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SIGNIFICANCE OF GEOTHERMAL AND GRAVITY STUDIES IN THE LAS CRUCES AREA

by

E. R. DECKER, F. A. COOK, I. B. RAMBERG,[1] and S. B. SMITHSON
Department of Geology
University of Wyoming
Laramie, Wyoming 82071

INTRODUCTION

The Las Cruces area in the middle of the southern Rio Grande rift (Fig. 1), as defined by Chapin (1971), exhibits several important geophysical features attributed to late Cenozoic rifting. These features are: 1) a geothermal high between Orogrande and Cookes Peak (Decker and Smithson, 1975), 2) large negative gravity anomalies over the Cenozoic basins of the rift, 3) gravity isoanomaly trends oblique to the rift (Ramberg and Smithson, 1975) and 4) a positive gravity anomaly that occurs along the axis of the rift just east of Las Cruces. This report will summarize description and interpretation of the heat flow and gravity data.

In such a brief account as this, discussion will be restricted to outstanding features and implications of the geophysical data. Emphasis is therefore placed on syntheses of results. For example, combined heat flow and radioactivity data are summarized on a map and two profiles, while gravity anomalies based on contours determined from measurements at about 4,000 stations are illustrated by a regional map and a single profile. The University of Wyoming's geothermal and gravity data are also discussed in two recent reports (Decker and Smithson, 1975; Ramberg and Smithson, 1975) and readers are referred to those papers for details concerning reduction and reliability of these measurements.

The areas of investigation are shown in Figure 1. The boundaries of the Basin and Range province, the High Plains, and the Colorado Plateau are taken from the map of Fenneman (1946). The outline of the Rio Grande rift follows the definition given by Chapin (1971) rather than that given by Kelley (1952, 1956).

Throughout the text the units of density (ρ) are gm/cm^3, the acceleration due to the gravity is in mgal., and the units of heat flow are abbreviated to HFU, where 1.0 HFU = 1.0 x 10^{-6} cal/cm^2 sec. The term "unreduced" is associated with the heat flow obtained after corrections for steady-state terrain and, if needed, complex geologic structure. The "reduced" heat flow refers to the flux obtained after the unreduced value was reduced for the heat from local bedrock radioactivity according to procedures given by Roy and others (1972) and Decker and Smithson (1975). Also, ranges of unreduced and reduced flux are shown for those sites at which corrections for complexities in local geology were applied.

HEAT FLOW AND RADIOACTIVITY DATA

Presently available heat flow and bedrock radiogenic heat production data in southern New Mexico and west Texas are shown in Figure 2. Summaries of the geothermal and crustal thickness data near lines A'A and A"A in the figure are shown in Figure 3. Data are after Decker (1969), Herrin and Clark (1956), Roy and others (1968), Warren and others (1969), and Decker and Smithson (1975). If the 2.0 to 1.1 HFU change of unreduced flux from Cornudas to Carlsbad is neglected, a striking feature of the map and profiles is the region of very high unreduced heat flow (2.4-3.6 HFU) defined by the measurements from Orogrande to Hachita. On the basis of the terrain-corrected data at these sites, the reduced flux in this anomalous zone ranges from 2.0 to 3.4 HFU. The reduced flux in this area would range from 1.8 to 3.4 HFU, after corrections for refraction at sites near Organ and Orogrande. West and north of these points, the data at Lordsburg, Santa Rita, and Tyrone confirm typical Basin and Range unreduced heat flows of 1.6 to 1.8 HFU, and significantly lower reduced values in the range 1.4-1.5 HFU. The data at Shafter, Texas also indicate significantly lower unreduced and reduced flux (1.5 and 1.2 HFU, respectively) in the Basin and Range south and east of Orogrande.

As is evident in Figures 2 and 3, the sites in the anomalous

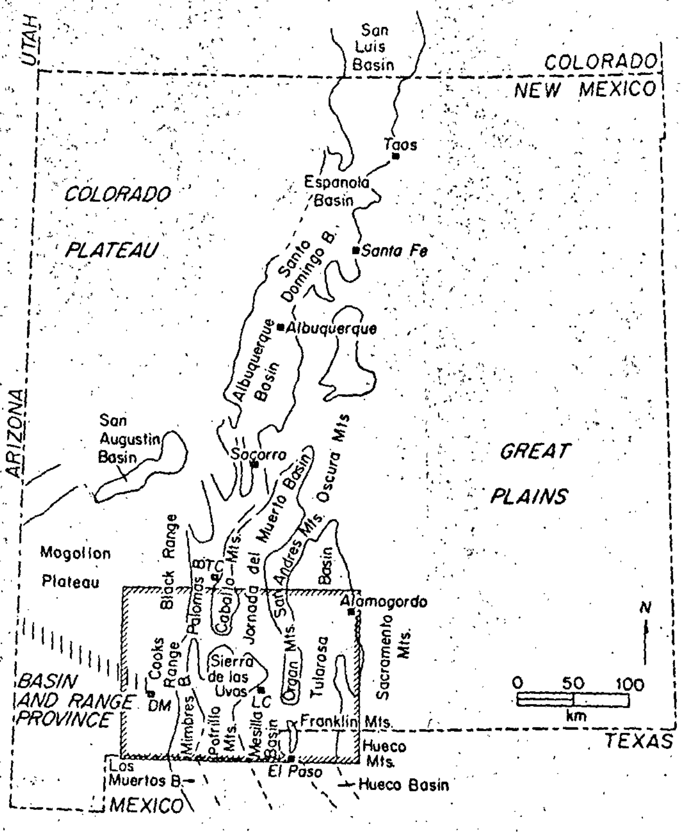

Figure 1. Location map showing major features of Rio Grande rift in south-central New Mexico (after Chapin, 1971). Area investigated by gravity outlined by rectangle. Dashed area in southwest is border between Basin and Range province and Mogollon Plateau.

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[1] Present address: Institutt for Geologi, University of Oslo, Oslo 3, Norway.

