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IMPLICATIONS OF RECENT GEOPHYSICAL STUDIES OF THE BIG HATCHET MOUNTAINS AREA, SOUTHWESTERN NEW MEXICO

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Abstract—A detailed gravity survey conducted in the boot heel area of southwest New Mexico provides evidence of steeply dipping (45–65°) faults with intersecting trends beneath the valley fill. Abrupt changes in gravity (up to 30 mgal) measured along the west side of the Little Hatchet and Big Hatchet mountains over a narrow (3–4 km) strip correlates with range-bounding faults delineated previously by seismic data. In contrast to the northwest-southeast orientation of Big Hatchet Mountains and the shallow structures associated with the Hachita Valley, the Bouguer values outline a deep (>3000 m), elongate (~40 km long by 10–14-km wide), north–south oriented basin along the west side of the Big Hatchet and Alamo Hueco mountains. A smaller, northwest-oriented trough is present west of the Little Hatchet Mountains and a strong, positive feature extends northeast beneath the Playas Valley. The results show a clear image of north–south and northwest–southwest-oriented fault blocks and associated, elongate, Cenozoic grabens within the larger Paleozoic-age Pedregosa basin.

INTRODUCTION

A major focus of the literature on the tectonics of southwestern New Mexico and southeastern Arizona centers on whether Laramide structures demonstrate evidence for a thin-skinned, décollement-type fold and thrust belt or for thick-skinned, basement-involved reverse faulting (e.g. Drewes, 1978; Seager and Mack, 1986; Woodward and DuChene, 1982). Physiographic evidence indicates that the mountains in which Laramide shortening has been studied are flanked by normal faults associated with subsequent Basin-and-Range extension. To date, few workers have investigated the interplay between the compressional and extensional structures in this area. Here we present results from a new gravity survey that suggest that the boundary between the Playas Valley and the Big Hatchet Mountains is formed by a north–south-trending normal fault(s) that cross-cuts northwest-trending Laramide structures.

GEOLOGIC SETTING

The Paleozoic history of the southwestern New Mexico and southern Arizona area is dominated by the accumulation of mostly shallow marine carbonate strata (Greenwood and Kottlowski, 1975) in the Pedregosa basin, which extends from southeastern Arizona and northeast Sonora, Mexico through southwest New Mexico (Thompson et al., 1978, 1989). It contains over 4570 m of strata, primarily carbonate rocks.

The Mesozoic history of the region consists of episodes of magmatic activity, punctuated by tectonism as recorded by continental deposits adjacent to uplifts (Dickinson, 1981). A west-northwest to northwest-oriented rift basin, known as the Bisbee basin in Arizona and as the Chihuahua trough in Mexico, was formed during Early Cretaceous time (Bilodeau, 1982; Dickinson et al., 1986; Mack et al., 1988). Several episodes of deformation and magmatism affected the area during Late Cretaceous and Tertiary times but many details are obscured by limited exposures and uncertainty in geochronology.

From 90 to 75 Ma, coincident with the Sevier orogeny in Utah, Idaho, and Wyoming, Cordilleran thrust faulting deformed the area of what is now the southern Basin-and-Range Province (Lipman and Sawyer, 1985). Between late Albian and late Cenomanian, changes in sediment provenance and dispersal indicate that the Bisbee basin changed from a rift to a foreland basin (Clemons and Mack, 1988). Seager and Mack (1986) showed that Laramide deformation formed the Hidalgo uplift, a northwest-trending feature roughly encompassing the Big Hatchet Mountains, flanked to the northeast by the Ringbone basin and the southwest by the Little Hat Top basin. In the Little Hatchet Mountains, an early phase of Laramide deformation is represented by the Ringbone Formation, which is overlain by the Hidalgo volcanics (Clemons and Mack, 1988). Radiometric ages from the Hidalgo volcanic rocks range from 71 to 55 Ma (Marvin et al., 1978; Young et al., this volume). Debate surrounds the structural style of Late Cretaceous to Early Tertiary shortening, which has been interpreted in terms of both overthrust (Corbitt and Woodward, 1973; Drewes, 1978, 1981; Woodward and DuChene, 1982) and block-uplift models (Seager, 1983; Seager and Mack, 1986).

