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INTERPRETATION OF BASEMENT STRUCTURES AND GEOPHYSICAL ANOMALIES IN THE SOUTHEASTERN COLORADO PLATEAU

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Abstract—A preliminary analysis of basement structures in the southeastern portion of the Colorado Plateau was conducted using gravity, drilling and aeromagnetic data. A variety of gravity maps were constructed which delineate the dominant northeast trends which are at least mostly due to Precambrian structures and northwest trends which are mostly the result of Pennsylvanian orogenic activity. Basement heterogeneities were studied via computer modeling of the gravity data. These results indicate basement features which are interpreted to be the result of igneous activity exist beneath the Defiance uplift. The results obtained to date certainly attest to the complexity of the basement in the southeastern Colorado Plateau.

INTRODUCTION

The Colorado Plateau (CP) is a relatively undeformed, high-standing block of the lithosphere which has been of much interest recently. It covers a portion of Utah, Colorado, New Mexico and Arizona (Fig. 1) equal to approximately 360,000 km^2. Surrounding geological provinces include the middle Rocky Mountains on the north, the Southern Rocky Mountains on the northeast, the Rio Grande rift on the east and the Basin and Range on the south and west. Because of the Plateau's complex tectonic history and resource potential, it has become a highly studied region, although many questions still exist regarding relationships between basement features and previous zones of weakness, as well as timing and mechanisms for Plateau uplift.

The objective of this paper is to report a preliminary analysis of basement structures located in the southeastern portion of the CP. This regional structural analysis was performed using enhanced contour maps of gravity anomalies and aeromagnetic data along with geologic and drilling information. Heterogeneity of the basement was also investigated. Basement structures and composition were modeled by computer along an east-west-trending profile.

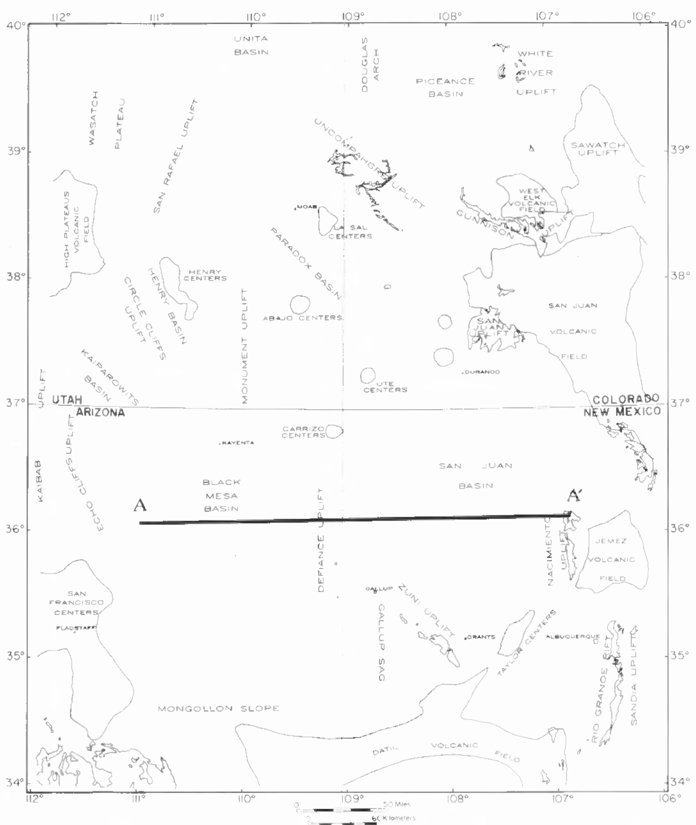

FIGURE 1. Index map of the Colorado Plateau showing major tectonic features. The profile (A-A') modeled in Figure 7 is indicated by the dark line.

DATA AND ANALYSIS

The gravity data base for this study consisted of approximately 22,500 gravity stations which were retrieved from a larger data base maintained at the University of Texas at El Paso. Each gravity station is associated with a simple Bouguer anomaly value. Outer (zones >0.9 km from the stations) and some inner zone terrain corrections are also included for each gravity station. This data base is tied to the international gravity network and reduced using an elevation datum at sea level and a reduction density of 2.67 g/cc. Further processing of these data was necessary to produce high quality maps for interpretation. This involved editing, determining inner zone terrain corrections for those stations near major topographic features, gridding and generating filtered and non-filtered contour maps from the gridded data set.

