour maps for each quadrangle were prepared. The first map, with values at 25,000-foot spacing, gave the gravitational effect of terrain lying beyond a rectangular area (50,000 feet on a side) surrounding the station. The second map, with values at 5000-foot spacing, gave the gravitational effect of the terrain within the 25 x 10⁸ square foot rectangular area around the station.

Terrain correction values for both maps were obtained by the "mass line method" (Heiskanen and Vening Meinesz, 1958, p. 181): The terrain was approximated by a series of prisms whose square cross sections became smaller nearer the point at which the correction was being determined. (The smallest prism used was 2500 feet on a side.) The vertical component of the gravitational attraction of each prism was computed after collapsing all its mass (density 2.667 gms/cm³) into a line passing vertically through its center.

For a majority of the stations, accurate terrain corrections could be read from the two maps. These values

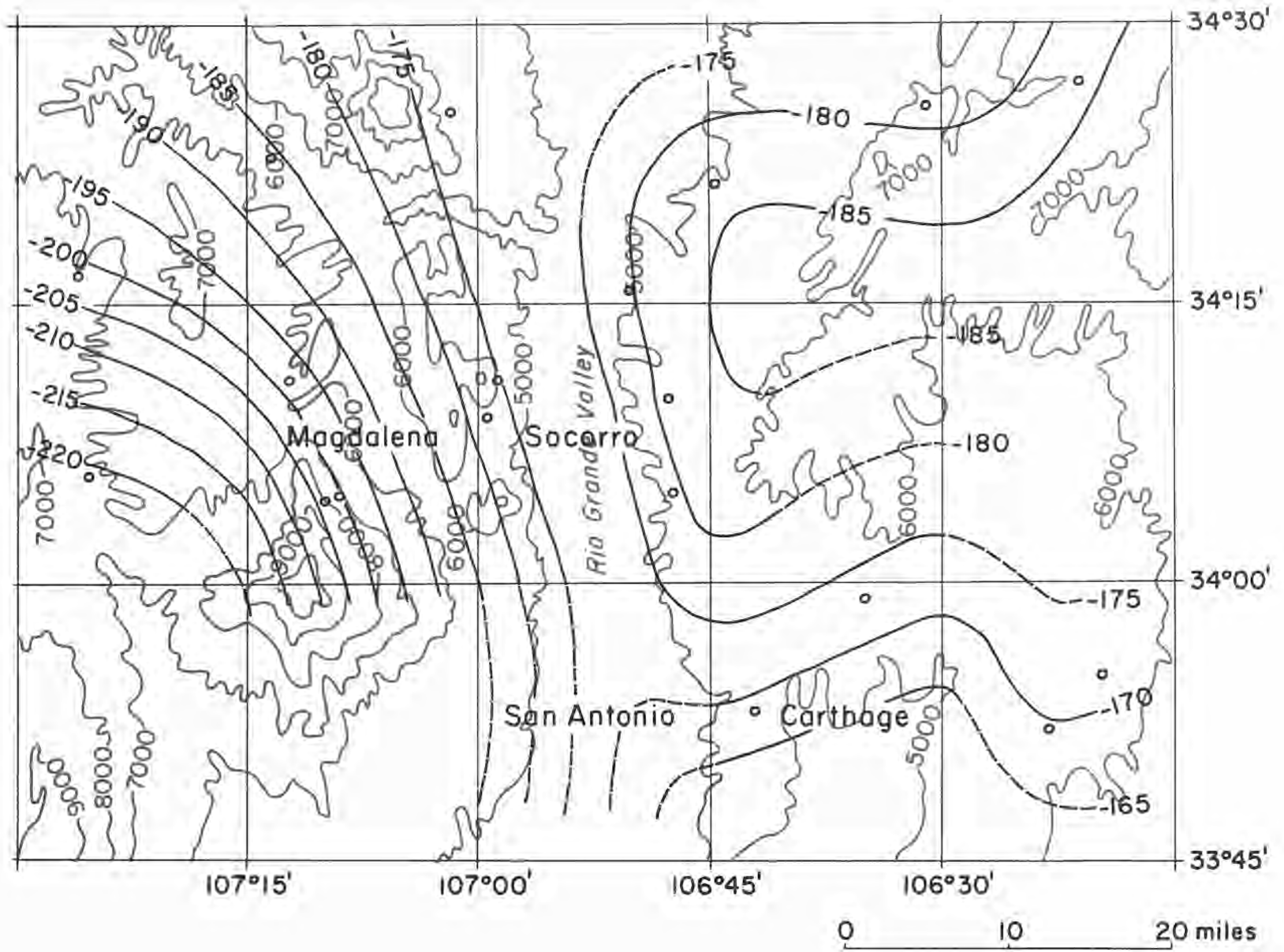


Figure 1
REGIONAL BOUGUER ANOMALIES

ranged from about 0.3 milligal to 4.5 milligals. For mountain top and deep canyon stations, it was necessary to compute terrain corrections for individual stations by the more conventional "Hammer method" (Nettleton, 1940, p. 144-148). Terrain corrections obtained in this manner ranged in value up to 16.9

Theoretical gravity. Theoretical values of gravity at each station were determined somewhat indirectly. First, the theoretical values of gravity and their derivatives (with respect to distance along a meridian) were calculated at 5-minute intervals of latitude using the International Gravity Formula (Landolt—Bornstein, 1952, p. 265). Second, distances of the stations north or south of the nearest reference latitude were measured and multiplied by the derivative of gravity at that latitude. The latter values were added to (if the station was north of the reference latitude) or subtracted from gravity at the reference latitude to obtain theoretical gravity at the individual stations.

