Open-file Report 81-101 Open-file Report 81-101

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY RESULTS OF GRAVITY INVESTIGATIONS OF THE CALICO HILLS, NEVADA TEST SITE, NYE COUNTY, NEVADA

By

D. B. Snyder and H. W. Oliver

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1981

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Contents

ILLUSTRATIONS

ABSTRACT

A total of 211 recently established gravity stations supplement 128 existing regional stations in providing data for a detailed gravity interpretation of the Calico Hills area of the Nevada Test Site. Reduction of these data to complete Bouguer anomalies combined with a regional correction of -0.8 mGal/km N.15° E. reveals an elliptical gravity high centered over the exposed Paleozoic rocks. The anomaly has an amplitude of about 7.5 mGal and extent of about 8 km, elongate in an east-west direction. A log from a 770-m drill hole and data from detailed surface geologic mapping, a seismic refraction line, electrical soundings, and magnetic traverses all provide some control on the interpretation of density variations or rock structure within the study area.

Two nearly perpendicular gravity profiles interpreted by $2\frac{1}{2}$-dimensional modelling suggest the Calico Hills gravity anomaly can be entirely attributed to a lateral density contrast of 0.50 g/cm^3 between Paleozoic rocks (= 2.60 g/cm^3) and the overlying Tertiary tuff (= 2.10 g/cm^3). This boundary can be constrained vertically to within several hundred meters and thus defines the domical structure of the Paleozoic rocks in this region. The strong contrast of this boundary produces anomalies that mask any gravity anomalies of smaller amplitude that might arise from structure internal to the Paleozoic rocks. Therefore, the existence of a relatively high- or low-density intrusive body in those rocks cannot be confirmed or denied.

INTRODUCTION

Gravity stations were established in the Calico Hills of the Nevada Test Site intermittently from March to August 1979 to help evaluate the area as a possible nuclear waste repository site. Thermal alteration observed in local rocks, surface dikes and plugs, and the structural dome in the Calico Hills suggest the existence of an intrusive body in the subsurface (Maldonado and others, 1979). Moreover, a broad magnetic anomaly occurs over the Calico Hills similar to a magnetic anomaly in the Wahmonie area about 15 km to the southeast where Tertiary felsic intrusive rocks crop out. Detailed gravity studies enlarging upon the work of Healey and others (1980b) were conducted in an attempt to verify the existence of such an intrusive body in the subsurface of Calico Hills.

The Calico Hills, the southernmost topographic expression of Shoshone Mountain, border Jackass Flats in the southwestern part of the Nevada Test Site (fig. 1). The area is best reached on land by roads traversing Jackass Flats from Mercury, about 35 km southeast. Many of the gravity stations were established using vehicles along a dirt road that cuts through the Calico Hills, generally in a north-south direction.

As one approaches the Calico Hills from Jackass Flats, the southern limb of a structural dome is being ascended (fig. 2). A facade of colorful altered tuffs forming a south-facing wall gives the area its name. Immediately upon crossing the topographic high, one stands directly on Paleozoic rock. To the left and right, high-angle faults form the contacts between Paleozoic rocks and tuffs in place of the dome-related erosional contacts. As one continues northward, an ever thickening tuff sequence overlies the Paleozoic rocks and continues into the Timber Mountain region far to the north.

ACKNOWLEDGMENTS

Appreciation is expressed to D. R. Jefferis, H. M. Van Buren, and D. A. Ponce for planning and coordinating the field work; to R. B. Livermore, of Fennix & Scisson, Inc., for many gravity observations, terrain corrections, and elevation control and for data reduction; R. N. Harris and J. B. Spielman for assisting in the gravity observation, and to D. C. Hohbach and E. G. Miller for providing a part of the elevation control; C. R. Karish and T. A. Sagara drafted the illustrations.