The Bouguer anomaly map produced is shown as Figure 2. When used to refer to the processing of potential field data, the word residual means the difference between original data values (Bouguer anomalies in the case of gravity) and certain long wavelength components (the regional) of the field. There are many techniques available to calculate the regional, and Simpson et al. (1986) point out that the choice of regional is usually not critical. Any reasonable choice will aid significantly in the interpretation of local anomalies. In this study, we employed the technique of Aiken (1976) to calculate the residual anomaly values mapped in Figure 3. This technique yields results very similar to the isostatic residual method of Simpson et al. (1986).

DISCUSSION

The residual map shown in Figure 3 is the primary focus of this discussion because it best depicts basement structure which is the emphasis of this study. In addition, three filtered maps were constructed to enhance long wavelength, northeast-trending (the primary Precambrian structural trend) and northwest-trending (the primary Paleozoic structural trend) features.

On the residual anomaly map, the Defiance uplift (a north-south-trending anticline exposing Permian and some Precambrian rocks) is associated with two positive anomalies which are separated by a northeast-trending gradient which is the dominant feature on the map in this area. The northernmost anomaly (40 mgal peak at 36.5°N, 109.3°W) is part of a northeast-trending series of positive anomalies. The southernmost anomaly is a north-south-trending lobe delineated by the 10-mgal contour and the label Defiance on Figure 3. The gradient coincides with a magnetic lineament referred to as the Holbrook line by Sumner (1985). This lineament extends from approximately 80 km southwest of Holbrook, Arizona to at least the Arizona-New Mexico state line, and the gravity data suggest it extends farther to the northeast. Sumner