ANOMALIES

The gravity anomaly obtained after adding the elevation and terrain corrections and subtracting the theoretical gravity is called the *Bouguer anomaly*. Changes in its value reflect lateral variations in the distribution of mass beneath the surface. Lateral variations in mass can arise from near-surface geologic conditions, such as basins filled with low-density sedimentary rock, or from lateral density variations in deep crustal or subcrustal materials.

In this survey, gravity variations arising from near-surface geologic factors were of principal concern. For this reason, an attempt was made to remove the effect of crustal and subcrustal structure on the gravity maps. This correction is called the "regional correction," as it represents the slowly varying and smooth gravitational effects of deep-seated regional structure.

Regional correction. Figure 1 gives the regional correction map. It is based on 19 Bouguer gravity anomalies (table 1) scattered over an area considerably larger than the region of detailed gravity observations. These particular stations were selected because they lie on or fairly near the Precambrian surface and to some extent are removed from large near-surface structural features. For those stations that did not lie directly on the Precambrian surface, a positive geologic correction was applied (table 1). This correction was based on the idealized sedimentary section presented under *Interpretation*. In addition, some adjustment was made in the contouring of Figure 1 to allow for the effect of the structural Rio Grande depression, which decreases the observed values; therefore, contour values in the vicinity of the trough are slightly higher than the station values.

Figures 2 through 5 show the residual Bouguer gravity maps obtained after subtracting the regional correction. The dark contours (at 1-milligal intervals)

represent that part of the total Bouguer anomaly attributable to near-surface geologic features. The gray contours (at 5-milligal intervals) indicate the regional gravity from Figure 1 and represent that part of the total Bouguer anomaly attributable to regional structure. Values for the total Bouguer anomalies can be obtained from these maps simply by adding the residual and regional values.

INTERPRETATION

REGIONAL BOUGUER ANOMALIES

The most important characteristic of the regional gravity map (fig. 1) is a general correspondence between mean elevation (gray contours) and Bouguer anomalies (black contours). As the average elevation decreases, as it does toward the Rio Grande valley, the Bouguer anomalies become less negative. The relation between elevation and observed gravity anomalies indicates that some form of isostatic compensation exists. Without additional geophysical data, no determination of the mechanism or degree of compensation can be made. However, in view of the relative narrowness of the Rio Grande valley, it is unlikely that this topographic and structural feature could be completely compensated (Heiskanen and Vening Meinesz, 1958, p. 137).

RESIDUAL BOUGUER ANOMALIES

Rio Grande depression. A series of elongate gravity lows extends north-south through the Socorro and San Antonio quadrangles (figs. 3 and 4). These lows are the gravitational expression of the Rio Grande "graben." They indicate that this structural feature is in detail a series of linked structural depressions. Minimum and maximum negative anomalies along the depression are closely related to the topography and structure. Where the valley is relatively broad, as in the northern part of the Socorro quadrangle and the central part of the San Antonio quadrangle, the Bouguer anomalies reach the maximum negative values. Where the valley narrows, as it does just north of Socorro (about 34° 05' N.), the Bouguer anomalies have minimum negative values.

The spacing of gravity contours indicates the shape of the Rio Grande depression. If the spacing is very close, as along some parts of the western margin of the valley in the Socorro quadrangle, the boundary of the depression must be defined by a narrow fault zone with large displacement. On the other hand, the relatively wide contour spacing existing between the lowest gravity areas and the eastern boundary of valley in the Socorro quadrangle probably indicates step faulting with or without some tilting. Thus, on the basis of the gravity contours, the Rio Grande depression in the Socorro quadrangle is quite asymmetrical, being down-dropped more sharply along the western margin than the eastern margin.

TABLE I. GEOLOGIC CORRECTIONS FOR STATIONS
USED FOR REGIONAL BOUGUER ANOMALY MAP

STATION	BOUGUER ANOMALY (milligals)	ESTIMATED DEPTH TO PRECAMBRIAN (feet)	GEOLOGIC CORRECTION (milligals)	CORRECTED BOUGUER ANOMALY (milligals)	REFERENCE
1	-210.1	5500	9.6	-200.5	Tonking (1957)
2	-222.9	1000	1.7	-221.2	Kottlowski (Pers. Com.)
3	-188.7	2000	2.6	-186.1	Foster (Pers. Com.)
4	-197.9	<100	0	-197.9	Foster and Stipp (1961)
5	-203.1	0	0	-203.1	
6	-200.4	0	0	-200.4	
7	-174.1	0	0	-174.1	
8	-180.2	0	0	-180.2	
9	-178.6	0	0	-178.6	
10	-180.3	0	0	-180.3	
11	-184.1	2500	3.5	-180.6	Wilpolt and Wanek (1951)
12	-184.5	2500	3.5	-181.0	Wilpolt and Wanek (1951)
13	-182.9	0	0	-182.9	
14	-178.9	5000	9.6	-169.3	Wilpolt and Wanek (1951)
15	-177.8	3400	4.9	-172.9	Wilpolt and Wanek (1951)
16	-174.5	2900	4.4	-170.1	Wilpolt and Wanek (1951)
17	-175.2	2900	4.4	-170.8	Wilpolt and Wanek (1951)
18	-178.7	0	0	-178.7	
19	-185.1	750	1.5	-183.6	Foster and Stipp (1961)

In the San Antonio quadrangle, the gravity contours do not extend far enough westward to ascertain the general shape of the depression. However, the gravity values to the east suggest step faulting from the lowest part of the depression to the exposures of Triassic and Cretaceous rock near the boundary between the San Antonio and Carthage quadrangles. The obvious surface fault that brings the Triassic and Cretaceous rock into juxtaposition with Tertiary rock (Wilpolt and Wanek, 1951) does not have a large amount of vertical displacement. The gravity values indicate that most of the vertical movement along the eastern side of the Rio Grande depression has taken place along buried faults to the west of this surface feature.

