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RIFT BASIN STRUCTURE IN THE BORDER REGION OF NORTHERN CHIHUAHUA

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Abstract—In order to increase our understanding of the tectonics and basin structure in the border region between El Paso and the boot-heel region of New Mexico, an integrated study focused on gravity, remote sensing, and geologic data was undertaken. The basin structure delineated shows that continuity of major structures between the U.S. and Mexico is limited and that few areas in border region of Mexico are underlain by deep basins. We have delineated a new feature that we have named the El Parabien basin, and a smaller feature to the east that Mexican workers call the Conejo Medanos basin. There is a series of gravity highs that connect the East Potrillo Mountains, Sierra de Sapello, Sierra Samalayuca, and Sierra de Presidio. The trend and relative continuity of this anomaly suggest that it correlates with an older structure that played a role in the development of subsequent Laramide and rift structures.

INTRODUCTION

The State of Chihuahua, the largest state in the Mexican Republic, borders New Mexico and west Texas and the border regions of the three states have a shared geologic history. It is clear that we cannot fully understand the geological evolution and natural resources of the border region without understanding the structure and evolution of Chihuahua. There have been a number of geologic studies of the scattered outcrops of pre-Cenozoic rocks in the border region of Chihuahua, and Dyer (1988) compiled a bibliography of these studies. In this study, we present new gravity data and an integrated analysis of basement structure in the border region between El Paso, Texas and Columbus, New Mexico.

GEOLOGIC SETTING

Outcrops and penetrations of the Precambrian basement of the State of Chihuahua are rare, but the area seems clearly to be part of the North American craton (Denison et al., 1970; Campa and Coney, 1983; Bally, 1989). In Mexico, the closest outcrop to the study area is in the Sierra del Cuervo (Blount, 1983) just north of Chihuahua City (Fig. 1). Other Precambrian rocks in Chihuahua have been encountered in PEMEX exploratory wells. For example, the Chinos-1 well encountered an orthogneiss at 4411 m (Fig. 1). The Moyotes-1 well, located 50 km southwest of Ciudad Juarez encountered a gneiss at 4810 m (Figure 1). The granite-gneiss encountered by this well was dated by the rubidium-strontium method at 890 ± 32 Ma (Thompson et al., 1978). The whole pre-Permian Paleozoic section is missing in this well.

At the beginning of the Paleozoic, northern Chihuahua was near the margin of the North American craton (Stewart, 1988), and as in adjacent New Mexico and Texas, epeirogenic subsidence characterized much of the Paleozoic era. The breaks in sedimentation, particularly during the Silurian, Mississippian, and Pennsylvanian, are striking in northern Chihuahua. The ancestral Rocky Mountains orogeny and development of the Pedregosa and Orogrande basins (Fig. 1) began in the late Mississippian. The Pedregosa basin is flanked to the northeast by the Diablo platform and Florida-Moyotes uplift and to the southwest by the Bavispe platform, and connected with the Orogrande basin by a north–south-trending corridor (Tovar and Valencia, 1974; Ross and Ross, 1986). In northern Chihuahua, Paleozoic marine sedimentary rocks are known only from well data and a few outcrops (Thompson et al., 1978). Rocks that are of early Paleozoic age have been identified at

