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Rootless mountains and gravity lows in the Sangre de Cristo Mountains, southern Colorado-northern New Mexico

L. Trevi??o, G. R. Keller, C. Andronicos, and O. Quezada
2004, pp. 264-271. https://doi.org/10.56577/FFC-55.264

in:

Geology of the Taos Region, Brister, Brian; Bauer, Paul W.; Read, Adam S.; Lueth, Virgil W.; [eds.], New Mexico Geological Society 55 th Annual Fall Field Conference Guidebook, 440 p. https://doi.org/10.56577/FFC-55

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ROOTLESS MOUNTAINS AND GRAVITY LOWS IN THE SANGRE DE CRISTO MOUNTAINS, SOUTHERN COLORADO-NORTHERN NEW MEXICO

LEANDRO TREVIÑO, G. RANDY KELLER, CHRISTOPHER ANDRONICOS, AND OSCAR QUEZADA
Department of Geological Sciences, Pan American Center for Earth and Environmental Studies, University of Texas at El Paso, El Paso, TX 79968

Abstract.—Gravity lows over large portions of the Sangre de Cristo Mountains are a geophysical curiosity in the southern Rocky Mountains. The Sangre de Cristo Mountains are largely composed of Proterozoic basement and Paleozoic sedimentary rocks. The exposure of uplifted, presumably dense, Proterozoic basement in the Sangre de Cristo Mountains should be associated with gravity highs, but this is not the case. In this study, we focused on two gravity lows in northern New Mexico-southern Colorado. One is centered over the Sangre de Cristo Mountains in Colorado and northernmost New Mexico, and the other is located near Mora, New Mexico. The northern low can be attributed to Precambrian rocks being thrust over less dense Paleozoic rocks resulting in a rootless basement. In the Mora area, the low is attributed to unusually low-density Precambrian granitic rocks (the 1.68 Ga Guadalupita pluton) underlying a thick sequence of Late Paleozoic and younger sedimentary rocks.

INTRODUCTION

The Laramide Rocky Mountains of Colorado and New Mexico are among the best known examples of basement involved foreland compression in the world (Erslev, 2001). Basement involved shortening affected the region during both Ancestral Rocky Mountain deformation and Laramide deformation (e.g., Marshak et al., 2000). Following Laramide deformation, basement involved compressional structures were overprinted by extensional deformation related to the development of the Rio Grande rift. Uplift and extension associated with this rifting produced at least some of the topography seen today.

Geological Background

The San Luis Basin lies between the San Juan and Sangre de Cristo Mountains (Fig. 1) and straddles the Colorado-New Mexico border. This intermontane basin is approximately 240 km long in a north to south direction and is filled largely with Tertiary sedimentary and volcanic rocks (Keller et al., 1984; Brister and Gries, 1994; Kluth and Schaftenaar, 1994). The shallow Chama Basin (Fig. 1) is located west of the Tusas Mountains (Kelley, 1950). East of the Sangre de Cristo Mountains, the Raton Basin (Fig. 1) filled with Late Cretaceous and Eocene sedimentary rocks deposited during Laramide deformation (Johnson and Wood, 1956; Applegate and Rose, 1985).

The topography of the study area is shown in Figure 1. High elevations are found west of the Sangre de Cristo Mountains, the opposite is true for the region east of the Sangre de Cristo Mountains. Tertiary volcanic rocks and Precambrian basement, with lesser amounts of Paleozoic and Mesozoic sedimentary rocks, dominate the San Juan Mountains (Tweto, 1979a; Green, 1992). The Sangre de Cristo Mountains contains Precambrian basement, Paleozoic and Mesozoic sedimentary rocks, and Tertiary volcanic rocks associated with several large volcanic centers (Tweto, 1979a).

The study area was once part of an elevated portion of the late Paleozoic (Late Pennsylvanian-Permian, 280-240Ma) Ancestral Rocky Mountains (Case, 1966; Kluth, 1986). Erosion reduced these late Paleozoic uplifts, and sediments buried them beginning in the late Permian through the early Mesozoic (Case, 1966; Steven, 1975; Tweto, 1975). The Late Cretaceous-Early Tertiary (75-35 Ma) Laramide orogeny re-elevated this region to its present position (Tweto, 1975). The Rio Grande rift in this region is manifested by the San Luis Basin and extends southward across the Colorado-New Mexico border and through New Mexico as far south as El Paso, Texas (Chapin, 1971). Basins of the Rio Grande rift are commonly asymmetric, fault-bounded, half-grabens divided by intrabasin horsts. Grabens terminate at transfer faults (Gibbs, 1984) or accommodation zones (Bosworth, 1985) that serve to transfer fault offsets to adjacent grabens.