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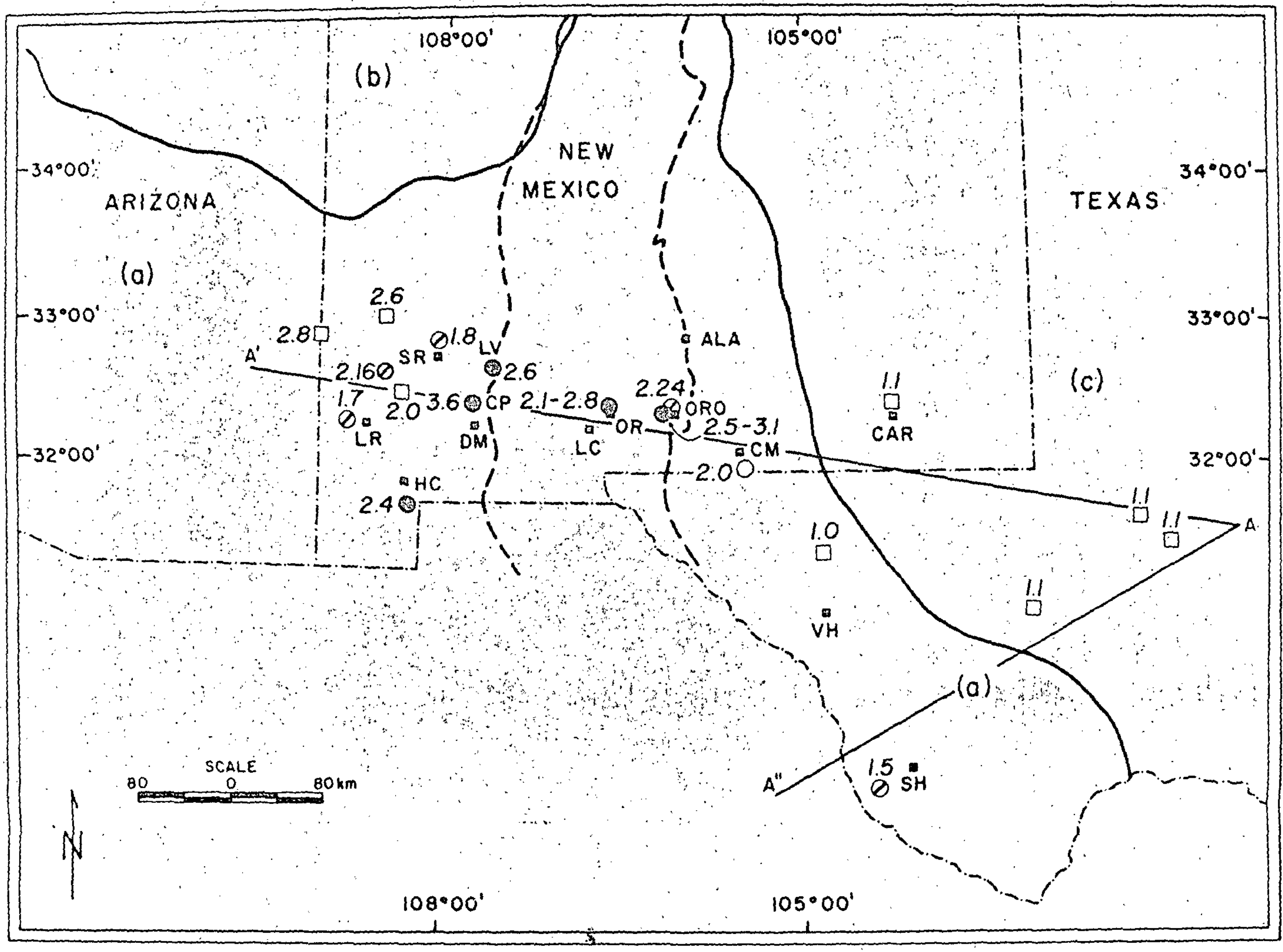

Figure 2. Heat flow in southern New Mexico and west Texas. Unreduced heat flow values shown next to each locality; see text for references. Units are HFU. Open squares represent localities where there are unreduced heat flow values only; shaded circles locate sites where reduced values are in the range 1.2-1.5 HFU; and solid circles locate sites where reduced values are in the range 1.8-3.4 HFU. Lines A'A and A"A show locations of profiles in Figure 3. Physiographic provinces after Fenneman (1946): (a) Basin and Range; (b) Colorado Plateau; and (c) High Plains. The dashed line outlines the Rio Grande rift as defined by Chapin (1971). Abbreviations for localities: ALA-Alamogordo; CAR-Carlsbad; CP-Cookes Peak; CM-Cornudas Mtn; DM-Deming; HC-Hachita; LC-Las Cruces; LR-Lordsburg; LV-Lake Valley; OR-Organ; ORO-Orogrande; and SR-Santa Rita; SH-Shafter; and VH-Van Horn.

region bounded by Orogrande and Hachita are in or near the Rio Grande rift as defined by Chapin (1971). Based on the refraction-corrected data at Organ and Orogrande, and the data at Lake Valley and Hachita, the reduced heat flow in the rift area is +0.4 to +0.7 HFU higher than the values in bordering portions of the Basin and Range. Relative to the High Plains, the reduced anomaly in the rift area ranges from +1.0 to +1.7 HFU, if the 1.0 to 1.1 HFU observed values in the Plains are taken to imply a reduced heat flow of 0.8 HFU. The reduced heat flow anomaly in the rift area near Cookes Peak would be 2.0 and 2.6 HFU, respectively, relative to the Basin and Range and High Plains.