Late Cenozoic faulting and associated magmatism were significant in southwest New Mexico. The structure and physiography of the southern Basin-and-Range Province are dominated by regional middle to late Tertiary extensional deformation. The early Tertiary was a period of uplift and erosion, whereas the remainder of the period was dominated by extensional continental tectonics and associated volcanism (Drewes et al., 1988).

Middle to late Tertiary extensional deformation is not well documented in the study area, although a number of models have been proposed for the Basin-and-Range Province. One proposes an early period of extension along low-angle normal or detachment faults (Anderson, 1971, Proffett, 1977, Davis and Hardy, 1981) and a subsequent late Miocene–Pliocene period of high-angle faulting that formed the current, deep, alluvial plains separated by protruding bedrock horsts (Scarborough and Pierce, 1978; Eberly and Stanley 1978). Davis (1980, 1983) suggests that the middle-Tertiary volcanic and sedimentary rocks are commonly rotated along listric normal faults that sole into a detachment. Dickinson et al. (1987) point out that many of the mountain fronts in this area follow older extensional structures. Chang et al. (1999) suggest that normal faulting in Hachita Valley is listric.

The surface geology and main physiographic units of the geophysical study area (~31.3°–31.9° N and 108.2°–109.1° W) are shown in Figure 1. This area includes the southwest parts of the Burro-Florida uplift and the northern part of the Pedregosa basin. North to north-northwest-trending valleys and mountains dominate the area. The exposed stratigraphy of the Peloncillo, Animas, and Alamo Hueco mountains consist primarily of Cenozoic extrusive rocks. The Big Hatchet Mountains are composed of Paleozoic sedimentary rocks, whereas Cretaceous sedimentary rocks, Cretaceous–Cenozoic intrusive rocks, and Cenozoic extrusive rocks are identified in the Sierra Rica and Little Hatchet mountains. With some exceptions, most of the surface faults in the sedimentary strata have a north-northwest trend similar to the north-northwest physiographic trend of the Big Hatchet Mountains (Zeller, 1975).

REMOTE SENSING IMAGE

The geophysical study area is shown in the south-central portion of a subscene of an October 1987 Thematic Mapper Landsat image (path 34 row 38) of the southwest New Mexico (inside guidebook front cover). The image was created by mapping reflection data from sensor bands 7, 4 and 2 into the blue, green and red color spectrum and merging them in order to show surface details. The image was warped to the Universal Transverse Mercador (UTM) projection (zone 12) and the 1927 North American Datum (NAD27). As an aid for field logistics during the gravity survey, USGS digital line graphs (DLGs) of public land boundaries, roads, and trails were overlain on the image.

The Peloncillo, Animas, Little Hatchet, Big Hatchet, Apache Hills-Sierra Rica, and Cedar mountains and their north–northwest-trends are clearly delineated by green and red-brown shades in the south half of the false color image. The exception is the Palomas lava field south of Columbus, which is expressed by red and dark gray colors. From the