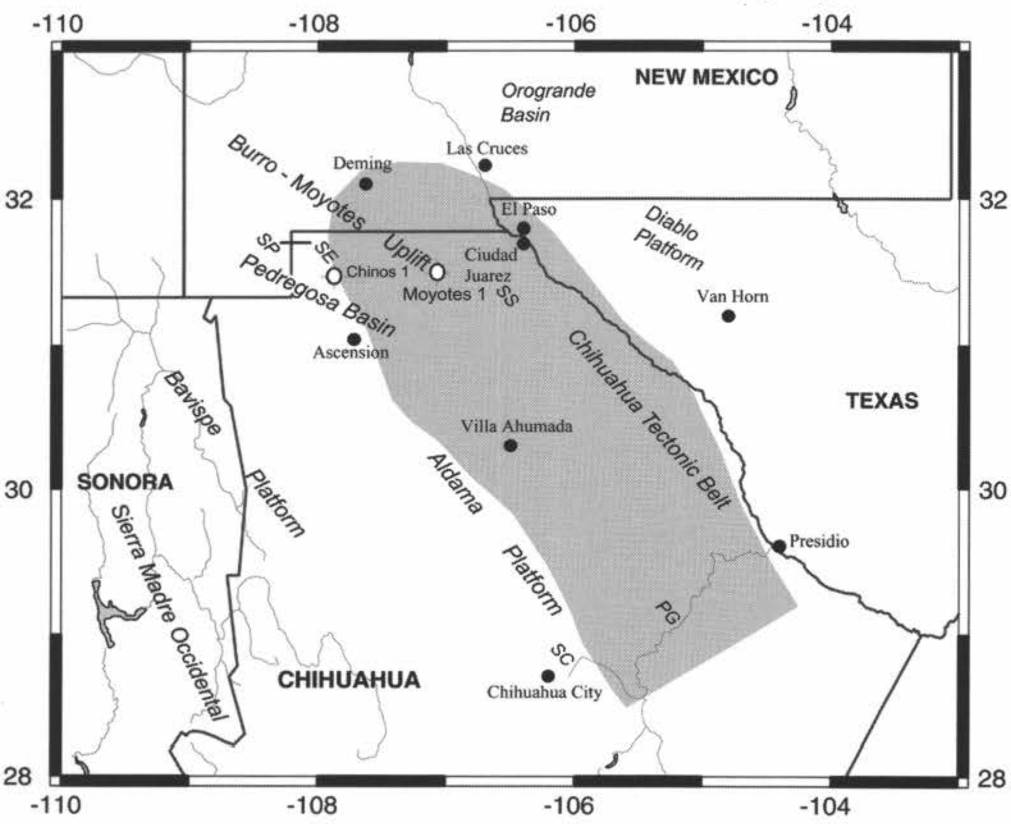

Figure 1. Index map of the border region of New Mexico, Chihuahua, and west Texas. PG, Placer de Guadalupe; SE, Sierra de Enmedio; SP, Sierra de Palomas; SC, Sierra del Cuervo; SS, Sierra de Samalayuca. Shaded area is approximate extent of the Chihuahua trough.

Placer de Guadalupe (Bridges, 1964) east of Chihuahua City and at Sierra de Enmedio (Fig. 1). Rocks of late Paleozoic age are found at Sierra de Palomas (Fig. 1; Brown, 1985) and at Sierra del Cuervo (Mellor and Breyer, 1981).

A major unconformity observed in northern Chihuahua ranges from the Late Permian to Late Jurassic (Thompson et al., 1978). The Chihuahua trough began to form in the Late Jurassic. This trough is situated along and to the southwest of the former Orogrande and Pedregosa basins and was bounded by the Diablo platform to the northeast and the Aldama platform to the southwest (Fig. 1). The Chihuahua trough continued to form until the Early Cretaceous, allowing for the accumulation of in excess of 5000 m of sedimentary rock (e.g., Gries, 1979). This sedimentary sequence consists of evaporites, sandstones, limestones, and shales (La Casita, Navarrete, and Las Vigas, or equivalent formations). These formations record a series of marine regressions and trangressions. In terms of the big picture, they represent the overall transgression in the Chihuahua trough.

The Laramide orogeny had profound effects in Chihuahua forming a variety of compressional structures. Laramide deformation is present in each of the main Mexican mountain ranges that parallel the Rio Grande southeast of El Paso (Chihuahua tectonic belt, Fig. 1). The structures in these mountains developed as a result of anticlinal flexures whose axial planes strike from 35° to 310°. These anticlines often verge to the northeast and are typically surrounded by NW-striking thrust faults with SW dips and by strike-slip tear faults striking to the northeast and southwest (Molina, 1997). The timing for the initiation of this event is constrained by the age of the youngest Cretaceous formation found in northern Chihuahua, which is the Picacho Formation of Maastrichtian age (74–66 Ma). Andesitic rocks in the El Paso/Juarez area have been dated at about 45 Ma and were probably emplaced during the final gasp of the Laramide orogeny (Chris Andronicos, personal commun., 1999)