TEMPERATURES AND HEAT SOURCES BENEATH THE RIO GRANDE RIFT

Roy and others (1972) have shown that the combination of high unreduced and reduced flux (2.0 and 1.4 HFU, respectively) in the Basin and Range province is consistent with equilibrium temperatures at or near melting at 50 to 70 km depths in the upper mantle (see, also, Warren and others, 1969; Lachenbruch, 1970). Because the Rio Grande rift area in southern New Mexico appears to be characterized by higher unreduced and reduced heat flow (2.4-3.6 and $\geq$ 1.8 HFU, respectively), zones of melting could occur at shallower depths in the upper mantle. This is evident from the equilibrium temperature profiles plotted in Figure 4; in particular, the profiles calculated by using a 1.8 HFU mantle flux in the rift lead to 1,100 to 1,300°C temperatures at depths of 30 to 45 km and imply extensive partial melting in the lower crust and upper mantle. Higher upper-mantle temperatures in the rift are consistent with an upwarping of higher electrical conductivity in the mantle between Las Cruces and Cornudas, New Mexico based on long-period transient magnetic variation studies (Schmucker, 1964, 1970). The widespread occurrence of late Tertiary basaltic volcanism in the rift area (Dane and Bachman, 1965; Kottlowski and others, 1969) also implies very high upper-mantle temperatures, as may an upwarping of electrical conductivity in the mantle in the Deming, New Mexico

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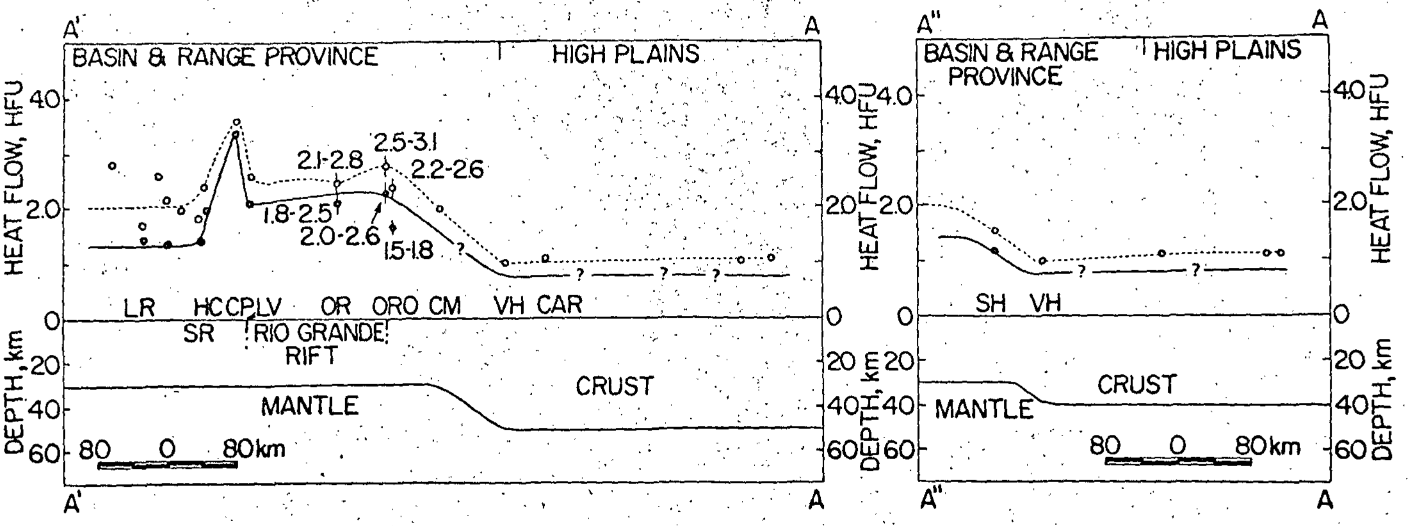

Figure 3. Summary of geothermal and crustal thickness data along two profiles in southern New Mexico and west Texas (see lines A'A and A"A in Figure 2). The open circles are unreduced heat flow values and the solid circles are reduced heat flow values. Abbreviations for localities given in Figure 2. See text for references.

area inferred from magneto-telluric studies (Madden and Swift, 1969).

The profiles in Figure 4 were calculated by using steady heat sources in the lower crust and upper mantle to explain increased flux in the rift. However, because the rift is an area of late Tertiary volcanism and extensional tectonics (Kelley and Silver, 1952), another interpretation is that part of the excess flux could be due to the transient effects of fairly recent crustal intrusions or penetrative convection in the lower crust and upper mantle. The use of models based on the transient effects of young intrusions or penetrative convection also might reduce possibilities for large amounts of crustal anatexis. For example, Roy and Blackwell (1966) postulated cyclic disturbances (+300°C) at the crust-mantle boundary to explain high flux in the Basin and Range, without implying extensive melting of the lower crust. Sass and others (1971) also infer that the combination of Quaternary volcanism and very high unreduced flux (2.1-3.8 HFU) near Battle Mountain, Nevada is consistent with transient heat sources in the crust in this portion of the Great Basin.

Whether steady or transient thermal models are used to explain excess flux in the rift area, the sources responsible for the anomaly must be in the crust or upper mantle because of the narrow widths of the transitions to lower flux in the Basin and Range. Two good examples are the 60 to 70 km wide transitions from 1.4 reduced flux at Santa Rita to 2.1 and 3.4 reduced values at Lake Valley and Cookes Peak, respectively (Fig. 2). From Cornudas, with unreduced flux of 2.0 HFU, to Orogrande, with 2.5 to 3.1 HFU, the lateral distance is about 90 km (Figs. 2 and 3). Unless future research demonstrates that greater thicknesses or higher values of bedrock radioactivity occur in the rift, models that employ the transient effects of recent crustal and upper mantle may be needed to account for the sharp boundaries of the anomaly. But the abrupt heat flow transitions would not, by themselves, imply the presence of transient heat sources as does the combination of unusually high flux and late Tertiary volcanism and extensional tectonics in the rift.

GRAVITY ANOMALIES

Figure 5 shows a Bouguer gravity anomaly map of the hatched area in Figure 1. Contours are based on gravity measurements at about 4,000 stations, of which 2,300 were measured by the authors. Simple Bouguer gravity anomalies were calculated by using a density of 2.67 g/cm^3 for the near-surface units. Terrain corrections have not been applied to the contoured data because they are less than 0.2 mgal at most of the stations, and would not significantly change the Bouguer anomaly values.

The Bouguer gravity anomaly map (Fig. 5) is characterized by a complex pattern of gravity lows and highs. The maximum amplitude of the lows and highs is 50 mgal, and most occur over Cenozoic basins and intervening ranges, respectively. Although some major anomalies (e.g., the San Andres Mountains) trend north-south and coincide with major structural trends on the geologic map of Dane and Bachman (1965), close examination of the map reveals that the iso-anomaly lines trend obliquely to the northwest and northeast (Fig. 5). The most pronounced Bouguer gravity high in the Rio Grande rift area occurs in the Franklin and San Andres Mountains. This anomaly occurs along a north-south zone and ranges from 20 to 30 mgal.