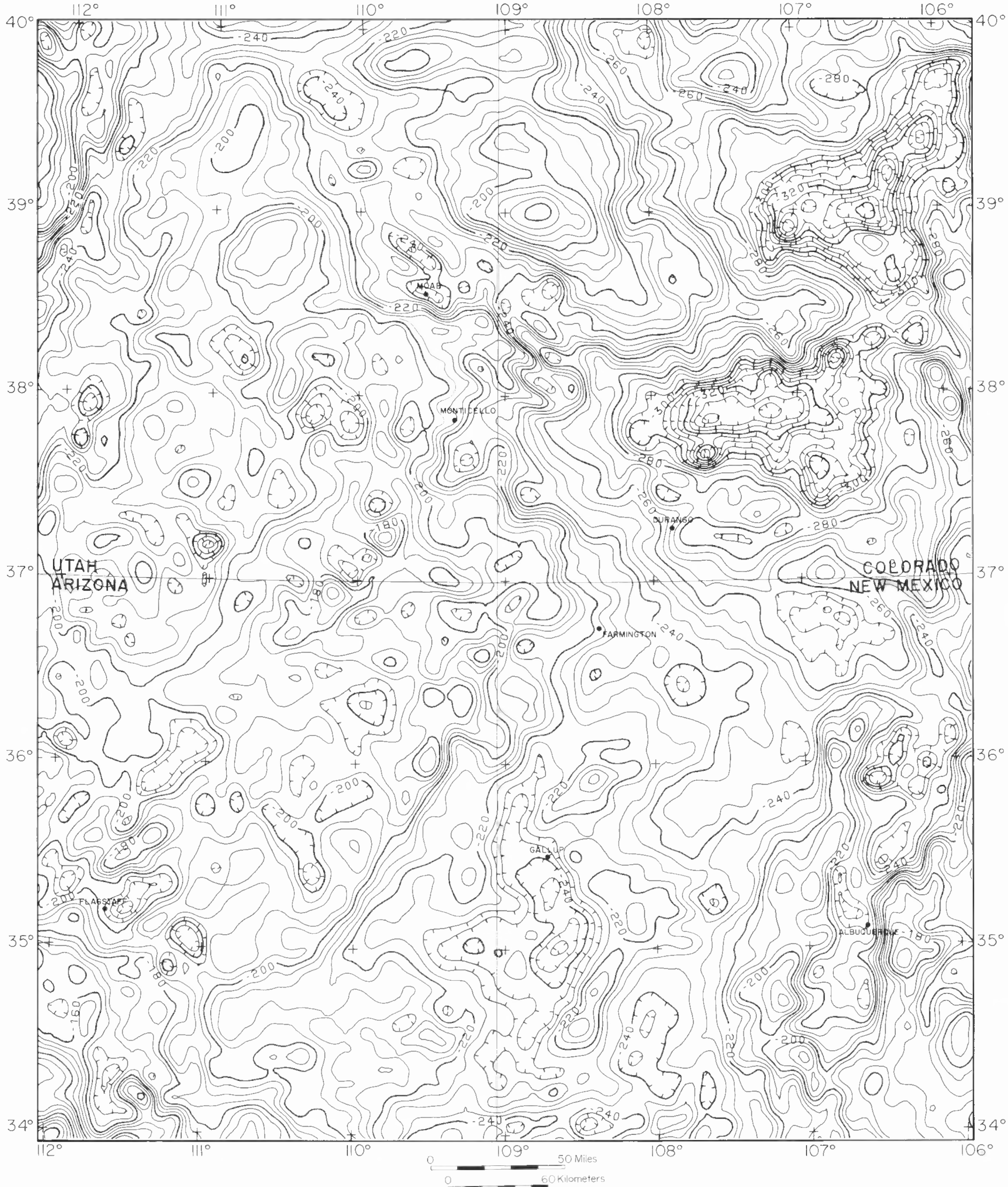

FIGURE 2. Bouguer gravity anomaly map of the Colorado Plateau. Contour interval = 5 mgal. Reduction density = 2.67 g/cc. Reduction datum = sea level.

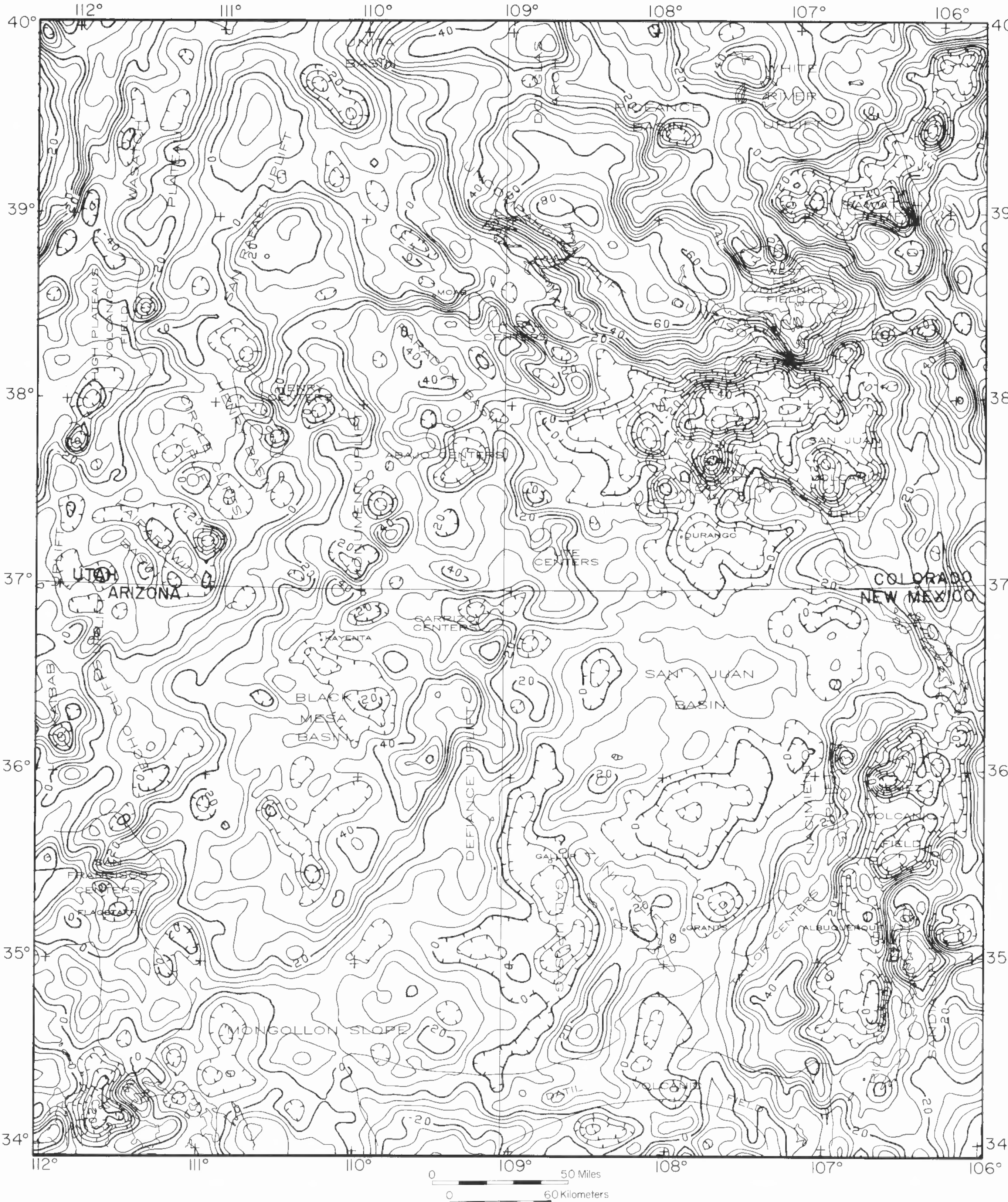

FIGURE 3. Residual gravity anomaly map of the Colorado Plateau. The technique of Aiken (1976) was used to calculate the anomaly values. Contour interval = 5 mgal. Tectonic features as shown in Figure 1 are an overlay to this map.