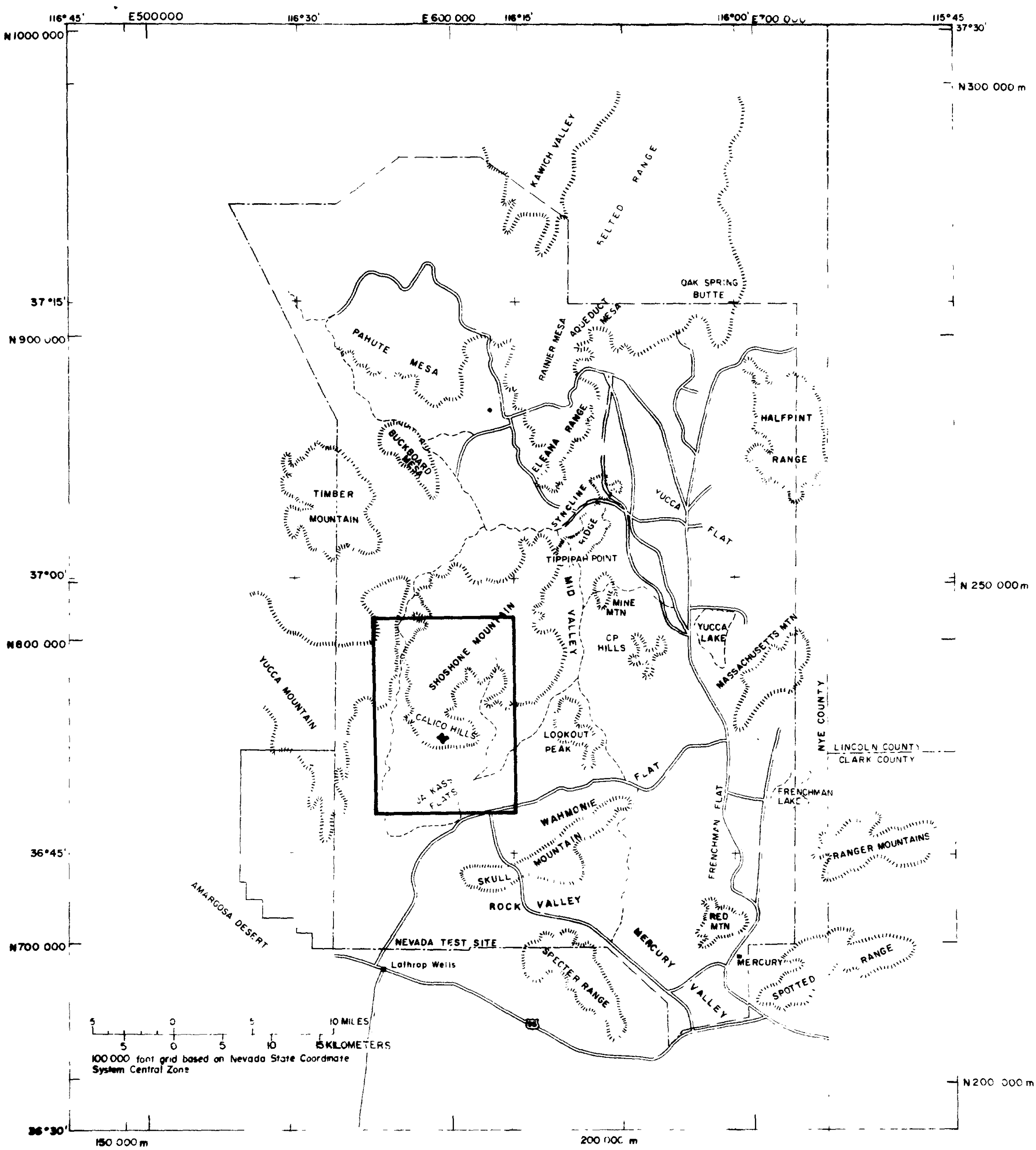
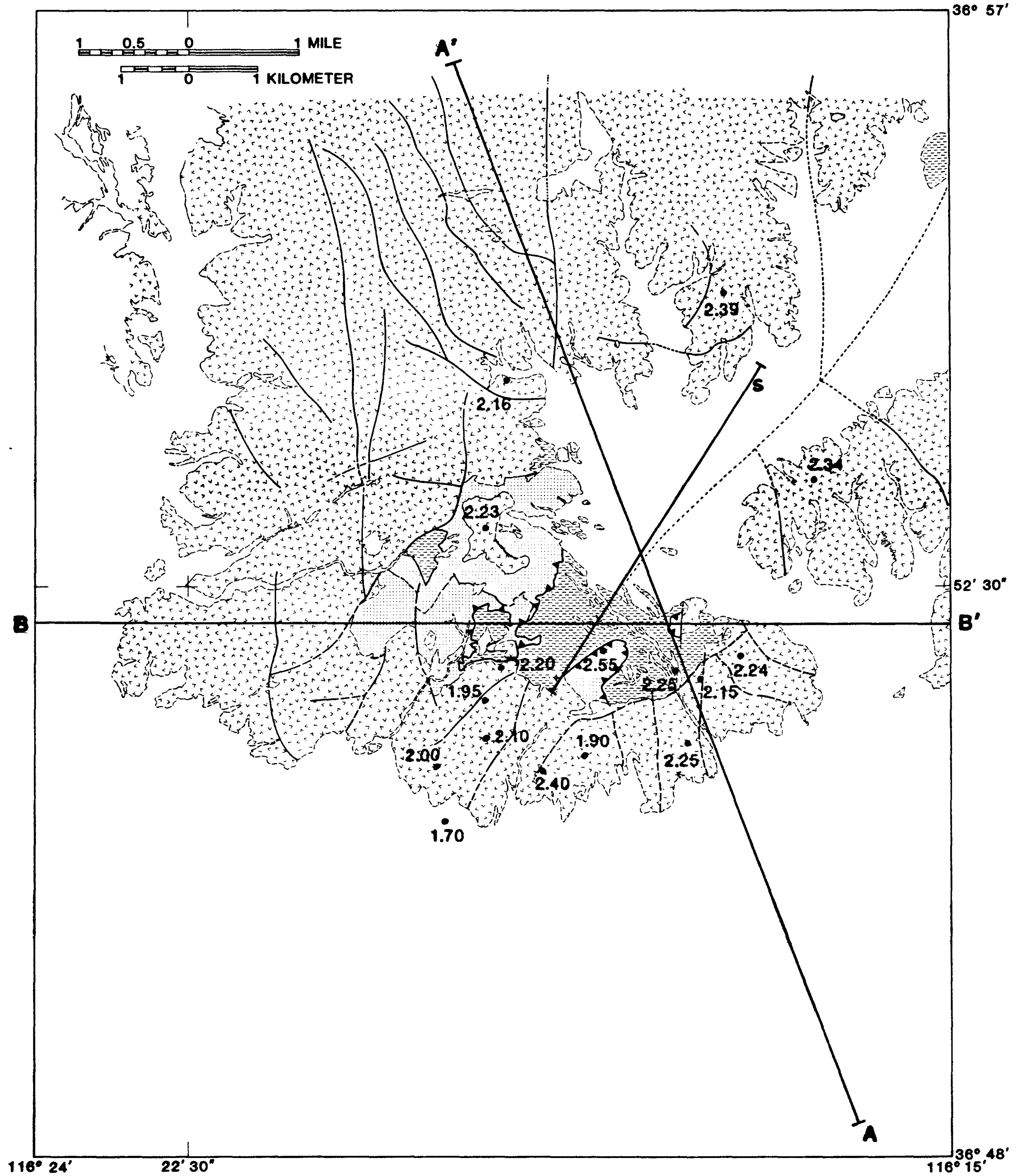