Other structural depressions. Much of the Magdalena quadrangle (fig. 2) is a structural depression. This depression, which the Bouguer anomalies in Figure 2 indicate is nearly as deep as the Rio Grande depression, lies between the Magdalena and the Socorro-Polvadera mountains in a region called Snake Ranch Flats. Inasmuch as the gravity contours are not closely spaced anywhere around the northwest-trending low on the gravity map, the structure probably results from step faulting and possibly tilting over a broad zone from the mountain fronts to near the center of the depression.

Another structural depression of interesting shape is partly defined by the residual Bouguer anomalies on the Carthage quadrangle (fig. 5). This depression, which lies in the northern end of the Jornada del Muerto, is as deep as the Rio Grande depression in the San Antonio quadrangle. From the contour spacing, this basin appears to be bounded by a sharp fault along its western margin. The gravity values appear to indicate that the basin becomes shallower to

the north and the south, which would give the axis of the depression an unexpected east-west orientation. However, it is also possible that the gravity low defined on the map is simply the northern tip of an extensive north-south-trending depression along the entire length of the Jornada del Muerto.

Depth of structural depressions. Estimates of basin thickness were obtained along three gravity profiles: AA' and BB' through the Magdalena and Socorro quadrangles at 34° 7' 30" N. and 34° 2' 30" N., respectively, and CC' crossing the San Antonio and Carthage quadrangles at about 33° 53' N. To calculate depth to Precambrian basement along these profiles, the author had to make several assumptions. Because the credibility of the depths hinges on these assumptions, the procedure followed in making the computations will be explained in detail.

The first step was to compile a pre-Santa Fe Formation geologic section for the basins (fig. 6). The section assembled was based primarily on the lithologies and thicknesses of rocks exposed in the low hills to the east of the Rio Grande valley in the area of the gravity survey (Wilpolt and Wanek, 1951).

The total thickness of this section, 8700 feet from the Precambrian to the base of the Santa Fe, was divided into 1000-foot-thick layers, and the percentages of sandstone, shale, limestone, and volcanics for each layer were determined. These percentages were multiplied by mean densities for each rock type and totaled to obtain the average density of each layer. Densities of rock types as a function of rock age were obtained from our own measurements on 70 rock samples and from data in the literature (principally *Handbook of Physical Constants* (Birch et al., 1942)).