Mid-Tertiary magmatism was widespread in Chihuahua and was extensive in the Sierra Madre Occidental (Stewart, 1978; Clark and Ponce, 1983; Henry et al., 1991). The age of these rocks is often considered to be concentrated between the end of the Laramide compression and the beginning of Basin-and-Range/Rio Grande rift extension (Keller et al., 1990), but many are older than 45 Ma and some are younger than 30 Ma (Clark and Ponce, 1983; McDowell and Mauger, 1994). In the State of Chihuahua, Tertiary volcanic rocks often sit on an eroded sequence of Cretaceous sediments. Cenozoic igneous rocks in the Sierra Madre Occidental and adjacent areas of Chihuahua can be categorized into four distinct suites: (1) The oldest igneous rocks range in age from early Paleocene to mid-Miocene and coincide with the Lower volcanic series (Clark and Ponce, 1983). These volcanic rocks are composed primarily of andesites and overlie an angular unconformity on Cretaceous sediments (Clark and Ponce, 1983). (2) The next set of igneous rocks is primarily of rhyolitic composition and has an age that ranges from Eocene to Oligocene (Clark and Ponce, 1983). These rocks coincide to the Upper volcanic series of the Sierra Madre Occidental. Groups 1 and 2 are consequences of subduction of the Farallon plate under the North American plate. The Lower volcanic series is related to a volcanic arc in trangressive motion, whereas the Upper volcanic series corresponds to a volcanic arc underoing regression (Clark et al., 1983). (3) The third volcanic episode occurred at 30 Ma and is characterized by bimodal volcanism that has been documented in northern (Bautista and Goodell, 1983) and central Chihuahua (Mauger, 1981). This particular volcanic sequence may be related to the development of the Basin-and-Range province/Rio Grande rift, but also may precede the extension (McDowell and Mauger, 1994). (4) The most recent volcanic events consist of rift-related alkaline basalts located just south of Columbus, New Mexico (Frantes, 1981), which have been dated at between 5 and 3 Ma and cinder cones associated with Potrillo marr (Hoffer, 1976).

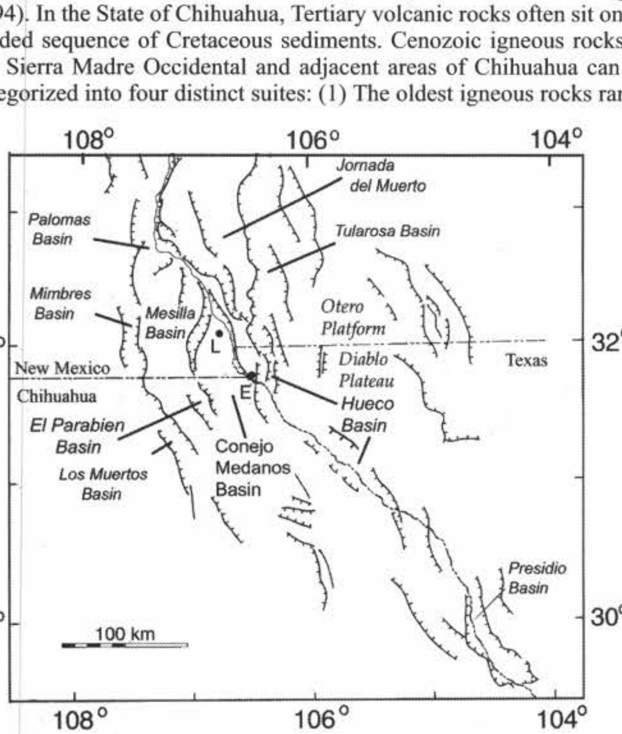

Figure 2. Index map of the rift basins in the border region. Dark lines depict faults that have experienced Quaternary movement.

The Rio Grande rift is generally regarded as a distinct feature environment that is related to, but distinct from, the Basin-and-Range province (Chapin and Seager, 1975). Based on surface structure, Chapin (1971) traced the rift from Colorado into southern New Mexico. Decker and Smithson (1975), Seager and Morgan (1979), and Keller et al. (1990) further argue that the thermal anomaly, low-velocity upper mantle, thin crust, and other shallow features affiliated with the rift in northern and central New Mexico extend southward in a relatively narrow zone into southern New Mexico, west Texas, and northern Chihuahua. In the northern parts of Chihuahua, extensional regional uplift and block faulting connected with the Rio Grande rift was superimposed over Laramide structural features (Fig. 2).