Figure 1.--Index map of the Nevada Test Site showing the location of the Calico Hills. The UE25a-3 drill-hole site and the borders of the gravity study area of figure 8 are shown.



1 0.5 0 1 MILE
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A
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1.70
36° 57'
52' 30"
36° 48'
116° 24'
22' 30"
116° 15'

ALLUVIUM (QUATERNARY)

VOLCANIC ROCKS (TERTIARY)

ELEANA FORMATION
(DEVONIAN-MISSISSIPPIAN, LOWER PLATE)

CARBONATE ROCKS (DEVONIAN, UPPER PLATE)

UE 25a-3 DRILL HOLE

THRUST FAULT (SAWTEETH ON UPPER PLATE)

FAULT-DASHED WHERE APPROXIMATELY LOCATED

CONCEALED FAULT

BULK DENSITIES IN g/cm^3

Figure 2.--Generalized geologic map of the Calico Hills, showing location of the drill-hole UE25a-3, seismic-refraction profile (S), and two modelled gravity profiles (A-A' and B-B'). Bulk densities determined by removing any topographic correlation with local gravity anomalies using the combined elevation-correction factor of Nettleton (1976, p. 89) are indicated at the location at which each was determined.

GEOLOGY OF THE CALICO HILLS

The Calico Hills lie on the southern flank of a structural dome (Maldonado and others, 1979 fig. 2) that exposes thrust plates of Devonian limestone and dolomite superposed on argillite of the Eleana Formation (Mississippian-Devonian). The Paleozoic rocks in turn are overlain by volcanic rocks of Tertiary age (about 8 to 14 million years old). Porphyritic rhyolitic plugs and an andesite dike of Tertiary age intrude the Eleana Formation. Intense alteration of the volcanic rocks has destroyed their pyroclastic texture; the carbonate rocks are locally altered to calcite, quartz, montmorillonite and in places metamorphosed to a white marble. Local alteration of the Eleana argillite has produced hornfels in places and irregularly bleached the rock throughout. A network of radially trending faults appears to be related to the domical structure. The dome, the radially trending faults and the extensive hydrothermal alteration all may have been caused by the intrusion of a magma body at depth.