Two large areas of low gravity are evident in southern Colorado and northern New Mexico (Fig. 2). The gravity low (-240 to -310 mGals) over the San Juan Mountains coincides with a large near-surface batholith of middle Tertiary age (Plouff and Pakiser, 1972; Steven, 1975). A second and more perplexing gravity low ranging in values from -220 to –280 is centered over the Sangre de Cristo Mountains, this low continues into New Mexico (Fig. 2) where it is due in part to a batholith beneath the Questa caldera (Cordell et al., 1985). Andreasen and Kane (1962) were the first to note the anomalously low gravity values over the Sangre de Cristo Mountains and suggested an isostatic imbalance in the region to explain the gravity low. Cordell and Keller (1984) also noted the gravity low in the Mora area of northern New Mexico, and Quezada (2000) and Quezada et al. (2004,this volume) undertook an integrated analysis of this gravity low showing that it is probably in part due to a Precambrian intrusion. The gravity model derived by Quezada (2000) has been extended westward and included in this paper.

Methods

Digital Elevation Models (DEMS) were gathered from the University of Texas El Paso (UTEP) database. Elevation data were manipulated with a Generic Mapping Tools (GMT, Wessel and Smith, 1998) script that produced the topographic map shown in Figure 1. Gravity data were gathered from the UTEP gravity database that is mostly based on the compilation of Cordell et al. (1982). These data were gridded using GMT (Wessel and Smith,