GEOPHYSICAL ANALYSIS

Gravity data provide an economical source of information on earth structure. In the Rio Grande rift, gravity data have contributed significantly to the location of normal faults, definition of basement structure, and delineation of basin geometry (e.g., Cordell, 1978; Ramberg et al., 1978; Daggett et al., 1986; Adams and Keller, 1994). The negative anomalies are associated with basin fill that has low density, while the positive anomalies are associated with uplifts (Decker and Smithson, 1975). In the deepest portions of the basins, the thickness of Cenozoic sediments typically ranges from 2 to 3 km based on gravity modeling, and removing the negative effects of the basins shows that there is a positive 30-mgal gravity anomaly along the southern Rio Grande rift (Ramberg et al., 1978). This anomaly cuts across shorter wavelength anomalies due to Phanerozoic structures and is too large and coherent to be a consequence of near-surface density contrasts within Precambrian basement. Daggett et al. (1986) and Sinno et al. (1986) showed that it is due to upwarping of the Moho discontinuity.

The region of primary interest is situated immediately west of Ciudad Juarez (Figs. 1, 2). The definition and investigation of the gravity lows in this area was the chief aim of this study. These gravity lows correspond to a series of basins west of the El Paso-Ciudad Juarez metroplex that may contain important water resources.

The data used in this study come from the University of Texas at El Paso gravity database that was supplemented by field work done in August 1997 and May 1998. This gravity database was assembled from numerous sources such as the U.S. Geological Survey, the National Imaging and Mapping Agency, the University of Texas at Dallas, and UTEP theses. A total of 217 gravity points were collected during these two periods of field work (Fig. 3).

Standard corrections were applied to the gravity readings collected (Cordell et al., 1982). These corrections account for the variations in gravity due to known effects such as changes in latitude and elevation. Terrain corrections were calculated using a standard template technique. The data collected were reduced to sea level and a crustal densi-

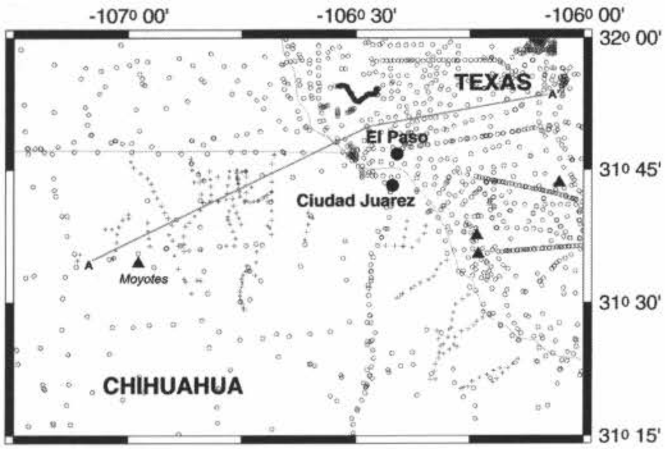

Figure 3. Map of gravity station coverage in the study area. Crosses are new stations presented here. A–A' is the profile for which the gravity model in Figure 6 was derived. The triangle is the location of the Moyotes-1 well.

ty of 2.67 g/cm^3 was utilized in the terrain and Bouguer corrections. Gravity meters are sensitive to variations in the acceleration of gravity due to effects of the Moon and Sun that are time dependent. These Earth tides were taken into account, along with instrument drift, by reoccupying base stations at regular intervals and assuming linear drift between reoccupations. In this study, secondary base stations were established and reoccupied every three hours. Global Positioning System, or GPS, was utilized to establish x, y, and z coordinates in the gravity survey. Since the gravity survey was conducted so far away from El Paso, a secondary GPS base station was established at the El Parabien ranch situated west of Ciudad Juarez on Mexican Highway 2. The ultimate base station for the survey was a permanent station operated by the Texas Department of Transportation (TXDOT) in El Paso. GPS coordinates were corrected for differences between height above the ellipsoid and height above the geoid using the GEIOD96 model.