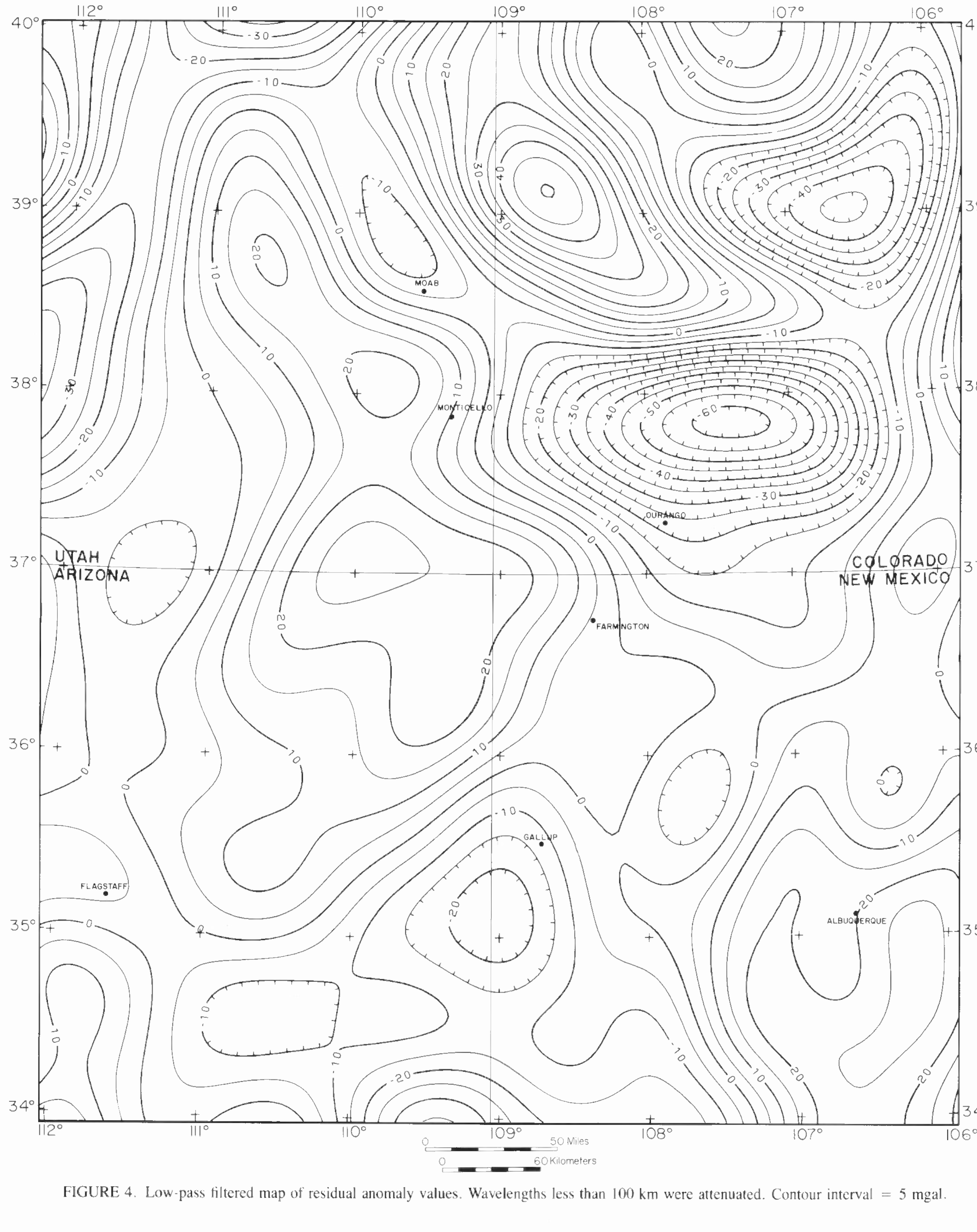

FIGURE 4. Low-pass filtered map of residual anomaly values. Wavelengths less than 100 km were attenuated. Contour interval = 5 mgal.