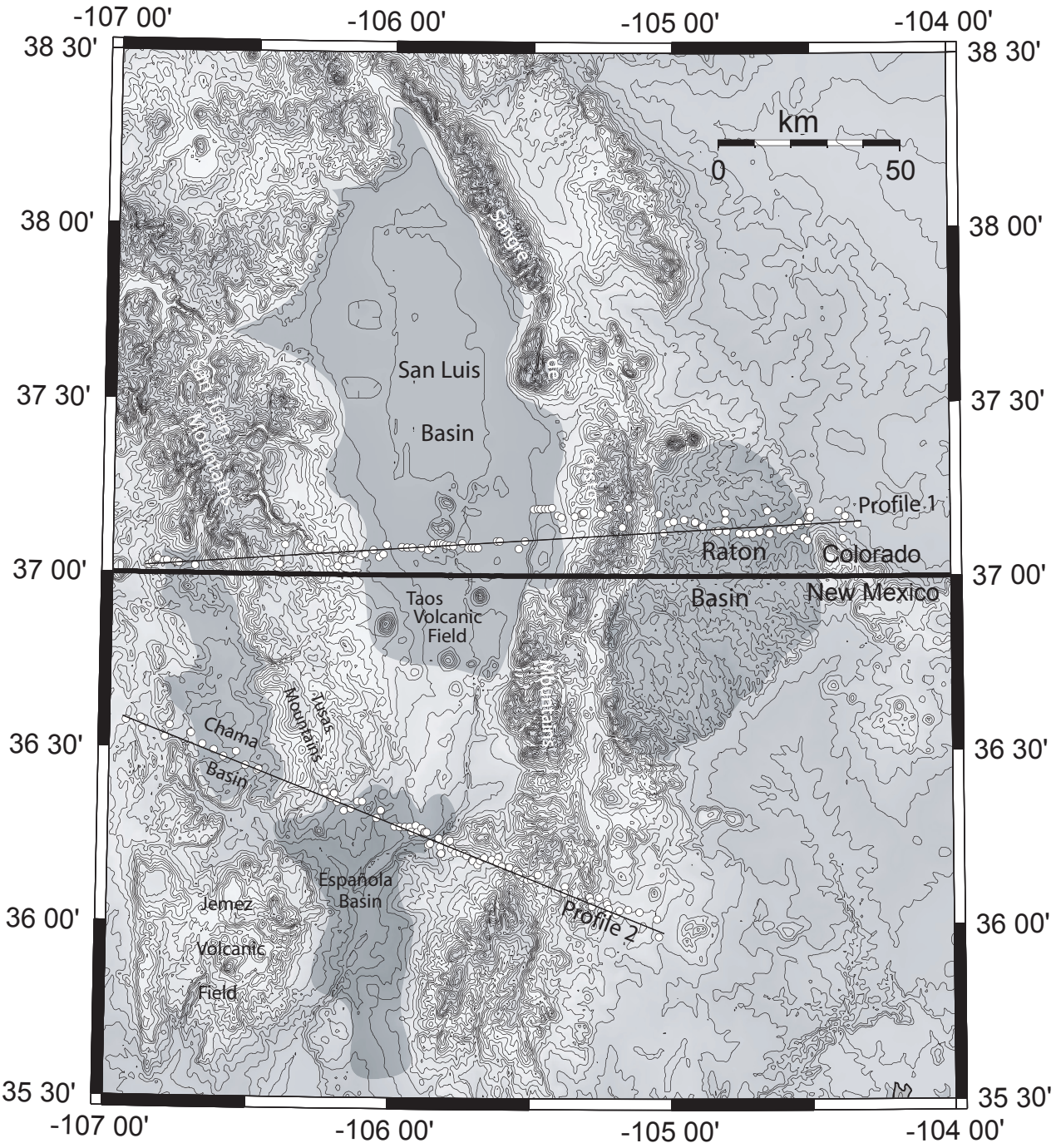


FIGURE 1. Topography of the study area. The map shows the location of the two gravity profiles discussed in the paper. Shaded areas indicate basins discussed in this paper. The lines are locations of the gravity profiles (Profile 1 and 2) taken between the endpoints of the available data. The white dots are the actual gravity readings, and their location with respect to the gravity profile. Contour interval is 100 meters.

1998), and a low-pass (10 km) filter was applied to produce a smoothed Bouguer gravity map (Fig. 2). A series of filtered gravity maps were also created from this same data set. The result chosen for our analysis (Fig. 3) best accentuated those elements of interest in the upper crust. To obtain this result, a low-pass (>20 km wavelengths) filter was first applied to the original data, and then another low-pass (>100 km wavelengths) filter was applied to the same data set. Using band subtraction in GMT, the difference (the bandpassed wavelengths) comprises all wavelengths between these two values. The results show similar anomaly patterns to isostatic residual gravity maps of Oshetski and Kucks (2000) and Kucks et al. (2001).

Two gravity profiles (Fig. 1) were created using software written at the University of Texas at El Paso based on the work of Cady (1980). The northernmost gravity profile is sub-parallel to the Colorado-New Mexico border (Profile 1, Fig. 1), and