In addition to the low-angle Mesozoic(?) thrust fault, the Calico Hills area is structurally influenced by its setting in the Basin and Range province and on the south edge of the Timber Mountain caldera complex. Near the Calico Hills, the caldera complex has deposited many layers of tuffaceous sediments that thicken and become more complex to the northwest. The generally north-south trending high-angle faults found throughout the Basin and Range province are present in the Calico Hills. These high-angle faults produce no impressive fault scarps in this area but do offset most tuff units and appear to modify the symmetry of the domical structure (McKay and Williams, 1964).

Geophysical basement rocks in the Calico Hills belong to the Eleana Formation of Carboniferous age. At least 2,350 m of these clastic rocks have been divided into ten major lithologic units, denoted in ascending order A through J (Poole and others, 1961), that contain argillite, quartzite, limestone, and conglomerate in varyious combinations. Only units I and J are of direct interest to gravity modelling. Unit J is predominately argillite; the uppermost unit is quartzite (Poole and others, 1961). At Calico Hills, unit J has been redivided by Maldonaldo and others (1979) into argillite, altered-argillite, and calcareous altered-argillite intervals. Digitized density logs were obtained for these rock units penetrated by the drill hole UE25a-3. Typical values are 2.55 g/cm^3 for the altered argillite intervals and 2.50 g/cm^3 for the argillite interval. Some fractures in the argillite interval are coated with, and may have been sealed or filled by, secondary mineralization during hydrothermal alteration but opened during drilling. The unit I marbles exhibit considerable variation in density. A median value of 2.60 g/cm^3 matches density values used in gravity studies in other regions of the Nevada Test Site where the Eleana Formation occurs (Wahl, 1969) and will represent unit I as well as lower stratigraphic subunits of the Eleana in modelling the Calico Hills.

The relatively thin (less than 200 m) Devonian carbonate rocks of the upper thrust plate directly overlying the Eleana in places will be considered part of the Eleana and assume its density values in the gravity interpretation.

Tertiary tuffaceous sediments unconformably overlie the Eleana Formation in most of the Calico Hills area. Near the northern edge of the study area, nonwelded to densely welded tuff units totaling many thousands of meters rest upon the Paleozoic rocks (Orkild and O'Connor, 1970). This large stack of tuffs includes all or parts of the following formations, in ascending order: Crater Flat Tuff, Rhyolitic tuffs and lavas of Calico Hills, Paintbrush Tuff, and Timber Mountain Tuff. To the south, only the Calico Hills and Paintbrush Tuffs appear. These tuffs vary in density from 1.08 g/cm^3 to 2.43 g/cm^3 depending on the degree of welding and amount of alteration (Carr, 1966; App. 2). Density determinations in the immediate vicinity of the Calico Hills utilizing the effect of density upon topographically related gravity anomalies (fig. 2) indicate a range of values of 2.17 $\pm$ 0.14 g/cm^3. Bulk tuff densities of 2.1 g/cm^3 and 2.25 g/cm^3 will be considered.

Quaternary alluvium covers the surface in both the shallow basin directly north of the Calico Hills proper and in Jackass Flats. A density value of 1.7 $\pm$ 0.1 g/cm^3 determined by the topographic effect mentioned above is deemed appropriate for this stratigraphic unit (D. L. Hoover, oral commun., 1980).

GRAVITY DATA COLLECTION AND REDUCTION

Healey and others (1980b) assembled regional gravity coverage that had existed in the southwest quadrant of NTS for a number of years. Better interpretation of the local gravity field required the more detailed field work begun in March 1979. This work established (1) 95 newly surveyed stations on the southern slopes of the Calico Hills reached by jeep or on foot, (2) 22 helicopter stations on isolated peaks, and (3) a line of 61 closely spaced stations trending north-northwest from the road pass in the Calico Hills (profile A-A', fig. 2). The principal facts for these stations and the 128 stations of Healey and others (1980b) are given in Appendix 1 at the end of this report.

All 339 stations have been reduced by the standard U.S. Geological Survey method using a computer program of D. F. Barnes (written commun., 1978) and Plouff (1977). The gravity datum is IGSN 1971 (Morelli, 1974); free-air anomalies are referenced to GRS 1967 (International Association of Geodesy, 1971). Terrain corrections to a radial distance of 0.068 km from the station were made in the field; those from 0.068 km to 0.59 km were made using cylindrical ring templates (Hammer, 1939). The remaining correction for terrain variations out to 167 km were computer-generated using the U.S. Geological Survey modification of the Defense Mapping Agency digital terrain data. Reduction density is 2.67 g/cm^3. The prime base station, Mercury, tied to IGSN Network stations DOD 0363-2 in Las Vegas and DOD 4027-1 in Indian Springs, is located at the geophysics laboratory bench in the USGS buildings at Mercury, Nev. The observed gravity value there is 979,518.80 mGals. All field measurements for these stations were made using LaCoste and Romberg gravity meters G17 and G177. These meters were calibrated on the Mount Hamilton or Mount Charleston gravity calibration loops before and after each field session (Barnes and others, 1969; Ponce and Oliver, unpub. data).