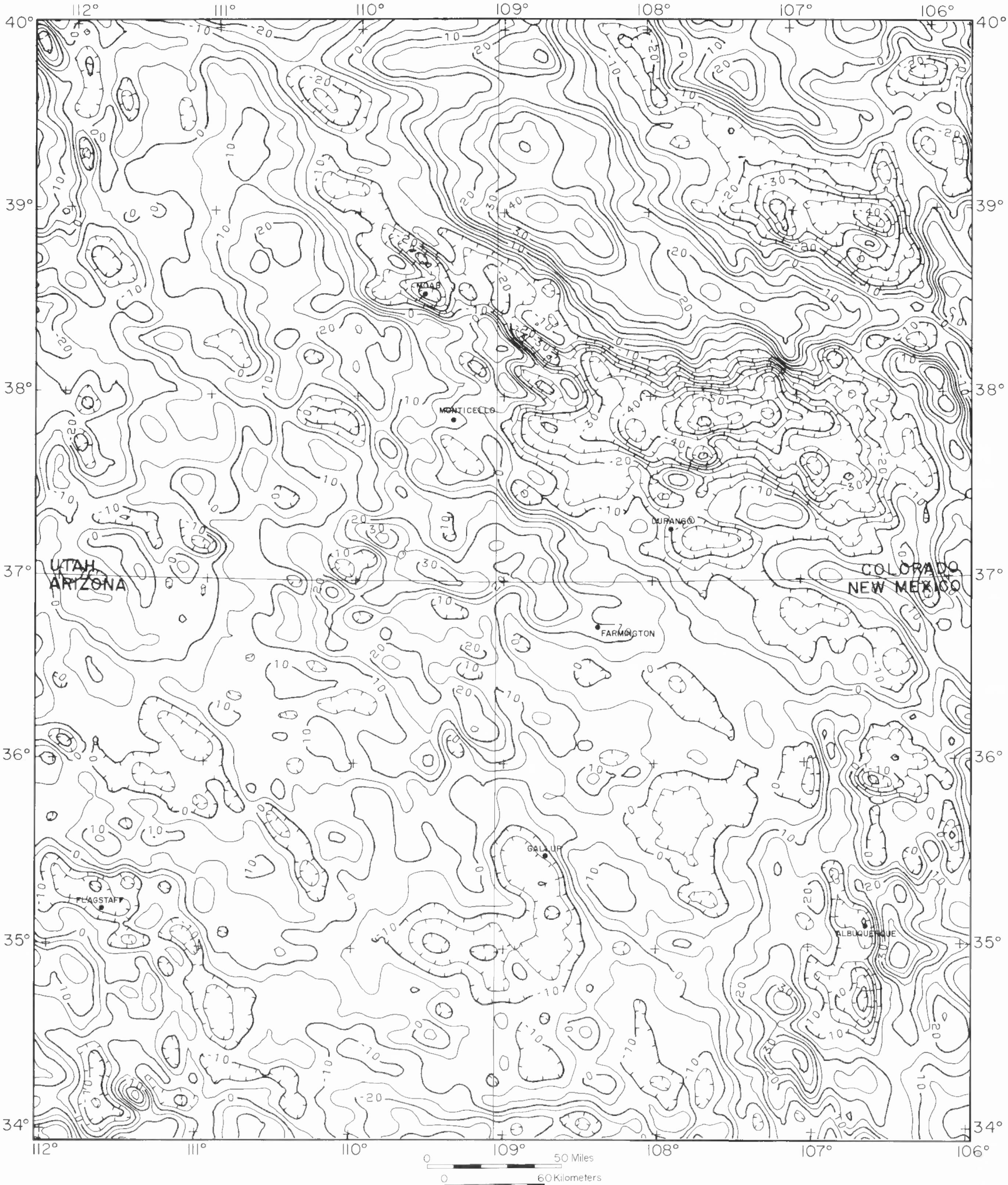

FIGURE 5. Strike-filtered map of residual anomaly values. Anomalies with trends of N40°E ± 25° were attenuated. Contour interval = 5 mgal.