INTERPRETATION AND DISCUSSION

The most prominent features on the regional Bouguer anomaly map (Fig. 4) are the gravity lows that delineate the deep portions of the sedimentary basins and the gravity highs associated with the intervening horst blocks. North of the border, the dominant trend of these anomalies is N–S. However in the border region, NW trends dominate. In particular, a gravity high extends across the map from the western edge at 32ºN to the SE corner of the map. Perhaps this trend is due to the combined effect of the Burro-Moyotes uplift and rift faulting. In order to examine the deeper structures present, we applied a 125-km low-pass

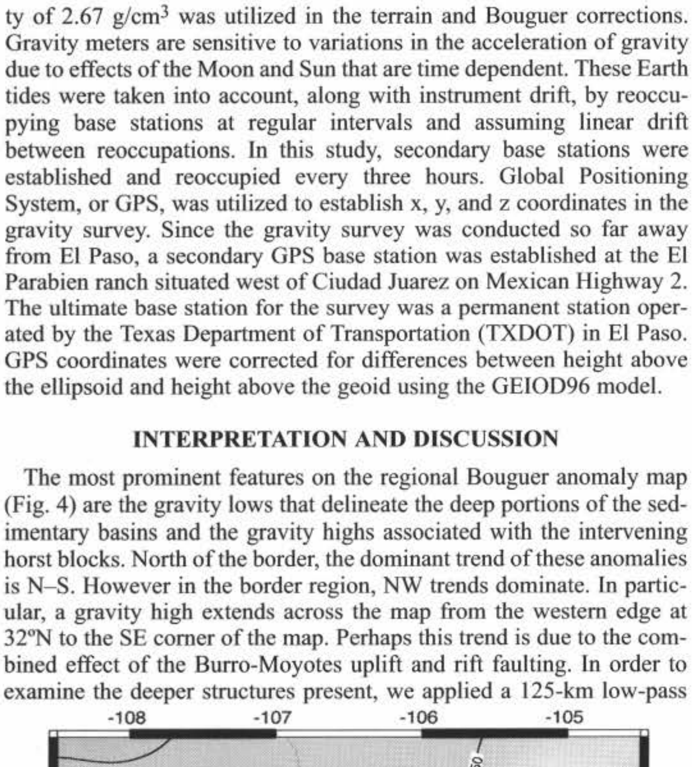

Figure 5. Low-pass (>125 km wavelengths) gravity map of the border region. Contour interval: 10 milligals. Seismic data in New Mexico show that the central gravity high correlates with areas of thin (~30 km) crust.

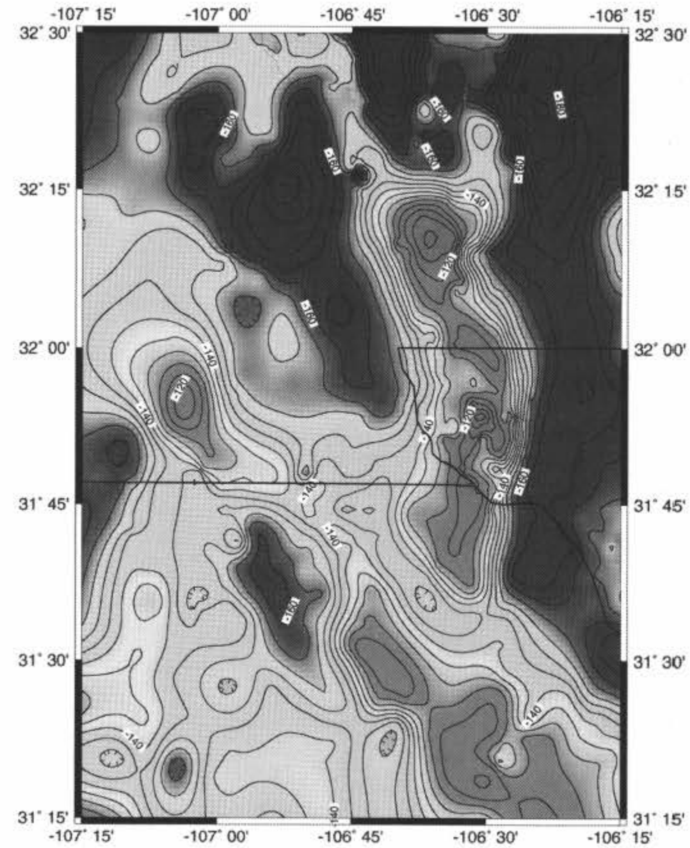

Figure 4. Bouguer gravity map. Contour interval: 4 milligals.

filter to the new data base. This map (Fig. 5) shows a prominent gravity high in the border region. Daggett et al. (1986) and Keller et al. (1990) showed that this feature is mostly due to crustal thinning associated with the Rio Grande rift.