In the interpretation of the gravity profiles, the as-

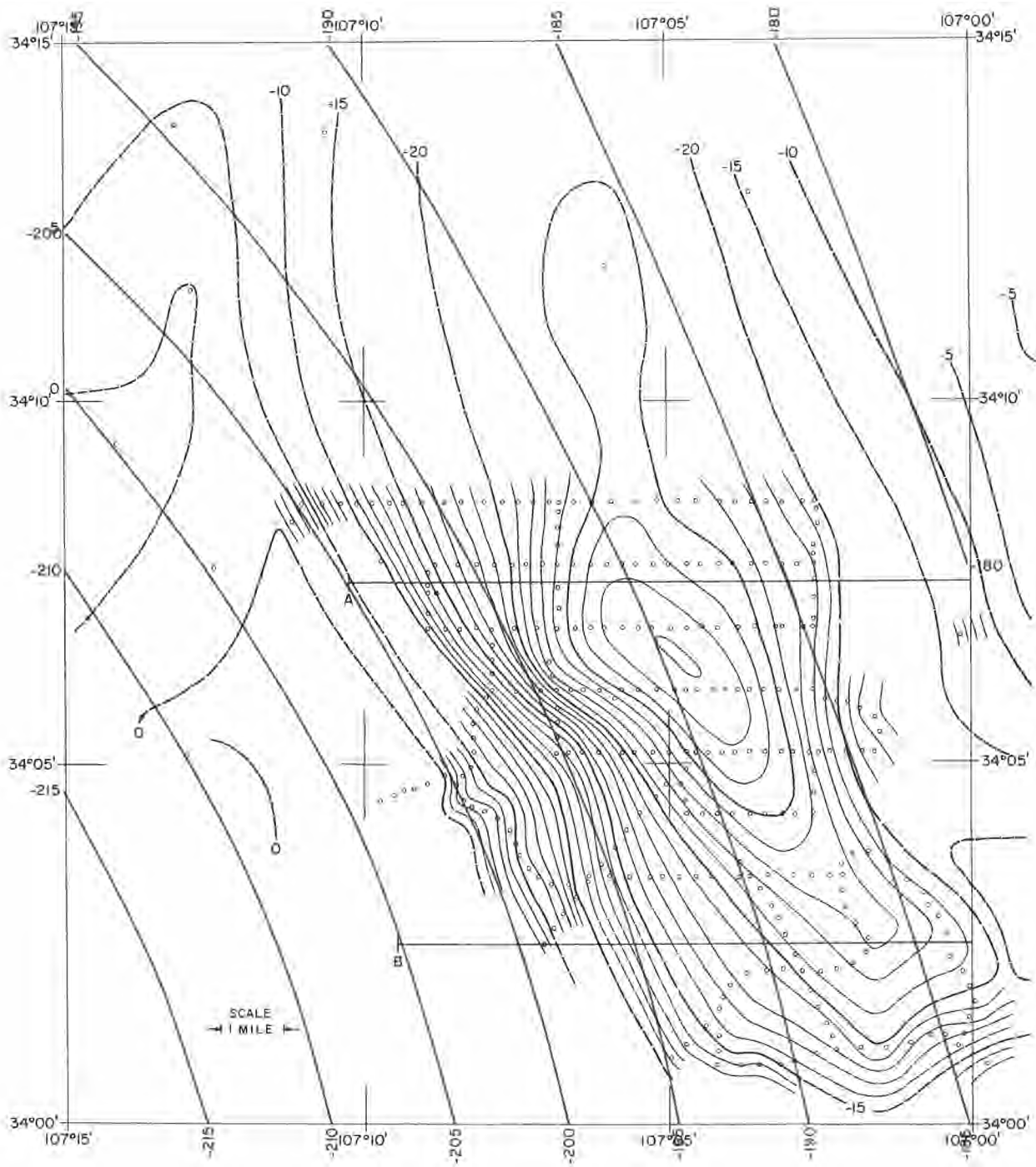


Figure 2
RESIDUAL BOUGUER ANOMALY MAP FOR THE MAGDALENA QUADRANGLE

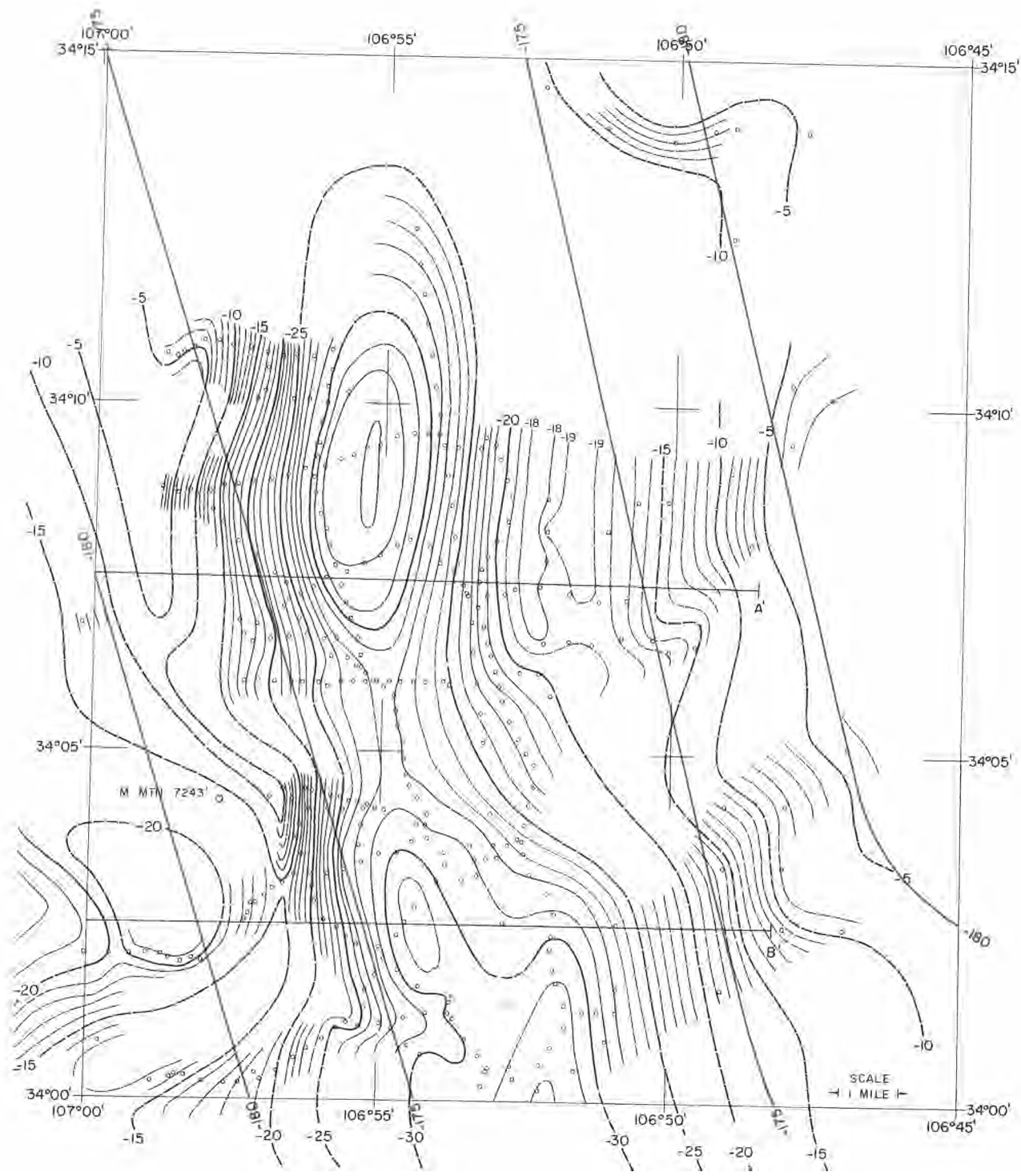


Figure 3
RESIDUAL BOUGUER ANOMOLY MAP FOR THE SOCORRO QUADRANGLE

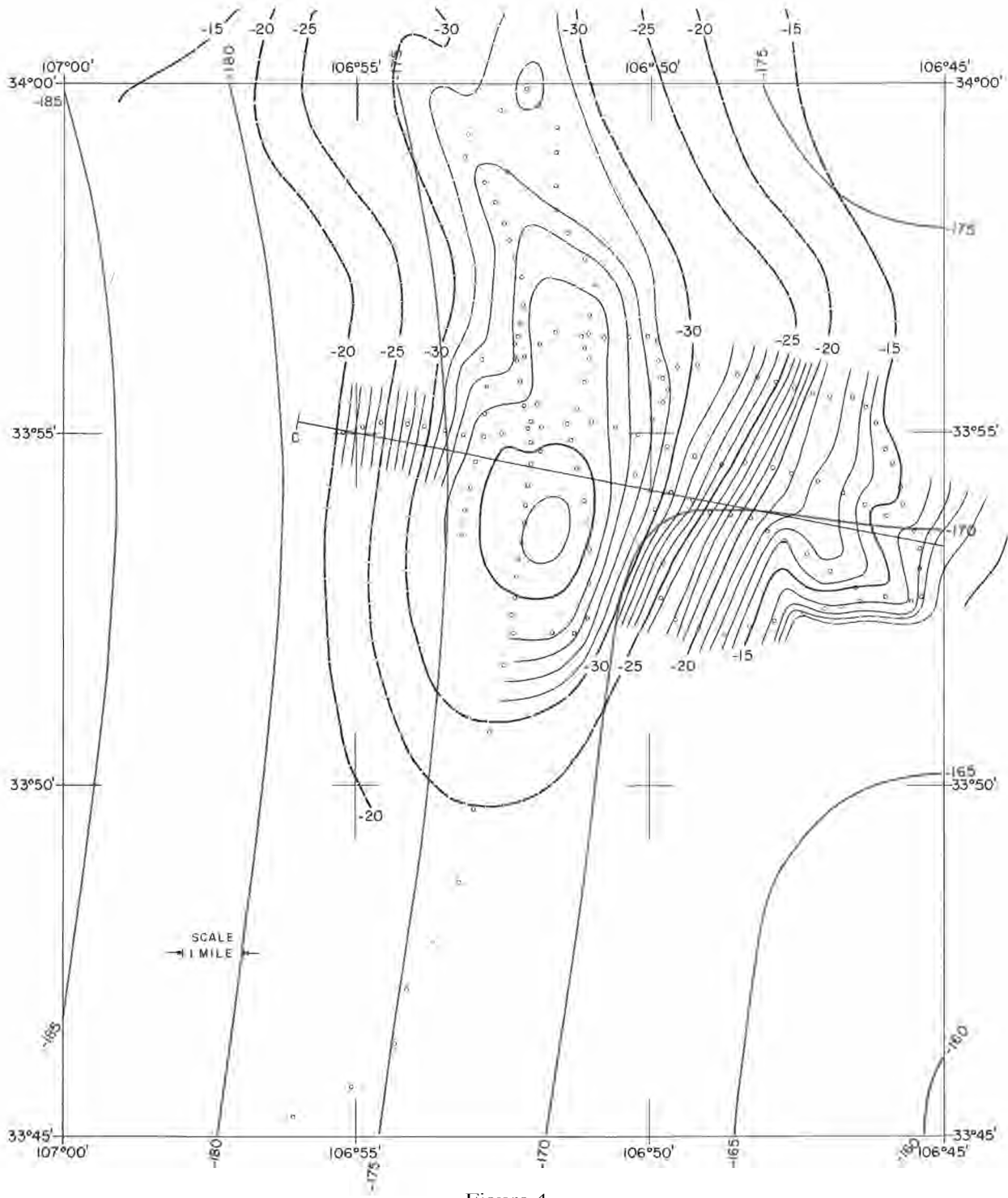


Figure 4
RESIDUAL BOUGUER ANOMALY MAP FOR THE SAN ANTONIO QUADRANGLE

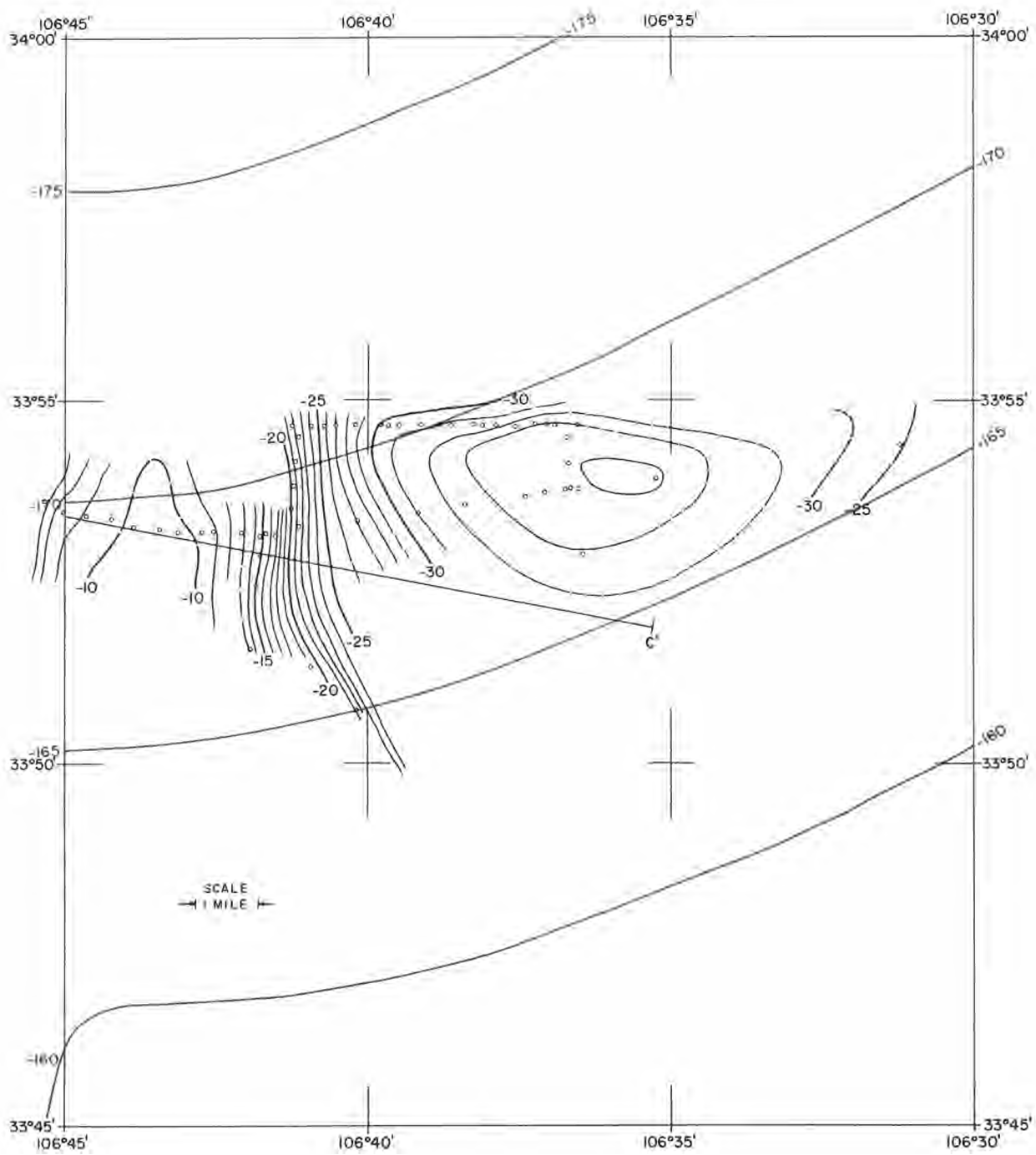


Figure 5
RESIDUAL BOUGUER ANOMALY MAP FOR THE CARTHAGE QUADRANGLE

sumption was made that all structural depressions contained the geologic section given in Figure 6. Whether or not the basins actually contain a rock section similar to the one assumed cannot be definitely established from existing geologic or geophysical data (including the gravity data).

The second step was to construct hypothetical geologic cross sections along the gravity profiles, using the assumed geologic section. Figures 7, 8, and 9 show these highly idealized model sections. All rock units are assumed to be horizontal, a most unlikely situation. Faulted areas are represented by single normal fractures, even when the gravity data indicate multiple step faulting over rather broad zones. These assumptions reduced the labor involved in computing gravity anomalies.

The final step was the computation of the gravity anomalies that would be observed if the structure actually conformed to the model cross sections. In making these computations, all model structures were assumed to be two-dimensional (Nettleton, 1941, p. 117), a good approximation for this area inasmuch as the gravity profiles are nearly normal to axes of the quite elongate basins and mountains. The rock units in the structurally depressed areas were separated into layers each 2000 feet thick and densities