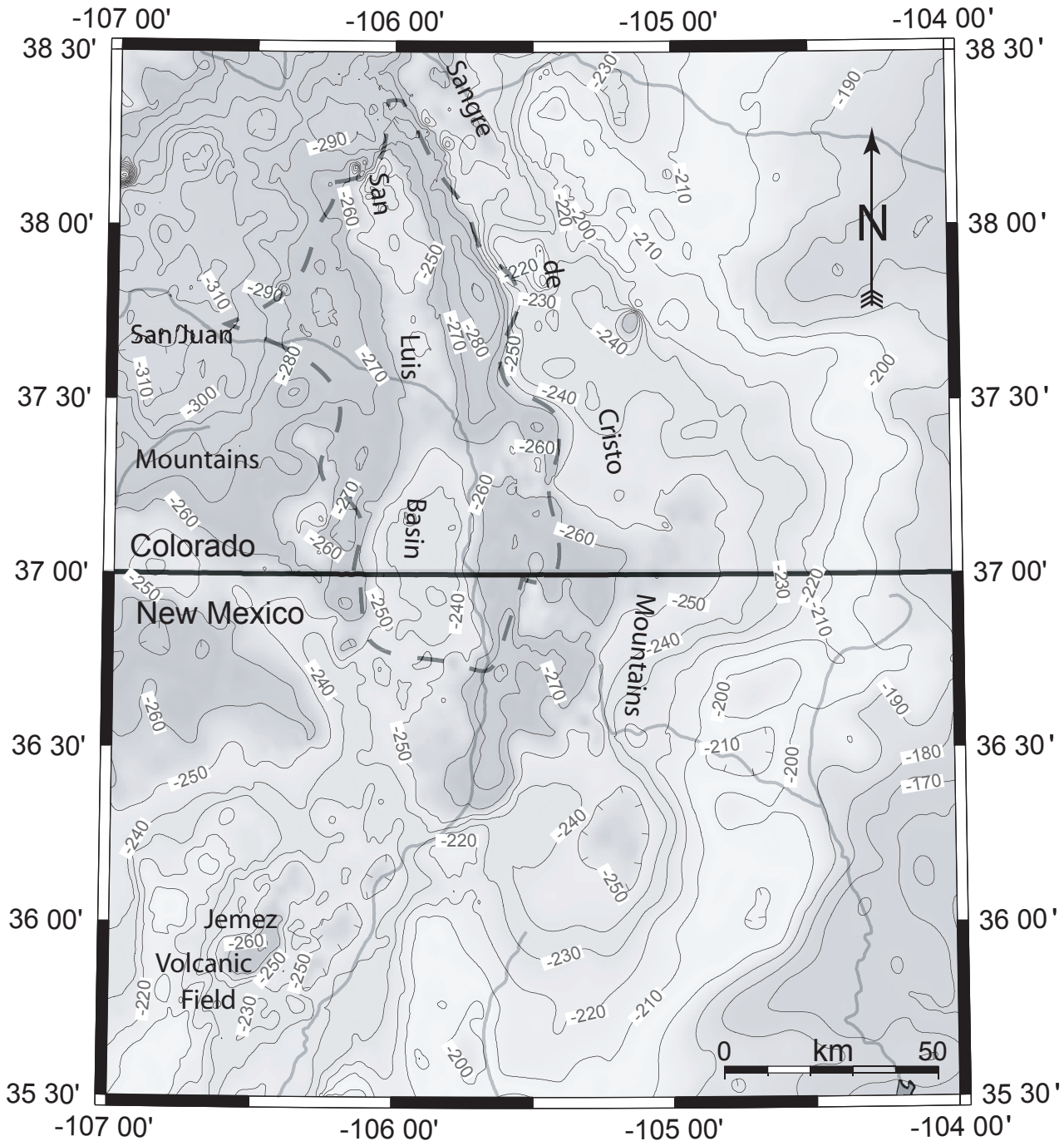


FIGURE 2. Smoothed Bouguer anomaly map. A 10 km low-pass filter was applied to smooth the contours. Anomalously low gravity values are located in the San Juan Mountains and in the vicinity of the Sangre de Cristo Mountains; these are shown in darker shades of gray. The outline of the San Luis Basin is shown as a dashed line.

the southern gravity profile (Profile 2, Fig. 1) crosses the Tusas Mountains and the Sangre de Cristo Mountains. Both profiles cross the Rio Grande rift, the surrounding mountain ranges, and the adjacent basins. Thus the chosen gravity profiles are representative of the major geological features in the area. Published geologic maps, seismic reflection sections, and drilling data (Keller et al., 1984; Applegate and Rose, 1985; Brister and Gries, 1994; Kluth and Schaftenaar, 1994; Baltz and Meyers, 1999) were used as constraints during the modeling process.

RESULTS

Filtered Gravity Maps

On the smoothed Bouguer gravity map (Fig. 2), darker shades of gray on the gravity maps indicate areas with low gravity values and lighter shades of gray are indicative of higher gravity values. Thus, the smoothed Bouguer gravity map (Fig. 2) is clearly divided between high and low gravity approximately along the