The use of residual gravity values in this study removes large scale effects of lateral density variations in Paleozoic rocks and even deeper structures. Diment and others (1960) calculated a regional gravity field using only stations on Paleozoic rock outcrops; in the Calico Hills region a linear regional gradient from this study is -0.88 mGal/kmn at N.15^{O}E. (fig. 3). In addition, isostatic corrections were calculated using differing compensation models, producing linear gradients about -0.25 mGal/km less. Datum shifts and differing reduction methods further increase the possible inaccuracy of the regional gradient by $\pm$ 0.05 mGal/km, but the concept of direct contact with the local Paleozoic rocks makes the gradient of Diment and others the most attractive in a study area as limited as the Calico Hills. The uncertainty in this regional gradient of $\pm$0.30 mGal/km causes an uncertainty of several degrees in the slope of the Paleozoic surface on the north and south flanks of the Calico Hills dome.

OTHER INVESTIGATIONS AT CALICO HILLS

Drill-Hole exploration

The UE25a-3 exploratory drill hole was completed on October 10, 1978, at Nevada State Coordinates N. 234,498, E. 183,772 m (fig. 2). The drill penetrated 771.2 m of Eleana Formation without finding an intrusive crystalline body that it was expected to verify (Maldonaldo and others, 1979, p. 1). The hole penetrated 422.5 m of the argillite subunit of the Eleana Formation unit J, 298.1 m of the lower subunit of unit J, and 50.6 m of unit I. Because these stratigraphic Eleana subunits of Poole and others (1961) differ from the zones of hydrothermal alterations, the following intervals were subsequently determined on the basis of the presence or absence of thermal alteration (Maldonaldo and others, 1979, p. 5-12): argillite, 0-416.1 m; altered argillite, 416.1-676.9 m; and calcareous altered argillite, 676.9-720.6 m.

The metamorphism of the rocks increases with depth. Although the argillite interval was not visibly bleached by thermal metamorphism, hydrothermal solutions migrated through fractures, depositing kaolinite. Heat drove off organic carbon, resulting in the bleaching of black argillite to lighter colors within the altered argillite and calcerious altered-argillite intervals. The marble present, representing the highest grade of metamorphism found in cored rocks, formed by thermal alteration or metamorphism of Eleana unit I(?) carbonates at temperatures near 350^{O}C.

Heat-flow measurements in this drill hole indicate a high rate, about 3.2 HFU. Temperatures range from 14^{O}C at the surface to 47^{O}C at the bottom depth of 750 m. Deep upward migration of water is hypothesized for the Calico Hills region (Sass and others, 1980).

Seismic surveys

A seismic refraction line surveyed the northern half of the Calico Hills area (line S, fig. 2) using stations extending northeastward from the UE25a-3 drill hole across the alluvial basin north of the Calico Hills proper and into the wash to the northeast, Topopah Wash. Four main features appearing in the seismic interpretive cross section (fig. 4) have been incorporated into the gravity modelling. Stratigraphic units with velocities equal to or less than 3.3 km/s are considered alluvium or highly weathered rocks. The 3.7 km/s unit is interpreted as the southern edge of the tuff sequence forming Shoshone Mountain. The 4.0 to 4.5 km/s units correlate with the Eleana Formation argillites, the higher velocities associated with thermal alteration and