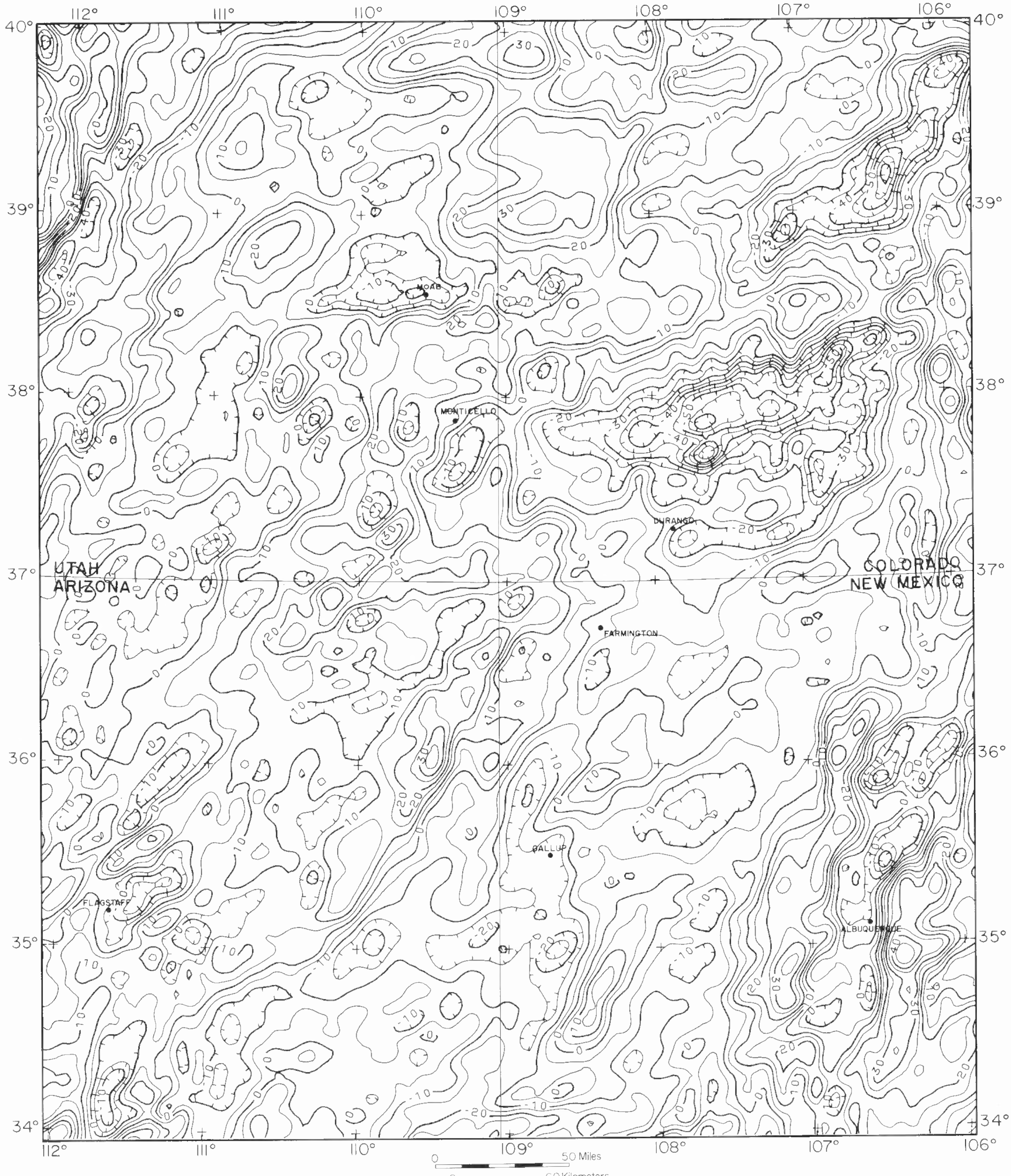

FIGURE 6. Strike-filtered map of residual anomaly values. Anomalies with trends of N50°W ± 25° were attenuated. Contour interval = 5 mgal.

(1985) attributed this feature to a Precambrian fault zone which may have been reactivated several times. This interpretation was based on the fact that the lineament has magnetic characteristics similar to the Mesa Butte and Bright Angel fault systems of north-central Arizona (Shoemaker et al., 1978). Shoemaker et al. (1978) used geologic data to demonstrate that these fault systems are related to displacements in the Precambrian basement.

Precambrian rocks exposed in the Zuni Mountains correlate with relatively small (10–15 mgal), northwest-trending gravity maxima. This gravity anomaly approximately delineates the Zuni uplift. A more prominent anomaly (34.5°N, 108.5°W) extends to the southwest from the Zuni uplift. This anomaly has been named the Chimney Hill gravity high by Ander and Huestis (1985). Using magnetotelluric data, these authors suggested that this anomaly is probably older than the late Cenozoic volcanics which define the Jemez lineament. In the regional perspective of Figure 3, this anomaly appears to be another northeast-trending feature related to the Precambrian structural grain of the area.