A gravity profile from Artesia through Las Cruces to Lordsburg along 32°40′ N. latitude is shown in Figure 6. This profile illustrates the small change of Bouguer gravity (20 to 30 mgal) from the High Plains to the Basin and Range province. For example, the anomalies decrease from −150 mgal southwest of Artesia on the east to −180 mgal at Lordsburg on the west (Fig. 6). The most positive Bouguer gravity in the Rio Grande rift is −125 mgal in the Franklin Mountains (Fig. 5).

GRAVITY INTERPRETATIONS

Because a given gravity anomaly may be explained analytically by an infinite number of models with different distributions of mass at depth, it is often desirable to apply other constraints to obtain the most reasonable interpretations. Con-

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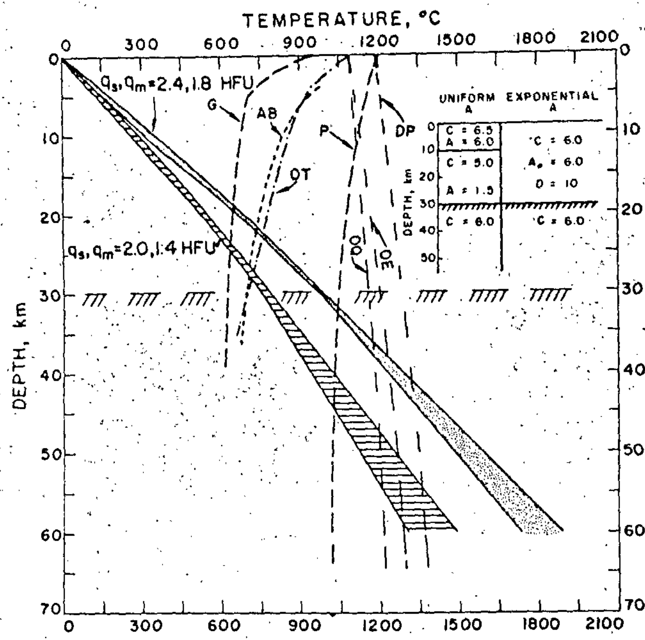

Figure 4. Equilibrium temperatures as functions of depth beneath the Rio Grande rift and Basin and Range province. Temperatures calculated for models with crustal layers with uniform radioactivity and crustal radioactivity that decreases with depth according to $A(x) = A_o e^{-x/D}$ where x is depth, Ao is heat production at x=0, and D is the logarithmic decrement. Horizontally-lined area represents the range of temperatures calculated using uniform (lower bound) and exponentially decreasing (upper bound) crustal radioactivity for most of the Basin and Range; surface flux (qs) is 2.0 HFU and the mantle flux (qm) is 1.4 HFU. Dotted area represents the range of temperatures calculated using exactly similar crustal models for the southern Rio Grande rift; qs = 2.4 HFU and qm = 1.8 HFU. Base of the crust is indicated by hatching. Solidus curves in presence of excess water after Wyllie (1971); Lambert and Wyllie (1972) and Yoder and Tilley (1962); G-granodiorite; P-periodotite; AB-alkaline basalt; and OT-olivine tholeiite. Dry solidus curves after Lambert and Wyllie (1972): OQ-olivine tholeiite to quartz eclogite at high pressures; OE-olivine tholeiite to olivine eclogite at high pressures; DP-peridotite. The dry peridotite curves are the upper boundary of all peridotite curves summarized by Lambert and Wyllie (1972). C is thermal conductivity in 10^{-3} cal/cm sec°C. A is radiogenic heat production in 10^{13} cal/cm^3 sec. Modified from Figure 5 in Decker and Smithson (1975).

straints that may be applied to restrict the number of possible gravity interpretations include local geology, isostasy, and seismic data. For the southern New Mexico-west Texas area, any possible interpretations must also be plausible in light of the geothermal data.

Free-air anomalies change with topography and average −9 mgal across southern New Mexico (Decker and Smithson, 1975). Free-air gravity anomalies whose mean is near zero indicate that an area is in isostatic equilibrium. We can, therefore, use isostasy (equal pressure at some depth) as a constraint in our modeling. This constraint will have major implications regarding the nature of the upper mantle in the Basin and Range province and Rio Grande rift.

Seismic refraction studies show that the crust thins from about 50 km in southeastern New Mexico (Stewart and Pakiser, 1962) to 30 to 35 km in southwestern New Mexico (Stuart and others, 1964). In addition, a single low P_n velocity of 7.9 km/sec is reported for southwestern New Mexico (Stuart and others, 1964) and normal P_n velocity of 8.1 km/sec. is found in southeastern New Mexico under the High Plains (Stewart and Pakiser, 1962). These data provide major constraints for gravity modeling of deep structure. Velocities are converted to densities by means of data of Birch (1960, 1961) and Drake (in Grant and West, 1965, p. 200).

Densities for near surface sediments and crystalline rocks have been determined from our own measurements and published data (Mattick, 1967; Sanford, 1968). Compared to the crystalline rocks with density of 2.67 g/cm^3, we use density contrasts of −0.1 g/cm^3 for Paleozoic sediments, −0.27 g/cm^3 for Mesozoic sedimentary rocks, and −0.50 for Cenozoic sedimentary rocks. The crust is assumed to be differentiated into two layers with densities of 2.74 g/cm^3 (Woollard, 1969; Smithson, 1971) and 2.94 g/cm^3. Thus the average density of the crust is 2.84 g/cm^3 (Worzel and Shurbet, 1955).

Geologic contacts, borehole data, and seismic and other geophysical data are incorporated into the model for shallow Basin and Range structure along the profile AA′ (Fig. 6a). The model accounts for the alternating Bouguer lows and highs by using near-surface contrasts between low density sediments in Cenozoic grabens juxtaposed against denser basement rocks in the intervening horsts. The two deepest basins are the Tularosa and Mesilla basins with depths of 4 km and 5 km, respectively. Irregular gravity anomalies over these basins also imply that each basin consists of several fault blocks of "steps" as is suggested by the geologic map in the Tularosa Basin (Dane and Bachman, 1965).