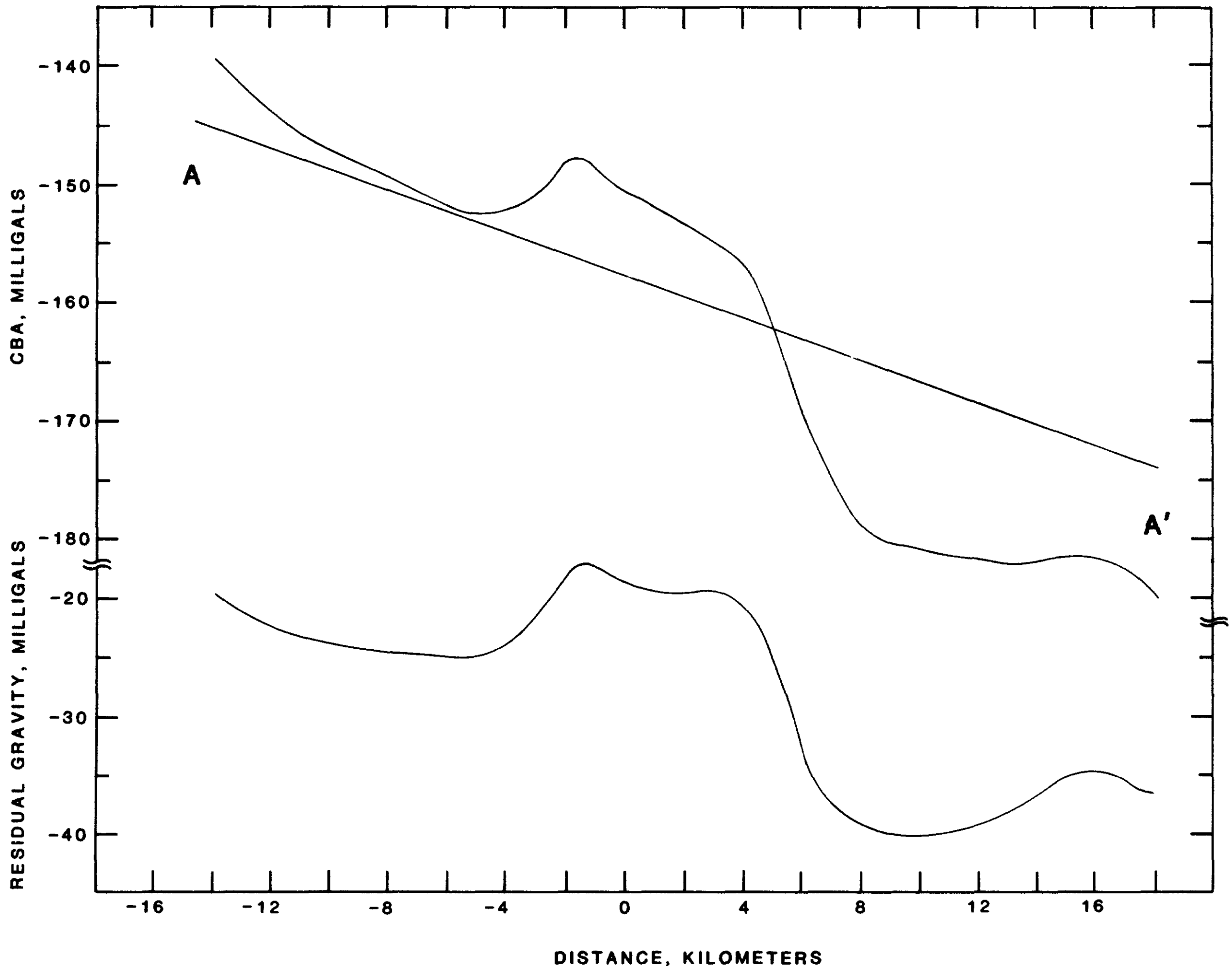


Figure 3.--Removal of the regional gravity gradient of -0.88 mGal/km at N15°E from the complete Bouguer anomaly gravity profile A-A'. The resulting residual gravity profile is used for interpretation in this study.