To study the subsurface structure and geometry, a gravity model was constructed for a profile (Fig. 3) crossing the area of interest. A computer program based on the two-and-a-half dimensional approach (Cady, 1980) was employed. This program determines the theoretical gravitational attraction based on the geometry and density of geologic bodies and then relates the calculated values to corresponding observed values. The gravity model was constructed using all available geological and geophysical data as controls and should be considered to be a geophysically constrained geologic cross-section. The Moyotes 1 (Fig. 1) well was a particularly important constraint. Changes in the shape and dimensions of the geologic bodies were made by trial and error to create an acceptable match between the observed and theoretical gravity values along a profile. Densities of geologic formations are a significant parameter in the calculations, and values compiled by Hadi (1991) were utilized. These values are based on outcrop samples, seismic velocities, and information obtained from well log data.

The gravity profile and resulting model are shown in Figure 6. Relatively low gravity values (-160 to -170) obtained in the El Parabien ranch area indicate the presence of a deep basin containing sedimentary fill with a thickness of 2.2 km. Here we name this feature as the El Parabien basin. In accord with the practice of Mexican colleagues studying the area, we call the smaller feature to east the Conejo Medanos basin. The addition of a dense mafic body was necessary to fit the high values (-120 mgal.) obtained near the Sierra de Juarez/Franklin Mountains. The steep gravity gradient at the 72-km point on the profile marks the western edge of the Hueco basin, which has a depth of 2.8 km in the model. Rather than make the assumptions needed to calculate a residual anomaly profile, we choose to model the original Bouguer anomaly values. The regional gravity high shown in Figure 5 was accounted for by including a tabular body at the base of

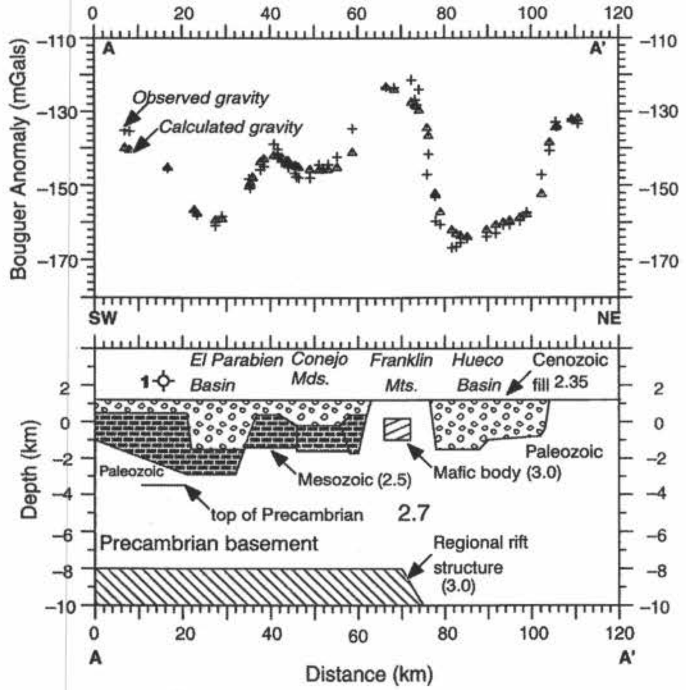

Figure 6. Computer model for Profile A–A' (Fig. 3). Numbers are densities in gm/cc. For the sake of minimizing vertical exaggeration, the regional rift structure was modeled at a mid-crustal depth. However, seismic data (Sinno et al., 1986) indicate that the true depth is about 30 km and that this feature represents east–west thinning of the crust.

the model. However, seismic results in the region (Sinno et al., 1986) indicate that this body is probably deeper, representing an east–west thinning of the crust.