Gravity highs and lows produced by shallow density contrasts associated with horst and graben structure in the Basin and Range mask the gravity effect of deeper structure. In order to circumvent this problem, the gravity effect of the sedimentary basins has been removed by "stripping." The gravity anomalies have been plotted by adding an appropriate amount to counteract the negative gravity effect of sediments in basins. This procedure is only as good as estimates of basin density and thickness but with reasonable data should provide a plausible approximation of the gravity field after removal of near surface gravity effects. The Bouguer anomaly field after stripping shows a broad high centered on the San Andres Mountains gravity high along the Rio Grande rift (Fig. 6).

The gravity model for deep structure across the High Plains-Basin and Range transition involves an east-to-west decrease of crustal thickness from 50 km to 30 km, coupled with a lower density upper mantle beneath the Basin and Range (Fig. 6). If lower density upper mantle were not present under the Basin and Range, Bouguer gravity anomalies would increase by about 200 mgal from the High Plains to the Basin and Range. In addition, isostatic balance between crustal sections in the High Plains and Basin and Range, abnormally high heat-flow, and low upper mantle velocities all require hot, low-density upper mantle under the Basin and Range.

Our gravity model for deep structure (Fig. 6), therefore, incorporates a large body or "pillow" of low density upper mantle under the Basin and Range. The positive gravity anomaly over the Rio Grande rift and isostasy require that dense mafic rocks be present under the rift. As alternate interpretations we present the following: 1) an upwarp in the upper

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Rio Grande Tectonic Map
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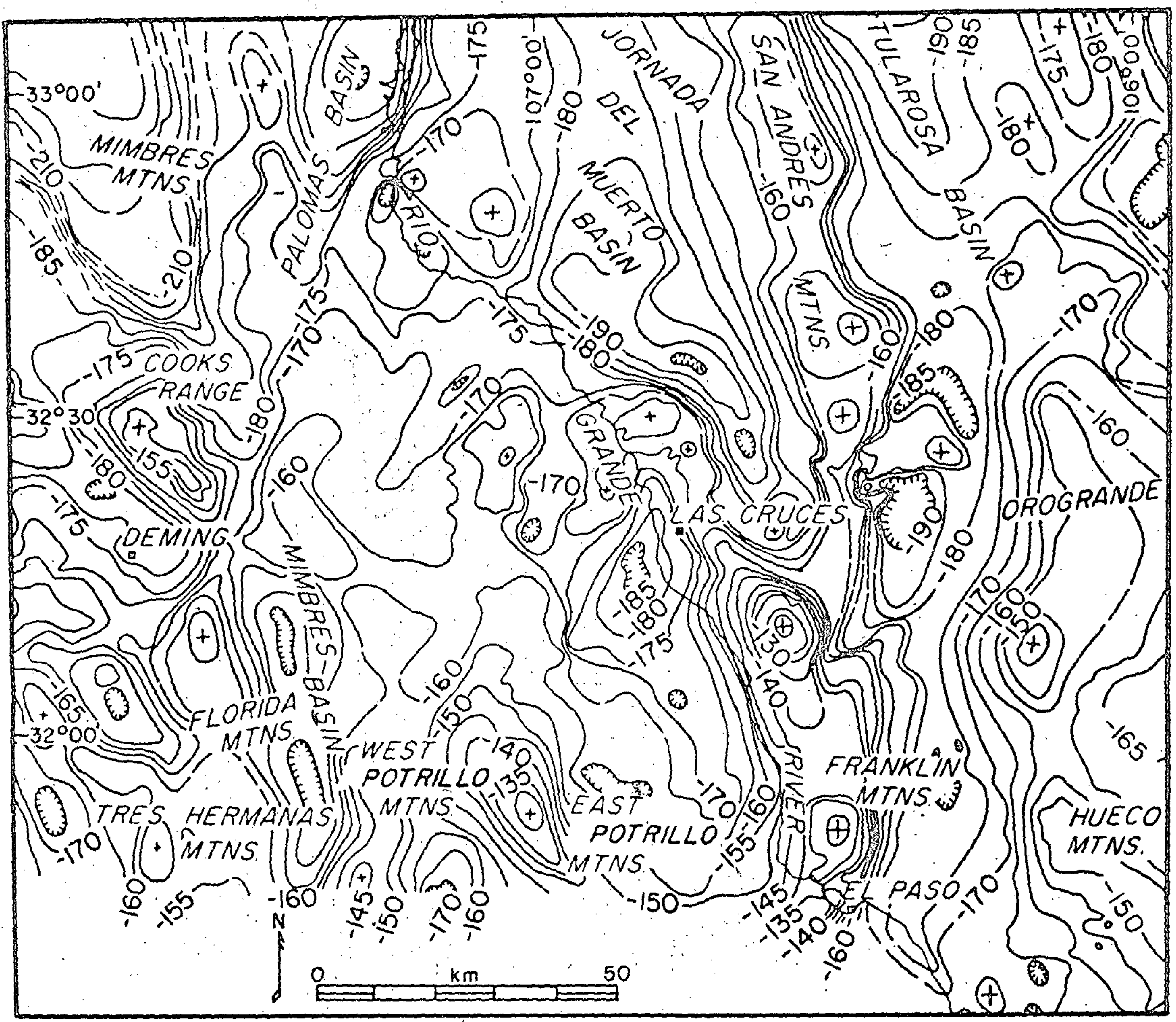

Figure 5. Bouguer anomaly map of south-central New Mexico. Same area as outlined in Figure 1. Contour interval: 5 mgal. From Ramberg and Smithson (1975).

mantle under the rift that results in crustal attenuation (Fig. 6, model A), or 2) a tabular intrusion of high density rocks (basalt?) in the upper or middle crust (Fig. 6, model B). Either model might explain the high heat flow over the rift, and either is equally satisfactory on the basis of known geophysical data.

A three-dimensional gravity model (Fig. 7) of the Mesilla basin has been calculated by means of a computer program developed by Cordell (1970). On the basis of the large negative residual gravity anomaly of 45 mgal, the Mesilla basin is one of the deepest basins in the area and forms part of the Rio Grande rift. The gravity model was calculated by using a uniform density contrast of -0.35 gm/cm^3 for sediments in the Mesilla basin. Any deviations from this uniform density will affect the gravity model accordingly. If the assumed density contrast is too low for some part of the basin, the calculated sedimentary thickness will be too great. Conversely, if this density contrast is too large, the sedimentary thickness will be too small. Any basement anomaly that was unknowingly included in the basin anomaly will also cause errors in basin geometry. The three-dimensional gravity model for the Mesilla basin shows a maximum thickness of 5 km near Las Cruces and Anthony and an irregular pattern of highs and lows.