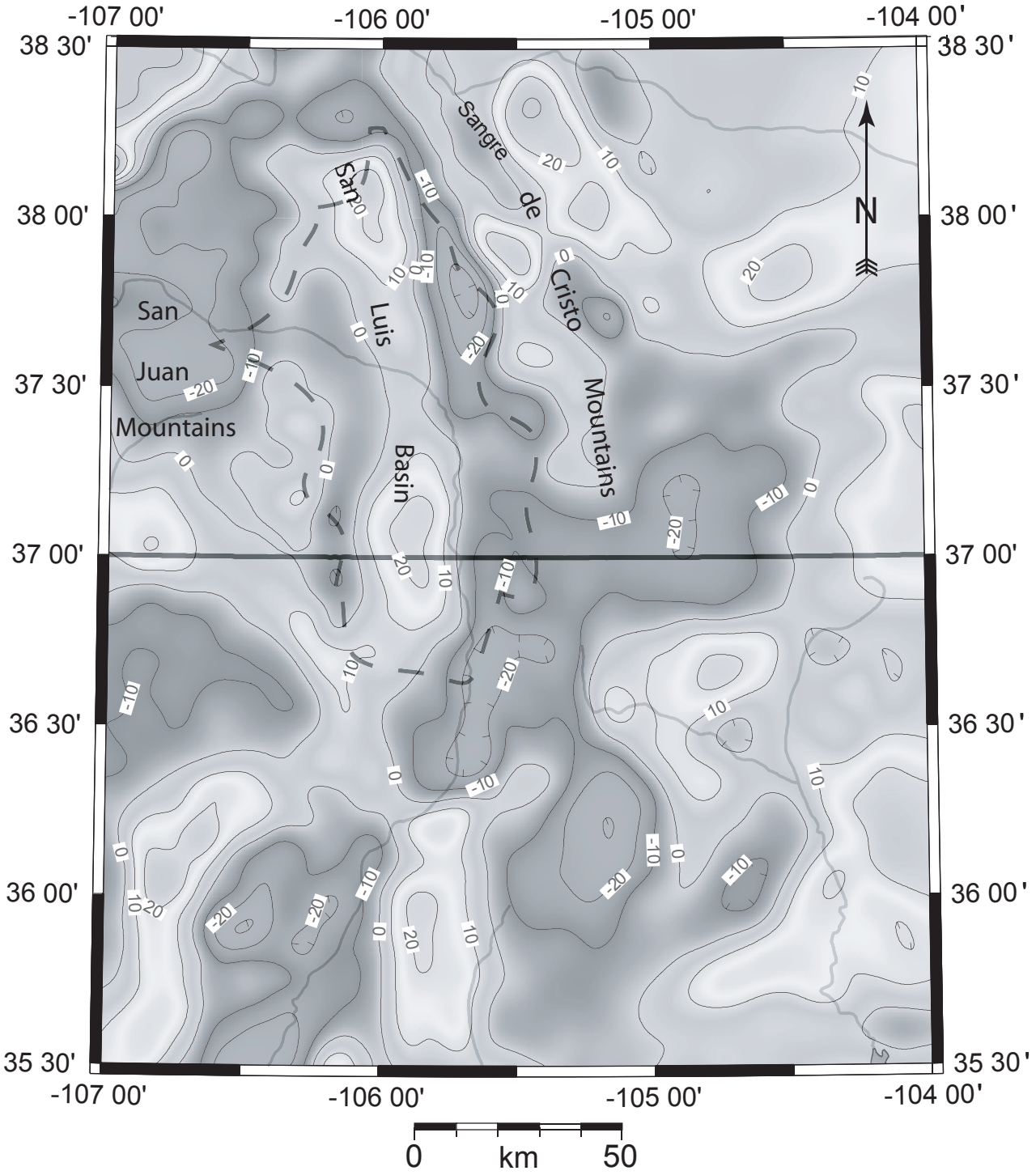


FIGURE 3. Filtered (20-100 km wavelengths passed) gravity map of the study area. Anomalous low values are present over the same areas as in the previous map (Fig. 2). Darker shades of gray are representative of low gravity values. The dashed line is the outline of the San Luis Basin.

105^0 45'N meridian. At the far eastern edge of the map in Colorado, the highest gravity values (-180 mGal) occur east of the Raton Basin, with low values found over the Sangre de Cristo Mountains (-250 to –270 mGal) and the lowest values occurring over the San Juan Mountains (-280 to –310 mGal). The San Luis Basin contains is dominated by a linear gravity high that is associated with the Alamosa horst (e.g., Grauch and Keller, 2004, this volume). The pattern of anomalies in northern New Mexico is similar except that the gravity low associated with the Sangre de Cristo Mountains is wider. The filtered map of gravity residuals (Fig. 3) displays a similar distribution of values. A comparison of the smoothed Bouguer gravity map with the filtered map highlights the gravity lows associated with the San Juan and Sangre de Cristo Mountains.