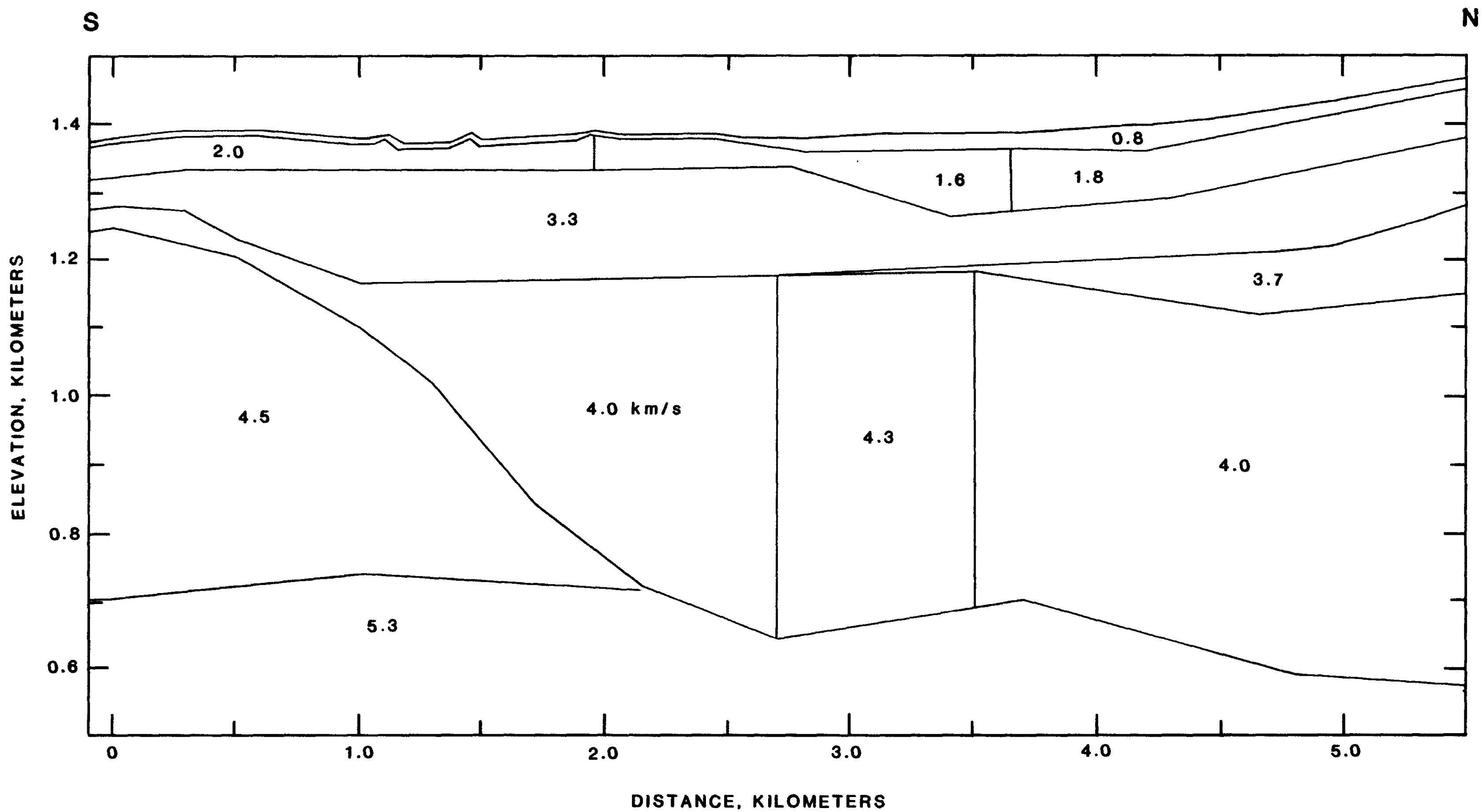


Figure 4.--Interpretive cross section of the seismic refraction line at Calico Hills produced by Lee Pankratz of the U.S. Geological Survey (written commun., 1980). In this report, all units indicating velocities less than 3.5-km/s unit were considered alluvium or highly weathered rocks, ρ = 1.7-1.8 g/cm^3, the 3.7-km/s unit was interpreted as tuff, ρ=2.1-2.25 g/cm^3, the 4.0-4.5-km/s units as Eleana Unit J argillites, ρ=2.5-2.55 g/cm^3, and the 5.3 km/s unit as Eleana Unit I, ρ=2.6 g/cm^3. Vertical exaggeration, 2.85.

related fracture filling. The 5.3 km/s stratigraphic layer is interpreted as the marbleized Eleana I(?) unit, the deepest rocks characterized by the drill cores and seismic survey.

Electrical soundings

Hoover, Chornack, Nervick, and Broker (unpub. data) have established five magnetotelluric soundings, 23 Schlumberger vertical electrical soundings, and six dipole-dipole induced polarization traverses in the vicinity of the Calico Hills. A resistivity log for the depth interval of 620- to 760-m in UE25a-3 is also available (Maldonaldo and others, 1979, pl. 1).

Resistivities generally increase from values of about 50 ohm-meters in the unaltered Eleana Formation unit J to about 1000 ohm-meters in the deeper marbleized Unit I(?). South of the drill hole, high resistivities suggest the absence of unaltered Eleana unit J near the surface to the 1500 m depth explorable by the electrical methods. Below about 1 km, only the magnetotelluric data provide information. These data show a high resistivity body beneath the Calico Hills with a top at about 2.6 km depth and bottom around 100 km.

The dipole-dipole arrays indicate faulting within a conductive zone associated with Topopah Wash that is linear and strikes north-northeast. The zone has an apparent resistivity of 20 to 100 ohm-meters at 100 m depth, inferred to be due to unaltered Eleana unit I.