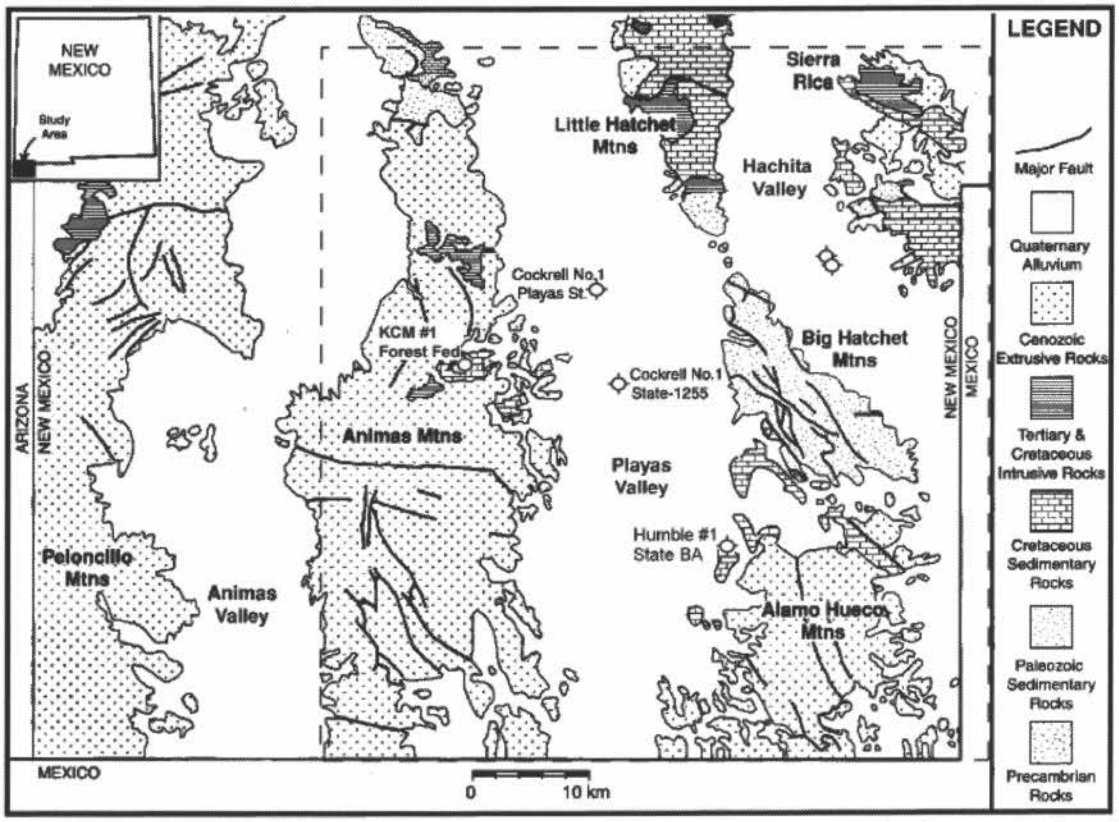

FIGURE 1. Geophysical study area, southwestern New Mexico, Hidalgo County (modified from Chang et al., 1999). Surface features and wells are identified on map. General stratigraphy is given in legend. The dashed line shows the extent of the gravity survey in Figure 2.

hamlet of Hachita, the paved public road (NM-81) runs south through the center of Hachita Valley, turns southwest across Hatchet Gap, and then south through the southern portion of the Playas Valley. Here the valleys are from 10–15 km wide and have moderate–low relief with a typical elevation of 1355 m at USGS bench mark next to NM-81 southwest of Big Hatchet peak. The Big Hatchet range dominates the geography with its massive outcrops of the Permo–Pennsyslvanian Horquilla Limestone forming the Big Hatchet peak at 2572 m above sea level.

GRAVITY SURVEY

In order to better define the subsurface structure, 216 new gravity readings were made in a 45- by 60-km area surrounding the Big Hatchet Mountains (Fig. 2). Measurements were collected at closely spaced intervals (1.0–1.6 km) along or near the acquisition paths of available seismic reflection records and at 2.5–5-km spacing in other areas. The survey traversed ~1400 km of ranch and back roads over the accessible area of the Hachita and Playas Valleys and the intervening canyon areas of the mountains. A Lacoste Romberg gravity meter and portable Trimble GPS units were used to collect the gravity readings. A two-station Global Positioning System (GPS) was used to provide high-quality horizontal and vertical control. A temporary GPS and gravity reference base station was established at a bench mark near the center of the survey area. Gravity reference stations in Deming and Lordsburg were used to establish the temporary gravity base station. Gravity measurements were tied to a common datum and corrected for local relief. Horizontal and vertical locations were tied to the WGS84 datum. Terrain correction techniques (Plouff, 1977) were used to correct for topographic relief. Field measurements of local terrain were supplemented with topographic map elevations of the near-field relief. A reduction density of 2.67 g/cc and sea-level datum were used for the Bouguer corrections.