A georeferenced Landsat image from the archive at the Pan American Center for Earth and Environmental Studies was employed for the purpose of overlaying gravity contours and other geologic data. Bands 7, 4, and 2 were utilized for this image. Overlaying gravity contours on the satellite image shows where the gravity highs and lows occur relative to known geologic features, and using this overlay as a guide, the interpretive map shown in Figure 7 was drawn. The extent of the El Parabien and Conejo Medanos basins and their interpreted bounding faults are shown on this map. This map shows that the Hueco basin actually consists of two sub-basins, a northern one with a N–S trend and southern one with a NW trend. A NW-trending series of gravity highs is associated with the East Potrillo Mountains, Sierra de Sapello, Sierra Samalayuca, and Sierra de Presidio. A significant point from a water-resources point of view is that the gravity anomalies show that the Mesilla basin is separated from the basins in Mexico by a structural high. In addition, the basins in Mexico are relatively small in areal extent suggesting that the deep ground-water resources are limited.

CONCLUSIONS

This integrated study employed gravity, remote sensing, and geologic data to study the tectonics and basin structure in the border region between El Paso and the boot heel region of New Mexico. Based on using gravity anomalies to connect points of geologic control, a structural high connects the East Potrillo Mountains, Sierra de Sapello, Sierra Samalayuca, and Sierra de Presidio. This feature may reflect an older structure that played a role in the evolution of subsequent Laramide and rift structures. The continuity of major basinal structures between the U.S. and Mexico is limited. In addition, few areas in Mexico adjacent to the border are underlain by deep basins. A new feature, the El Parabien basin, was delineated as was a smaller feature to east that Mexican workers call the Conejo Medanos basin.

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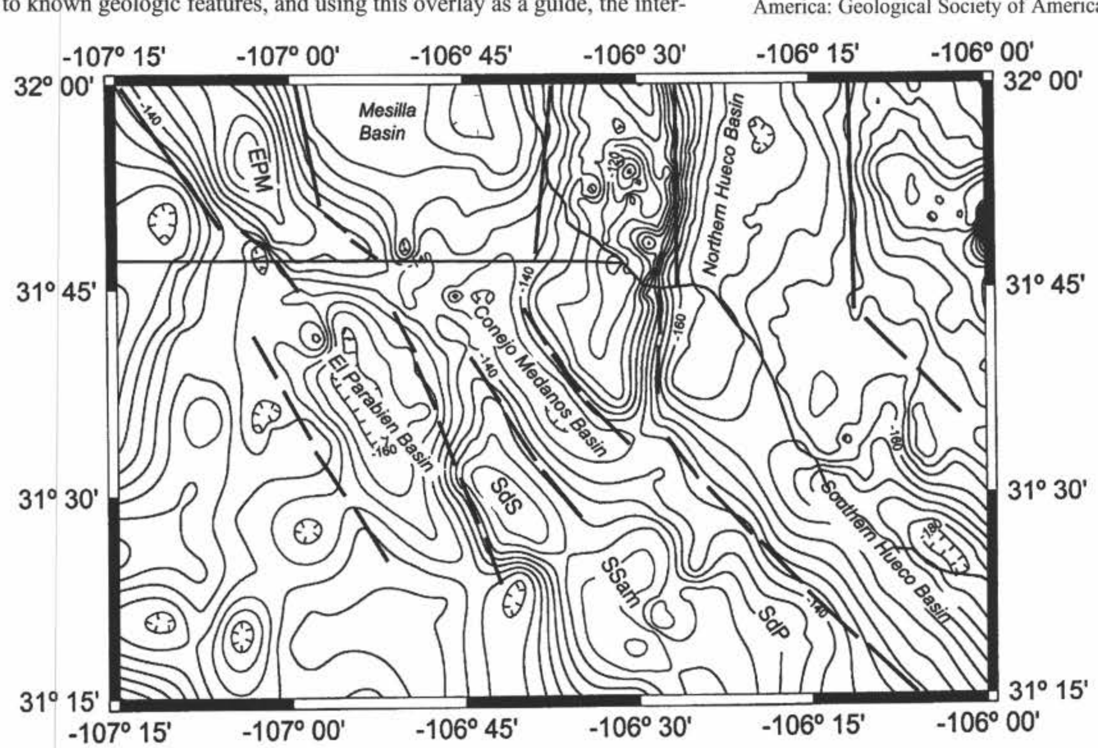

Figure 7: Gravity map with the interpreted extent of the main rift basins in the border region. This interpretation is based on the integrated analysis of gravity, drilling, geologic, and remote sensing data. EPM, East Potrillo Mountains; SdS, Sierra de Sapello; SSam, Sierra Samalayuca; SdP, Sierra de Presidio.

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