were assigned according to the values given in Figure 6. The gravitational value at a prescribed point along the profile involved the summation of the gravitational effects of each layer in each structural depression. The computed anomalies along with the observed anomalies are plotted below the model cross sections in Figures 7, 8, and 9.

At first glance, the comparison between observed and computed anomalies does not appear too good. However, most of the mismatch results from using single rather than multiple faults at the margins of the depressions. For a first approximation, the depths of the basins are quite good. The difference between maximum and minimum gravity values on the computed profiles falls within 4.5 milligals of that observed (the only exception is the Snake Ranch Flats area of Section BB'). In terms of thickness of the Santa Fe Formation, a discrepancy of 4.5 miligals is not large, inasmuch as 1000 feet of Santa Fe Formation (2.20 cgs) is approximately equivalent to 6 milligals. Thus, the first-order fit between observed and computed gravity profiles can be improved by adding or subtracting a few hundred feet of Santa Fe Formation to the structural depressions of the models.

In general, the positions of maxima and minima and the gradients of the computed profiles do not agree with the observed profiles. The most probable explanation is that the faulting along the margins of the basin is much more complex than assumed. For Section AA', the slope of the computed profile directly beneath the faults always exceeds the slope of the observed profile. Slopes of the computed profile could be made to conform with the observed profile by replacing the single fractures with suitably spaced step faults. Step faulting along the eastern margin of the Rio Grande depression in Section CC' would also improve the match between computed and observed anomalies.