Gravity Profiles

The Raton gravity profile (Profile 1, Fig. 1) is sub-parallel to the New Mexico-Colorado border and crosses the San Luis Basin, the Sangre de Cristo Mountains and the Raton Basin. The western end of the profile is south of the San Juan Mountains and the eastern end of the profile is in the basin fill at the eastern edge of the Raton Basin. The west-central portion of the gravity profile (Fig. 4) is dominated by a local gravity high of about 30 mGal amplitude having a maximum value of approximately -230 mGal. This feature, well established in the northern San Luis Basin (Burroughs, 1971; Tweto, 1979b; Kluth and Schaftenaar, 1994), is the Alamosa horst block, and its southern terminus is discussed by Grauch and Keller for the southern San Luis Basin elsewhere in this guidebook. At ~150-165 km distance along the profile, a 20 mGal amplitude local gravity high is associated with the Sangre de Cristo Mountains (Fig. 4). Here the mountains are divided into a Precambrian section, consisting of 1700 Ma granitic rocks (Tweto, 1979a), bounded by the Sangre de Cristo fault on the west and a thrust fault on the east. To the east, the Sangre de Cristo Mountains are composed of sedimentary rocks of Pennsylvanian to Permian age. Gravity values to the east of the Sangre de Cristo Mountains decrease slightly and then increase to the east end of the line. The eastern end of the gravity profile is