BOUGUER GRAVITY MAP

The new data were reduced to produce Bouguer anomaly values and merged with over 1000 existing gravity readings in the region, including those of Chang (1993). Many of the existing readings were taken at cultural features, such as earthen water tanks, historical locations, and the intersection of trails. Data point spacing over much of the area

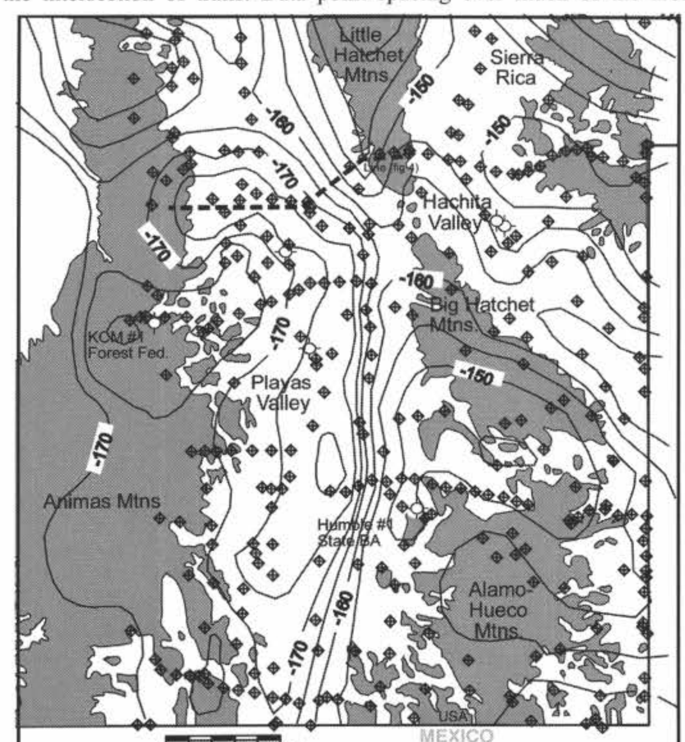

FIGURE 2. Bouguer anomaly map for the detailed gravity survey. Contour interval is 5 mGal. Locations of gravity measurements are marked by a cross within a diamond shape. The main geologic features are shown in gray. Dashed line shows profile of structural model in Figure 4.

ranges from 2 to 6 km in the valleys and >12 km in the mountains.

The data were gridded to produce a Bouguer anomaly map with values ranging from a high of -135 mGal over Little Hatchet Mountain to a low of -180 mGal in Playas Valley (Fig. 2). A marked feature of the new map is the definition of a narrow north–south-trending low beneath the Playas Valley with a latitudinal extent of 40 km from the southern tip of Little Hatchet Mountains south to the international border and maximum longitudinal extent of 14 km. This gravity low is bounded on the east by a strong, north–south-trending gravity gradient where gravity increases by 25–30 mGal over 3–4 km distance. The gravity low probably indicates substantial thickness of low-density basin fill in the Playas Valley. The southern part of the Playas Valley is separated from the northern part by a northeast-trending gravity high. This feature appears to be associated with a structural high at the KCM #1 Forest Federal test (Fig. 1) and extends from there across the Playas Valley.

Two distinct northwest–west-northwest trends are present in the gravity map in the Hachita Valley to the north and northeast of the Big Hatchet Mountains. Gravity values are higher beneath Hachita Valley compared to the Playas Valley suggesting less basin fill in the Hachita Valley. High gravity values at the southern end of the Little Hatchet Mountains probably result from the surface and near-surface igneous and metamorphic rocks present there.

A three-dimensional view that compares the Bouguer gravity surface before and after the new survey (Fig. 3) demonstrates significant differences between the two. The surface resulting from incorporation of new data clearly shows the pronounced, north–south-trending gravity gradient on the east of the Playas valley, where the previous data set had defined a subdued northeast-trending gradient. This feature stands in contrast to the more northwest trends of many other anomalies in the map.