An interesting and surprising feature of the Bouguer gravity anomaly map (Fig. 5) is the fact that iso anomaly lines trend northeast and northwest and cut across the predominant north-trending structures associated with the Basin and Range and Rio Grande rift (Fig. 8). Ramberg and Smithson (1975) proposed that these complex features were associated with faults that formed oblique to the trend of the rift. These faults, in turn, determined the detailed structure of the horsts and grabens associated with rifting.

Oblique fault directions are recognized by King (1969) in the San Andres Mountains and western Sacramento Mountains where they are sliced by major en echelon normal faults trending north-northwest (Fig. 8). Although other fault directions

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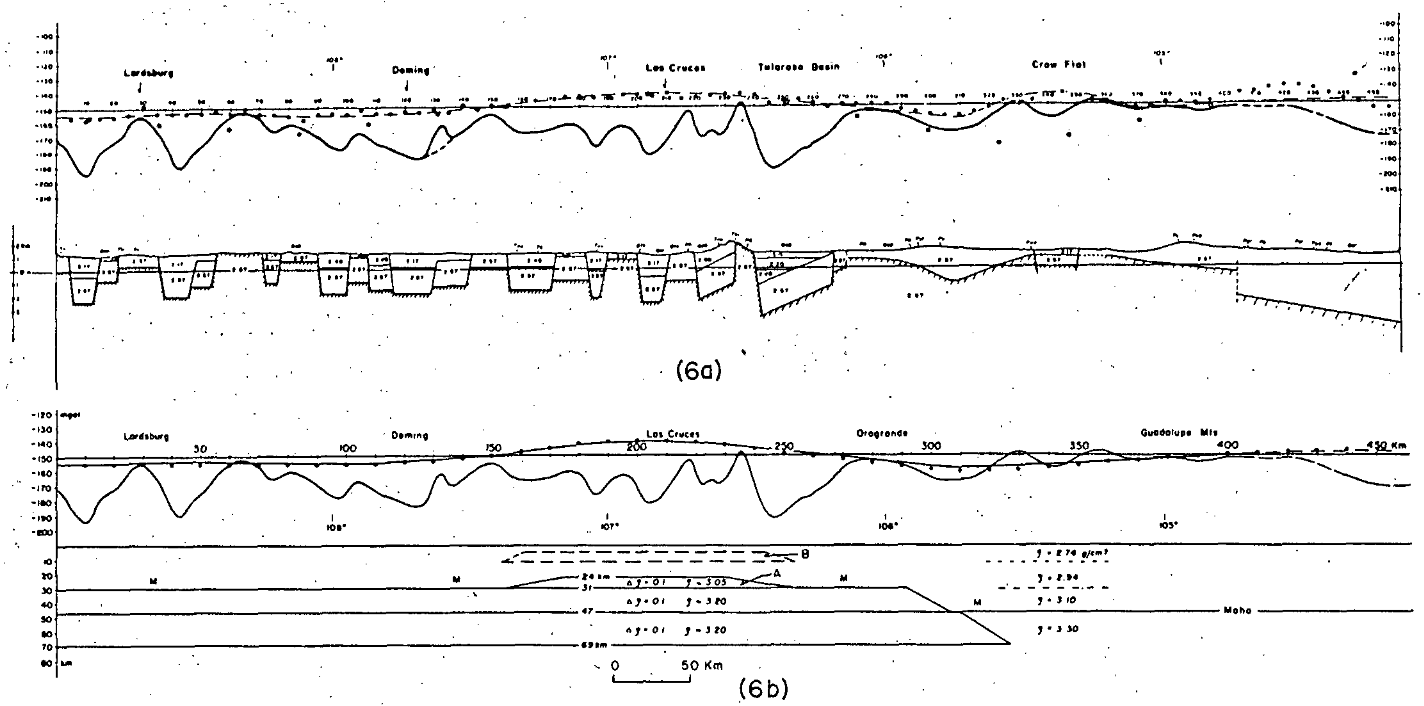

Figure 6. Gravity profiles and models along 32°40′ N. latitude from near Artesia to Lordsburg. Upper profile (6a) shows shallow horst and graben structure. Solid line shows Bouguer gravity anomaly profile. Broken line and solid dots show Bouguer gravity anomalies after "stripping" the gravity effect of sedimentary rocks. Open circles show regional gravity calculated by formula of Woollard (1969). Lower profile (6b) shows deep structure. Model A is an upwarp of the mantle. Model B is a shallow crustal intrusion of basalt to explain the postive gravity anomaly.

commonly occur, geological studies in uplifted areas show north-northwest and north-northeast fault directions obliquely oriented to the major basins and ranges; e.g., in the Franklin Mountains (Harbour, 1972), Organ Mountains (Seager, 1973), Sierra de las Uvas (Clemons and Seager, 1973), Rincon Hills (Seager and Hawley, 1973), San Diego Mountain (Seager and others, 1971), and Caballo Mountains (Kelley and Silver, 1952). Individual basins are clearly terminated by cross structures (Bryan, 1938).

Maximum gravity gradients coincide with major normal faults. Good examples are the marked changes of gravity near the boundary faults east of the San Andres and Franklin Mountains. Other examples occur near Alamogordo where southwestward-dipping normal faults in the foothills of the Sacramento Mountains (Pray, 1961) are correlated with a sharp gravity gradient trending north-northwest to northwest and in the Mesilla basin just southwest of Las Cruces where the Robledo and Fitzgerald faults (De Hon, 1965) are also associated with linear gravity trends.