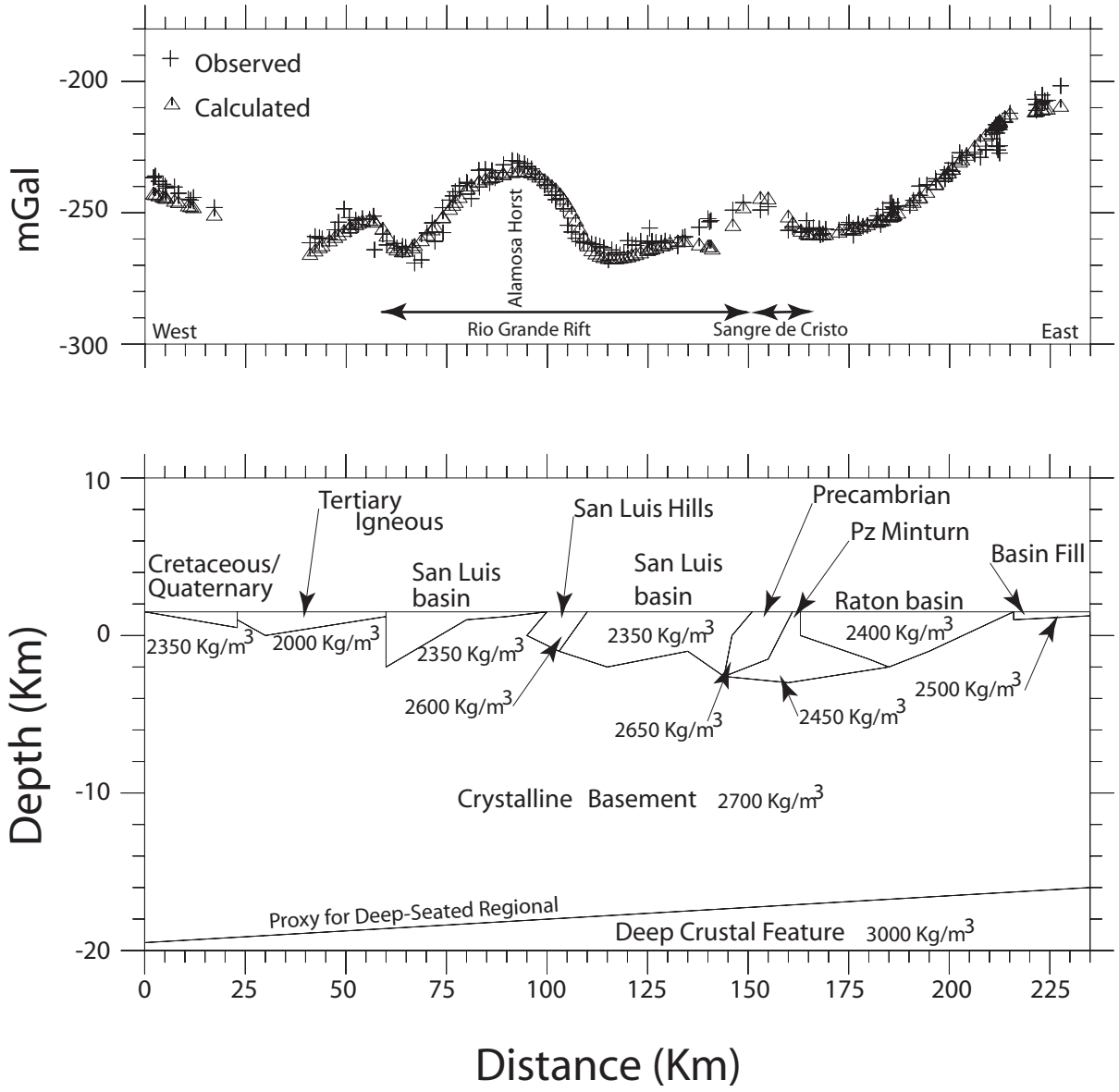


FIGURE 4. Profile 1. A gravity model for southern Colorado extending from the San Juan to the Raton Basin. Sandstones, shale, and other unconsolidated deposits are common to the sedimentary basins in the profile. The Santa Fe Group is extensive in the San Luis Basin. Extrusive igneous rocks are represented by the Tertiary igneous body and the San Luis Hills area. Precambrian granite outcrops in the western portion of the Sangre de Cristo Mountains.

associated with Cretaceous sedimentary rocks of the Raton Basin (Fig. 4; Tweto, 1979a). In the model, the Raton Basin is an asymmetric syncline similar in appearance to results from a seismic reflection study of the northern Raton Basin carried out by Applegate and Rose (1985).

From west-to-east, Profile 2 (Fig. 1) begins at the eastern edge of the San Juan Basin and crosses the Chama Basin, the transition zone between the northern Española and the southern San Luis Basins (Embudo constriction), the Sangre de Cristo uplift, and the Las Vegas Basin. Gravity values increase in an eastward direction (Fig. 5), peaking just east of the Taos Basin; gravity values then drop, gradually rising once again in the Las Vegas Basin area. The shallow Chama Basin is approximately 60 km long, and its width varies from 20 km at its southern extent where the profile crosses it to about 4 km at its northern extent (Woodward, 1974). Between 80-112 km, the gravity data are quite variable corresponding to the complex basin structure in the transition zone between the Española and San Luis Basins. To the east, the gravity values peak at approximately –210 mGal over the Picuris Range and then form a deep low (Mora gravity low) coinciding with the main portion of the Sangre de Cristo Mountains.

DISCUSSION

The gravity profiles hint at the subsurface complexity in the study area. The rift basins in the model for Profile 1 (Fig. 4) are asymmetric and the Raton Basin is synclinal in shape and contains approximately 3 km of sedimentary rocks. A local gravity high dominates this profile and is coincident with the Alamosa horst, which is associated with an outcrop of Oligocene age volcanic rocks. The basin to the west of this horst is filled with a sequence of Cenozoic strata, while the Baca sub-basin to the