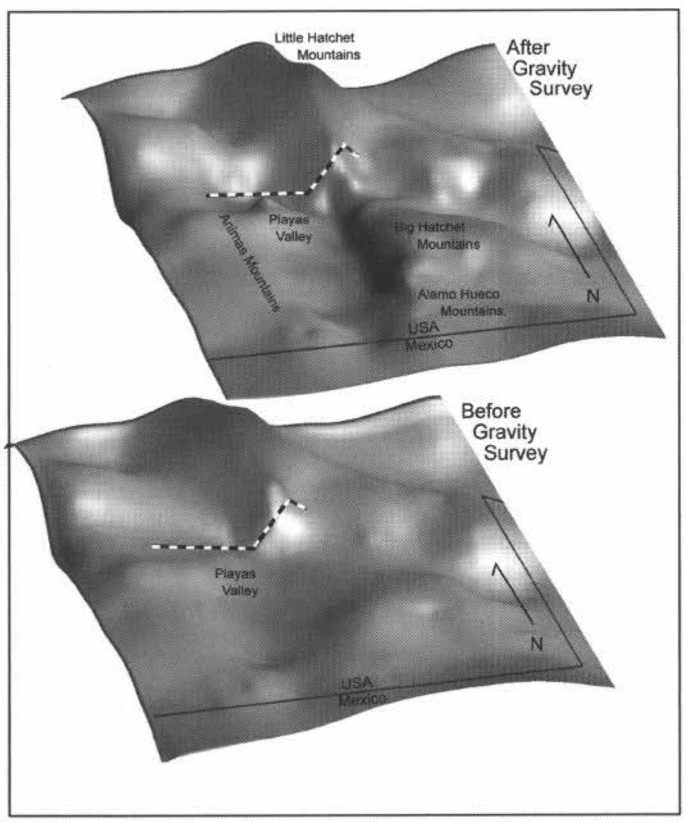

FIGURE 3. Three-dimensional view of the Bouguer gravity surface before and after the new survey. 'Before' surface was created from regional and local gravity data in UTEP database for area shown in Figure 2 as of September 1998. 'After' surface incorporates data points from the detailed gravity survey of the Big Hatchet area. The view is from the southwest. The main mountain ranges and Playas Valley are identified. The international border is shown in black. Dashed lines show the profile of structural model in Figure 4. Vertical and horizonal scales are the same for both surfaces.

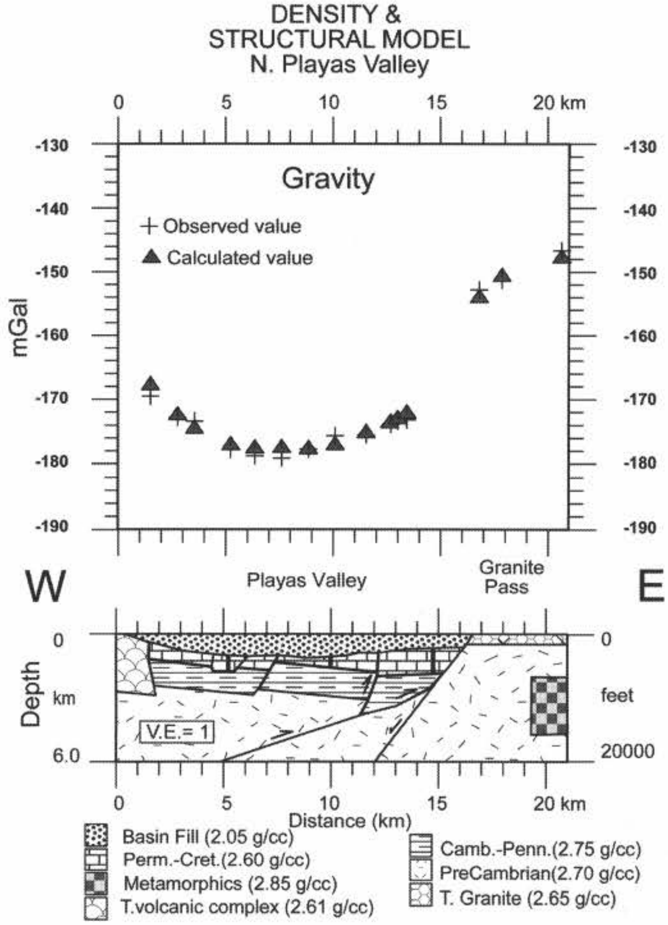

FIGURE 4. Density and structural model along a profile across the northern part of the Playas Valley profile (modified from Chang et al., 1999). Bouguer gravity values are in milligals. Density values used in the forward modeling ranged from 2.05 to 2.85 gm/cc. Profile location is shown by dashed line on Figures 2 and 3.