Sharp faulting, similar to the idealized representations in the model cross sections, does appear to occur at two places in the survey area, the eastern boundary of the Socorro Mountains (Section BB') and the western margin of the Jornada del Muerto (Section CC'). At those two points, the gradient of the observed profile over the fault exceeds the gradient of the computed profile. Closer agreement could be obtained by increasing the dip of the faults on the model cross sections.

STRUCTURE AND SEISMIC ACTIVITY

A majority of the seismic activity in the region of the gravity survey occurs in the southeastern corner of the Magdalena quadrangle and the adjoining southwestern corner of the Socorro quadrangle (Sanford and Long, 1965). (Some activity has been observed both northward and southward from this region but the rate is much less.) None of the activity appears to originate along the major structural feature of the region, the sharp fault bordering the western margin of the Rio Grande depression (Sections AA' and BB'). Instead, the activity lies westward beneath and along the eastern margin of the Socorro Mountains. A good part of this region is not well covered by gravity observations. However, the limited number of observations available do indicate some type of semicircular structural high surrounding a nearly circular structural low (*see* southwest corner of fig. 3). This rather peculiar structure could be interpreted as a volcanic collapse feature. Such an interpretation would support the hypothesis that the earthquakes are related to recent intrusives in the Socorro Mountains or possibly even to contemporary magmatic action at depth (Sanford, 1963).