Ample evidence exists that maximum gravity gradients are correlated with major faults, step faults, or flextures. Figure 8 is based on a gravity lineament analysis. The thick, solid lines denote zones of maximum gravity gradients, and the dashed lines denote less prominent zones. Shaded areas show the extent of well-defined gravity lows. Figure 8 indicates that larger structural units are consistently broken into smaller fault blocks in general following north-northwest and north-northeast trends. No marked change is evident from the Basin and Range province in Arizona and southwest New Mexico across the Texas lineament into the Rio Grande area, except that the northwest-north-northwest trend is more dominant in the Basin and Range province. Both directions seem equally developed in the southern Rio Grande rift to give an overall northerly trend of major structures in the area.

Predominant northwest to north-northwest and northeast to north-northeast fault directions seem not to be confined to late Cenozoic time, and they may be as old as Precambrian. In the Big Burro uplift, late Pliocene or Pleistocene fault zones follow northwest-trending Precambrian diabase dikes emplaced along earlier faults and fractures (Gillerman, 1970). DeFord (1969) suggested that the Texas lineament and other northwest-trending lineaments in Chihuahua may be pre-Carboniferous faults that have been reactivated at different geologic times. Similar repeated movements have occurred along faults near the Sacramento Mountains escarpment (Pray, 1961). In the Mogollon area to the northwest, there are faults trending northeast and northwest, and aeromagnetic anomalies show similar trends (Ratté and others, 1972). The predominant northwest and northeast fault directions are also recognized in a subcontinental-size fracture system covering the Colorado Plateau and adjacent Basin and Range province of the southwestern United States (Wise, 1968). The northeast trend is roughly parallel to the principal structural grain in the central Rocky Mountains and the dominant foliation in the Precambrian rocks surrounding the Colorado Plateau, whereas the northwest trend follows Laramide faults and large Permian-Pennsylvanian uplifts and basins (Kelley, 1955a).

SUMMARY AND DISCUSSION

The Rio Grande rift area near Las Cruces is a zone of unusually high unreduced and reduced heat flow, which contrasts strongly with lower values in adjacent portions of the Basin and Range high heat flow province and normal values in

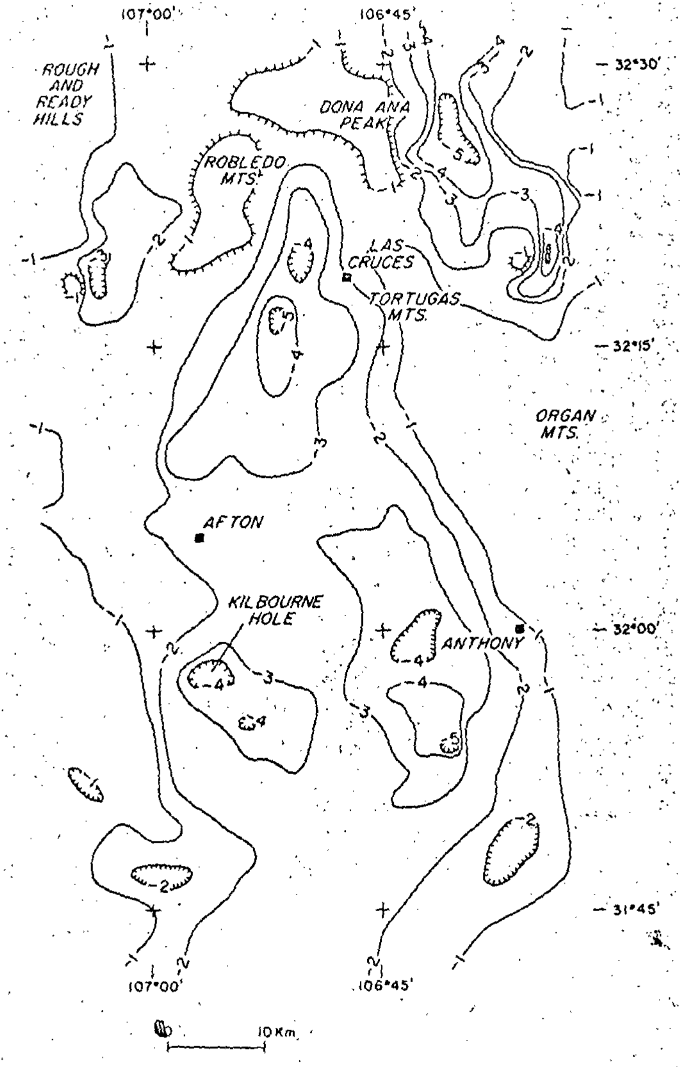

Figure 7. Three-dimensional gravity model of the Mesilla basin after computer program of Cordell (1970). A constant density contrast of -0.35 g/cm^3 is used for all sedimentary rocks. Thicknesses of sediments below surface are contoured in negative km.

the High Plains to the east. Because the transitions to lower heat flow in the Basin and Range occur over short lateral distances, the excess flux in the rift zone must be due to sources in the crust or upper mantle or both. Interpreted in terms of steady heat conduction and commonly accepted distributions of crustal radioactivity, the heat flow anomaly in the rift implies a large degree of melting in the lower crust and upper mantle. Although lower temperatures and less melting would occur if crustal radioactivity increased with depth or a thin lid of unmelted material occurred at the base of the crust in the rift, another interpretation is that the heat flow anomaly is due to the transient thermal effects of late Tertiary intrusions or penetrative convection in and below a thinner crust. Use of transient models to explain the excess flux, in turn, would reduce possibilities for massive amounts of anatexis in the rift and account for the sharp boundaries of the thermal anomaly. These interpretations would also be consistent with the widespread occurrence of Quaternary basalts in the rift zone.

Recent gravity measurements show that the Bouguer gravity relief from the High Plains to the Basin and Range is small, and that a positive Bouguer anomaly occurs in the rift near Las Cruces. Coupled with seismic evidence for contrasting crustal thicknesses in the Plains and Basin and Range, isostatic equilibrium and the small changes of Bouguer gravity in the east-west directions require that an abnormal, low-density upper mantle exist beneath the Basin and Range province. The positive gravity anomaly in the Las Cruces area indicates that an excess of high density mafic rocks occurs at depth in this portion of the rift. Two models of subsurface structure are consistent with gravity and heat flow anomalies in the rift: 1) tabular intrusions of late-Tertiary basaltic units in the middle or upper crust; or 2) a local upwarping of the mantle. There is thus geophysical evidence for significant crustal attenuation in the Rio Grande rift as was suggested by Chapin (1971).