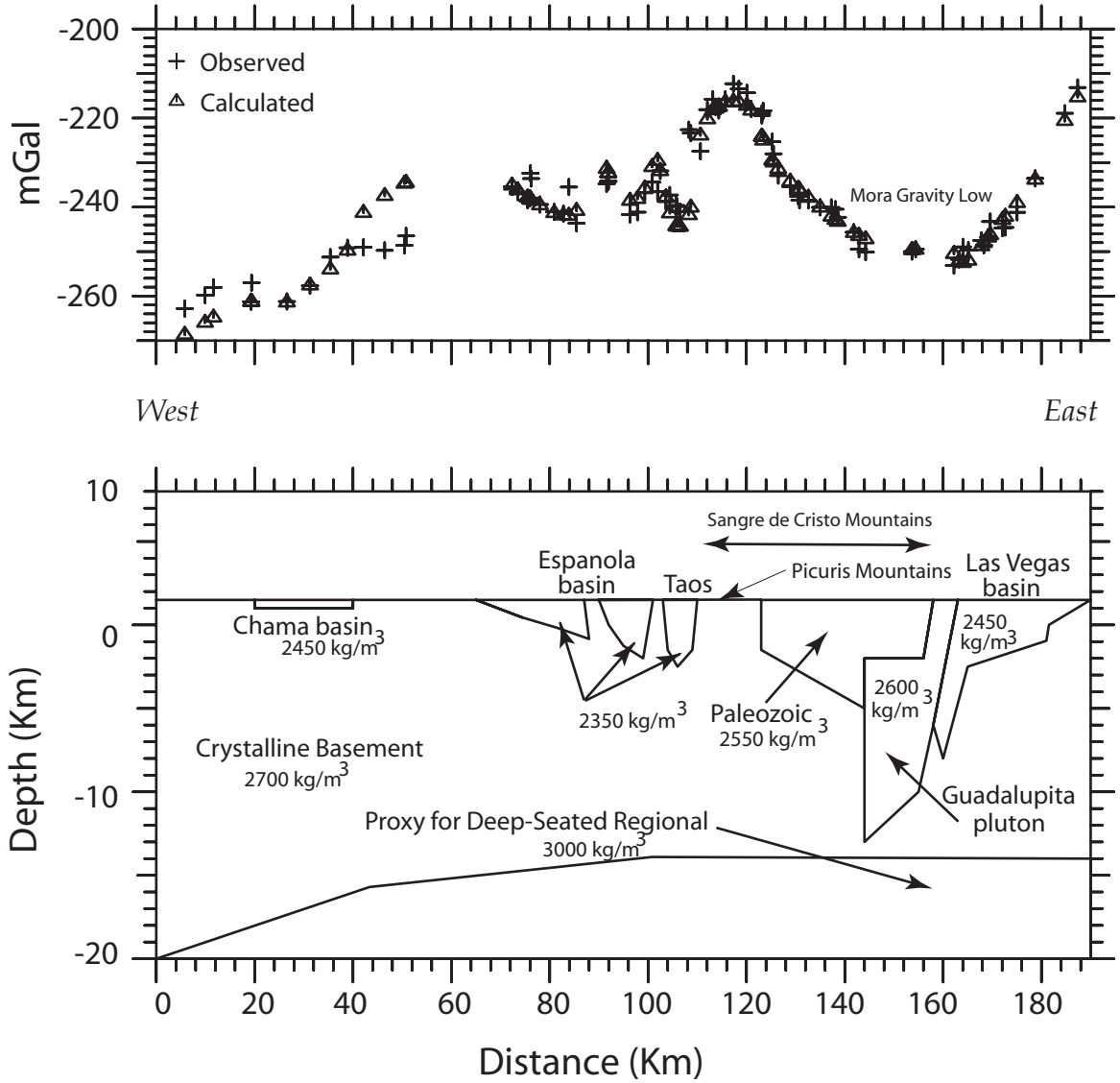


FIGURE 5. Profile 2. A gravity model for northern New Mexico extending from the Chama Basin to the Las Vegas Basin. Sandstones, shale, and other unconsolidated deposits are common to the sedimentary basins in the profile. Portions of the Santa Fe Group are found in the central basins.

east is a deep (3 km) rift basin (Brister and Gries, 1994). East of the San Luis Basin, a local gravity high at approximately 150 km from the west end of the profile is associated with the western Sangre de Cristo Mountains. The gravity high is lower than expected for Precambrian strata exposed at the surface, and we interpret the lack of a prominent high over these mountains as the result of the Precambrian basement present being a sliver that is thrust over Paleozoic sedimentary rocks.

The main feature of interest on Profile 2 is the area east of the Picuris Mountains (Fig. 5), which spans the Sangre de Cristo Mountains and includes the area of the Paleozoic Rainsville trough of Baltz and Myers (1999). As discussed by Quezada (2000) and Quezada et al. (2004, this volume), the Mora gravity low is due to the combined effects of unusually low-density Precambrian granitic rocks (the 1.68 Ga Guadalupita pluton) underlying a thick sequence of Late Paleozoic and younger sedimentary rocks

SUMMARY

Previous investigators have noted low gravity values in the Sangre de Cristo Mountains region (Andreasen and Kane, 1962; Cordell and Keller, 1984) and speculated on their origins. Our gravity models have used all the independent information available as constraints to arrive at two different explanations for the lows. The northernmost of the gravity lows is attributed to a detached slice of Precambrian basement being thrust over Paleozoic sediments in the Sangre de Cristo uplift. Thus, much of the uplifted Precambrian basement in the Sangre de Cristo Mountains appears to be detached and thrust over sedimentary rocks resulting in lower than expected gravity. In contrast, along the southern profile, the gravity low associated with the Sangre de Cristo Mountains is produced by a combination of low-density granitic rocks and deep sedimentary basins. Thus, the modern gravity field in the region is the result of the intricate interplay of features of diverse ages and origins.

ACKNOWLEDGMENTS

We wish to thank the CD-ROM Working Group and Ben Donegan for many helpful discussions. Funding for this project was provided by the Continental Dynamics Program of the National Science Foundation (EAR-9614269) and by the Pan American Center for Earth and Environmental Studies, which is supported by NASA. Database and computational support was provided by the GEON project (NSF grant 0225670). This paper was improved thanks to helpful reviews by Tien Grauch, Jose Hurtado, and Richard Langford.

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