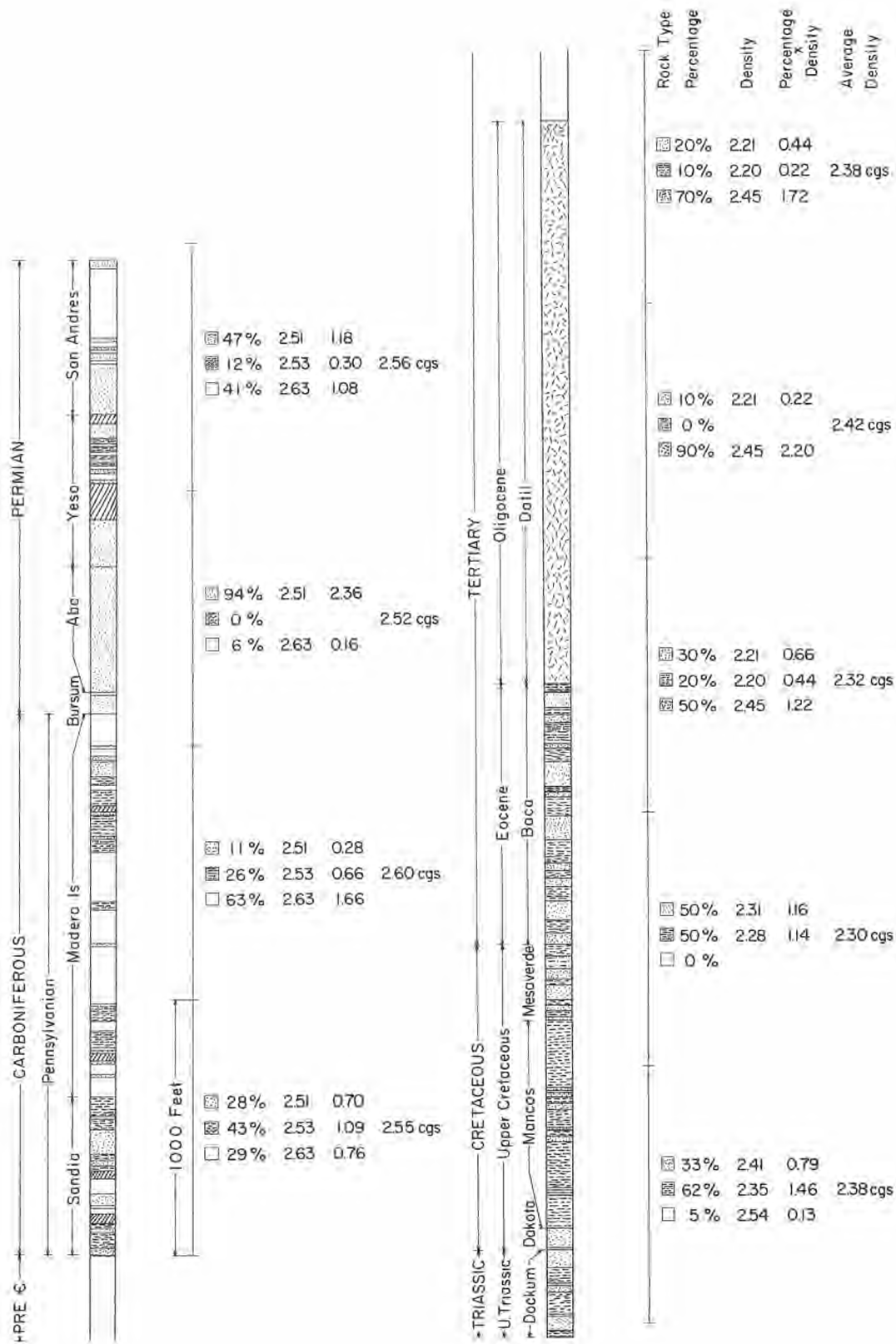


Figure 6
GEOLOGIC COLUMN USED IN GRAVITY INTERPRETATIONS

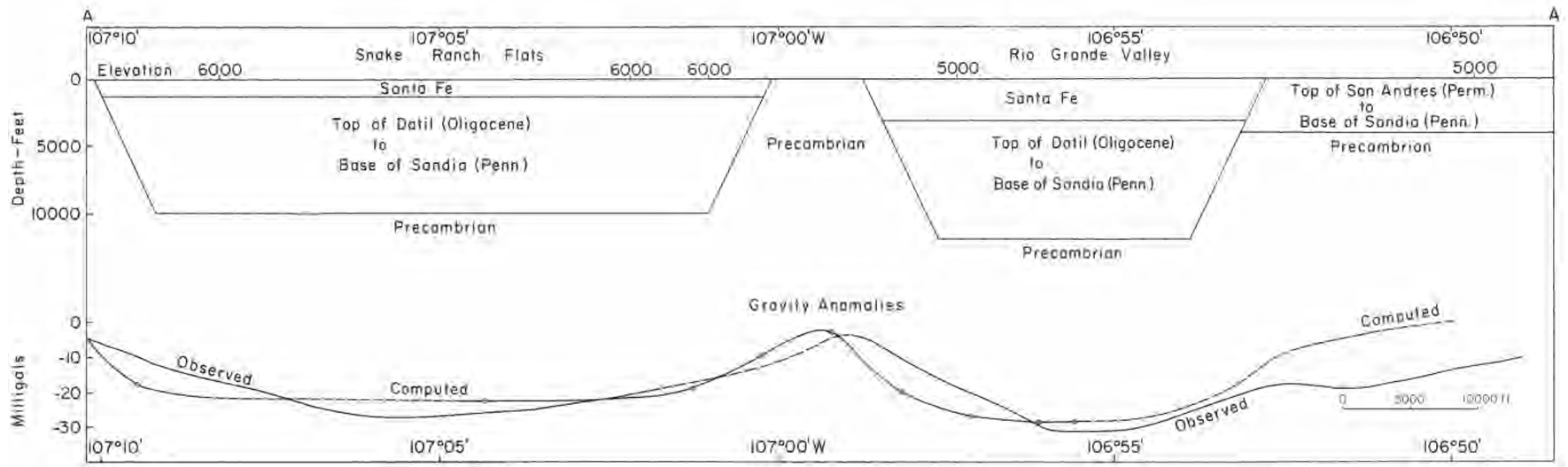


Figure 7
HYPOTHETICAL GEOLOGIC SECTION ALONG PROFILE AA' WITH OBSERVED AND COMPUTED GRAVITY ANOMALIES

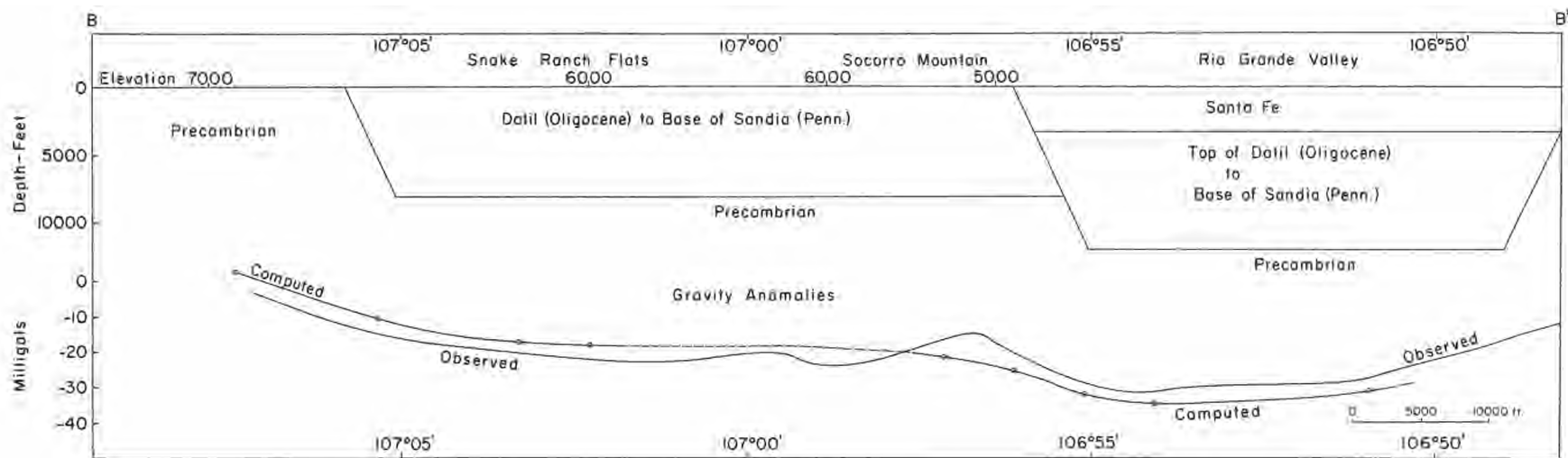


Figure 8