The Chaco slope area (36.0°N, 108.5°W), located north of the Zuni uplift, contains a northeast-trending, positive gravity anomaly. A correlative positive magnetic anomaly extends through this same area (Cordell and Keller, 1984; Cordell and Grauch, 1985). However, Cordell and Grauch (1985) showed that the predominant magnetic anomaly in this region is a negative east-northeast trend which extends across the San Juan Basin.

The Gallup sag contains a thickened sedimentary section which separates the Defiance and Zuni uplifts. This area of relatively low density rocks is seen on the residual anomaly map (Fig. 3) as a negative (15 mgal) anomaly striking north-south. The drilling data we have analyzed indicate that the Precambrian basement has approximately 2000 m of relief between the Defiance uplift and the Gallup sag.

The 100 km wavelength, low-pass filter map in Figure 4 was constructed to define anomalies due to large-scale crustal features. It is evident that the Defiance and Zuni uplifts are local crustal features which do not contribute significantly to wavelengths of this order and, therefore, are weakly represented on this map. However, a broad positive anomaly extending across the central Colorado Plateau from the northern Defiance uplift northward to the San Rafael uplift is evident. The northeast-trending Holbrook line which bisects the Defiance uplift is also evident on this map, suggesting it may be related to the boundary of a major crustal block. The Gallup sag and the Chimney Hill anomaly are only partially defined on this map.

Two strike filtered residual anomaly maps were generated to enhance northeast and northwest trends. Northeast-trending anomalies were rejected in Figure 5 in order to enhance northwest-trending features such as the Zuni uplift. Two positive gravity anomalies are depicted in Figure 5 in the area of the northern Defiance uplift suggesting a significant northwest extension of the Zuni uplift. This northwest structural grain is evident in northeastern Arizona and northwestern New Mexico, but it is not nearly as pronounced as in the Uncompahgre uplift region to the north. Note that the northeast-trending Holbrook line is obliterated from this strike filtered map. The Gallup sag is defined on this strike filtered map as an arcuate shaped anomaly curved around the southern tip of the Defiance uplift. The Chaco slope area contains a small circular anomaly, but its northeastern component (Fig. 3) has been attenuated.

Northwest-trending anomalies were rejected in Figure 6 in order to enhance features with significant northeastern trends. The positive anomaly associated with the northern section of the Defiance uplift is shown to be mostly due to a northeast-trending and largely unrelated anomaly. However, the geologic representation of the Defiance uplift trends north-south, which is a major exception to the tendency for structures in this area to trend either northeast or northwest. The Gallup sag separates the Chaco slope area anomaly from the Defiance uplift anomaly and curves around to form the northwestern border of the Chimney Hill gravity high. The Chimney Hill and Chaco slope areas show strong northeasterly trends, whereas the Zuni uplift area is only vaguely represented. This map demonstrates the extent to which a northeast-trending structural grain dominates northeastern Arizona and northwestern New Mexico.

Computer models were generated for a gravity profile extending from the northwestern portion of the Nacimiento uplift westward beyond the Defiance uplift to approximately 36°N, 111°W. The surface of the models was a 1830 m (6000 ft) datum relative to sea level. This datum represents the average elevation across this region. Information from the drill holes shown on the profiles was used to constrain the geometry of the stratigraphic units. Two models are shown which fit the drill-hole constraints and the gravity data (Fig. 7). The densities for the six