GRAVITY MODELING

The gravity survey was acquired in order to gain new insight into the subsurface structure of the region by combining gravity modeling with available geologic, well, and seismic data. One result from such an approach comes from a profile (Fig. 4) across the Playas Valley, from Granite Pass in the Little Hatchet Mountains west to the Animas Mountains (Chang, 1993; Chang et al., 1999). Subsurface structure along the profile is constrained in part by seismic reflection data shot in 1979 and 1980 by ARCO. Density values for the sedimentary rocks are based in part on the Cockrell #1 Playas State test located 2.9 km south of the profile, and on data from regional well control. Density values range from 2.05 g/cc for the Cenozoic basin fill to 2.85 g/cc for metamorphic rocks in the Precambrian basement (Fig. 4).

Forward modeling of the gravity data proceeded in an iterative fashion using an algorithm based on that of Cady (1980). Gravity values were calculated for different density models until a satisfactory fit to the observed gravity was achieved (Fig. 4) that was consistent with known geology. Gravity measurements vary by over 30 mGal along the profile. The gravity low associated with the Playas Valley is attributable to thick low-density deposits of Cenozoic basin fill and the Cretaceous–Permian-age units overlying lower Paleozoic strata and Precambrian basement. The Tertiary basin fill reaches ~1000 m in thickness in the central part of the valley and the total Phanerozoic sedimentary section reaches nearly 4000 m near the Little Hatchet Mountains on the eastern side of the trough. The gravity high on the east side of the profile is due primarily to the high density of Precambrian and Tertiary granites that crop out at Granite Pass in the Little Hatchet Mountains. A higher density metamorphic (or mafic) body within the granite is necessary to fully explain the high gravity values over Granite Pass. Precambrian basalt as large rafts within the Precambrian granite are observed at Granite Pass and support the presence of this high density body (Chang et al., 1999).

Seismic data (Chang et al., 1999) suggest that several west-dipping thrust faults cut the Mesozoic- and Paleozoic-age strata on the profile. Along the eastern edge of the valley, strata are juxtaposed structurally against Precambrian rocks at Granite Pass. In addition, both thrust and listric normal faults offset the Precambrian basement. A thrust fault plane along this interface dips at angles of 45° to as much as 65° near the surface but flattens below 3 km to less than 20°. Normal faulting includes high-angle, small-offset faults in the Animas Mountains, and a major, west-dipping listric fault on the west side of the Little Hatchet Mountains. The listric-fault plane begins near the surface and extends below ~6 km near the 12 km mark of the model (Fig. 4). This fault may be the master fault that sets up the strong gravity gradient along the eastern edge of the Playas Valley and creates the asymmetrical geometry of the valley.

Preliminary structural modeling in the southern Playas Valley (Shearer and Miller, 1999) shows results similar to that on Figure 4. The analysis incorporated detail gravity measurements, well, and seismic data along an east–west profile south of the Big Hatchet Mountains. This work indicates that a substantial thickness of Tertiary basin fill continues to the south and underlies the southern part of the Playas Valley. The strong gravity gradient on the east side of the valley likewise appears to be associated with a major, steeply dipping (>45°), north-trending normal fault that cuts across north-northwest-trending faults that crop out in the Big Hatchet Mountains (Zeller, 1975).

SUMMARY

New gravity data acquired in southwestern New Mexico are combined with surface, well, and seismic-reflection data to understand better the geologic structure of the region. The new gravity data define a strong north–south-trending gravity gradient that forms the boundary between the Playas Valley and the Big Hatchet and Alamo Hueco mountains. Gravity modeling and seismic reflection data suggest that the gradient is caused by a down-to-the-west listric normal fault that juxtaposes Tertiary basin fill in the Playas Valley against sedimentary and volcanic rocks of the mountains. This pronounced north–south-trending gradient demonstrates that Basin-and-Range normal faults cross-cut Laramide structures in the region.

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