 HYPOTHETICAL GEOLOGIC SECTION ALONG PROFILE BB' WITH OBSERVED AND COMPUTED GRAVITY ANOMALIES

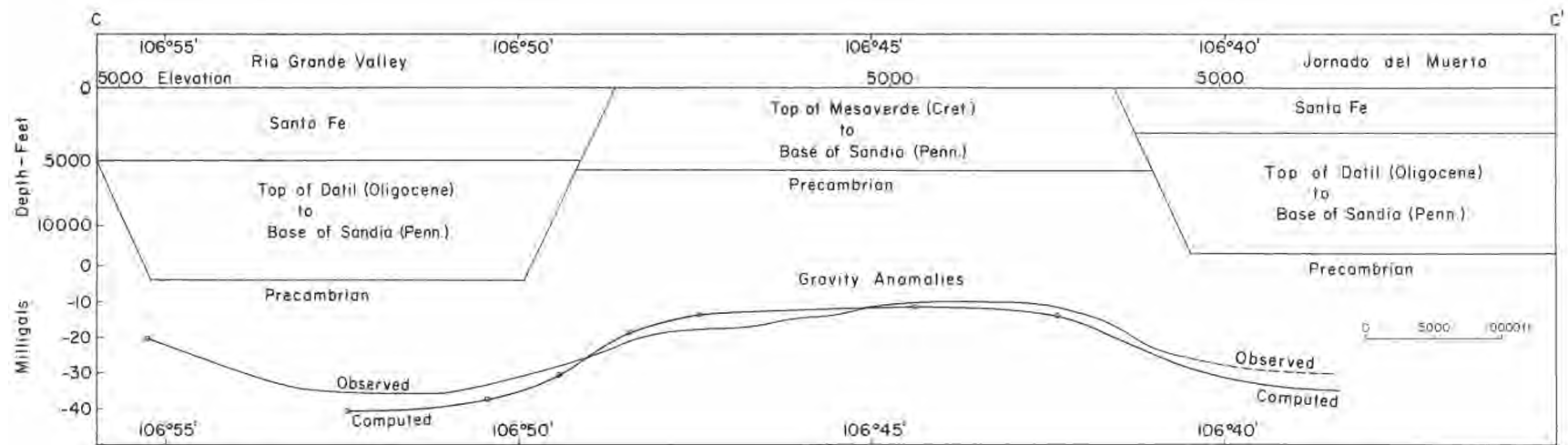


Figure 9
HYPOTHETICAL GEOLOGIC SECTION ALONG PROFILE CC' WITH OBSERVED AND COMPUTED GRAVITY ANOMALIES

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