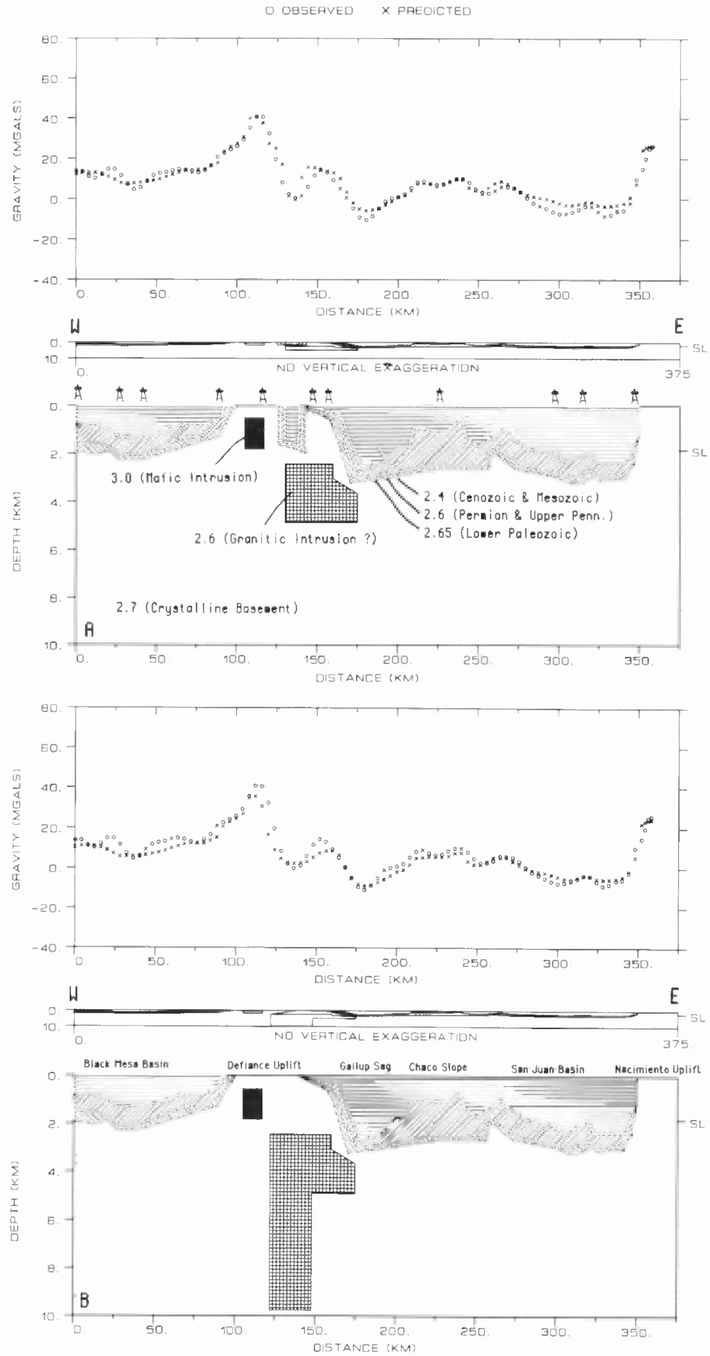

FIGURE 7. Computer generated models which satisfy the gravity data and geologic control for a profile extending along the 36th parallel from the Nacimiento uplift westward to 111°W (Fig. 1). The density values (g/cc) for major geologic units are indicated. The fits between observed and theoretical values are also shown. All drill holes shown penetrate the entire sedimentary section. In model A, the mass deficiency in the eastern Defiance uplift area is modeled partly by a structure involving Phanerozoic strata. In model B, this mass deficiency is modeled entirely with an intrabasement feature (granitic intrusion?).

bodies used are: (1) 2.4 g/cc for the Cenozoic and Mesozoic sedimentary rocks, (2) 2.6 g/cc for Permian and Upper Pennsylvanian sedimentary rocks, (3) 2.65 g/cc for lower Paleozoic sedimentary rocks, (4) 2.7 g/cc for the Precambrian basement, (5) 3.0 g/cc for the mafic intrusive body and (6) 2.65 g/cc for the low density material (granitic intrusion?) required to accommodate a match between the observed and theoretical gravity values. The gravity anomalies which exist require exotic basement bodies in order to satisfy the observed gravity profile. These exotic bodies include a high density mass beneath the western edge of the Defiance uplift. As was previously mentioned, Sumner (1985) recognized a highly magnetized zone in this same region, which suggests the existence of a mafic body. The determination of interrelations between this body and basement faults is particularly difficult in this area because it is at the intersection of what appears to be a northeast-trending series of mafic intrusions (and faults?) and the north-south-trending Defiance uplift. A mass deficiency is associated with the eastern edge of the Defiance uplift, and two possible models of this feature are shown in Figure 7. This complication is due to the fact that the gravity high associated with the Defiance uplift is less than the amount of known basement relief would predict. In Figure 7A, a near surface syncline (Kelley, 1960) and a small exotic body of low density material are employed to model the mass deficiency. This model seems unlikely but does not violate drilling or outcrop control. In Figure 7B, the deficiency is modeled entirely within the basement. This is our preferred model.

CONCLUSIONS

The strong northeastern grain in the gravity (and magnetic) maps of northeastern Arizona and northwestern New Mexico probably reflects the Precambrian structure as suggested by Sumner (1985). Later reactivation probably enhanced the geophysical signature of these zones of weakness. Pennsylvanian orogenic activity caused additional structures (i.e., Zuni uplift) in this area. Structures formed during this time were oriented in a northwest-southeast direction imparting a corresponding grain to the gravity maps. The limited drilling and outcrop data in these areas must be carefully evaluated to determine which geophysical anomalies involve structural relief on the crystalline basement surface and which anomalies are purely due to intrabasement inhomogeneities. The basement complexity indicated for the southeastern Colorado Plateau provides opportunities for further study by both industry and academia.

ACKNOWLEDGMENTS

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