The gravity data raise new questions regarding the relation between near-surface faulting and the major structural features in the southern Rio Grande rift. From the present data, the fact that the gravity isoanomaly lines are oblique to the northerly trend of the major rift structures strongly suggests that the Basin and Range broke up along already existing fractures to form a gridded fault pattern in the late Cenozoic. This fracture system probably existed before the end of the Miocene. Perhaps pre-existing fractures determined the near-surface structural detail in the rift, whereas the northerly trend of the major structures was determined by larger scale, deep seated causes that also led to the rifting.

Finally, the question arises as to whether the rift in southern New Mexico and west Texas is unique with its crustal attenuation, high density crustal intrusions, and gridded fault patterns. Lipman (1969) has suggested that late Tertiary uncontaminated tholeiitic basalts in the Rio Grande depression to the north fractionated at relatively shallow depths beneath an attenuated crust. Kudo and others (1971) propose, however, that young contaminated tholeiitic basalts found within the rift fractionated at shallow depths in the crust. These ideas agree with our interpretations of the depression to the south; penetrative convection of late Tertiary basalts to shallower depths in and below a thinner crust could produce the Bouguer gravity and heat flow highs in this portion of the rift without causing massive amounts of anatexis. These conclusions are consistent also with the geophysical evidence for high density crustal intrusions or crustal attenuation in other grabens of different ages (Girdler, 1964; Cook, 1969; Ramburg and Smithson, 1971; Searle and Gouin, 1972). Evidence for gridded fault patterns in the Ethiopian rift (Mohr and Girnius, 1974), Kenya rift (Baker and others, 1972), Rhine graben (Illies, 1970), and the western Great Basin in the United States (Thompson and Burke, 1974) adds additional support to our interpretation that near-surface structural detail in the rift in southern New Mexico could have been controlled by pre-existing fractures oblique to the main structural trends produced during late Tertiary rifting.

ACKNOWLEDGMENTS

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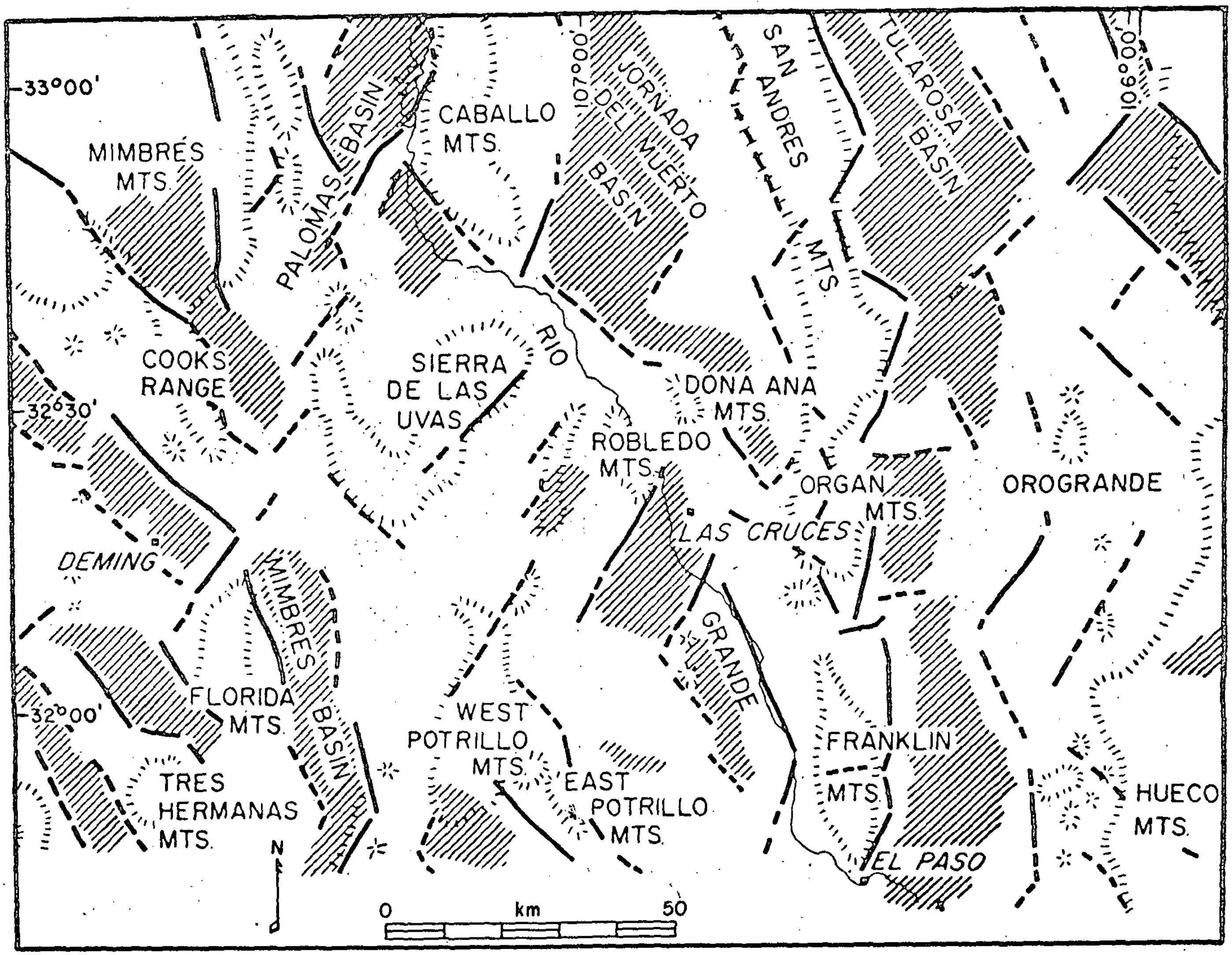

Figure 8. Gravity lineament analysis of south-central New Mexico. Same area as outlined in Figure 1. Shaded areas are Tertiary basins. Faults from Dunham (1935), King and others (1945), Jicha (1954), Kelley (1955b), Kuellmer (1954, 1956), Kottlowski (1960), Griswold (1961), Balk (1961), Seager and others (1971), Harbour (1972), Seager and Hawley (1973), and Clemons and Seager (1973). After Ramberg and Smithson (1975).

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