Magnetic surveys

Both aeromagnetic and ground magnetic data were collected along traverses in the Calico Hills area. The aeromagnetic map, figure 5, shows the sharp anomalies that originally turned attention to the Calico Hills. Anomalies from two sources may contribute to the broad anomaly over the Calico Hills (G. D. Bath, oral commun., 1980). The large circular anomalies are thought to be caused by the near-surface argillites of the Eleana Formation that have high magnetic content in this area. The broader anomaly probably arises from a deeper source. The ground traverse coincides with the detailed gravity survey and passes through the saddle between the two aeromagnetic maxima (fig. 5). The cross sections in figure 6 compare the ground magnetic traverse, the detailed gravity survey, and geologic outcroppings. In general, exposures of Paleozoic rocks correlate with magnetic highs, and alluvial pods and lenses match up with gravity lows.

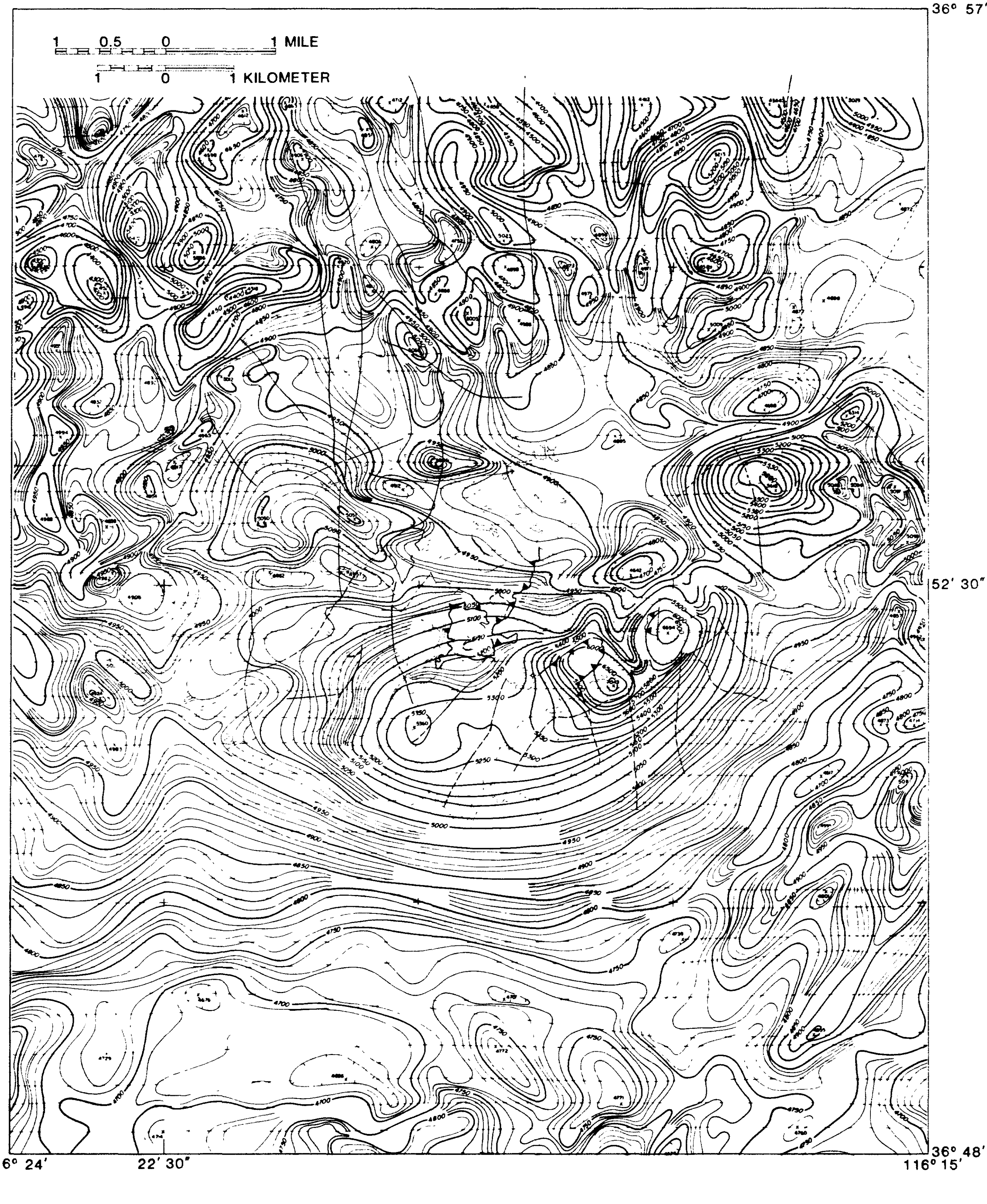
Previous gravity measurements

No detailed gravity measurements had been made at Calico Hills prior to this study. Extensive measurements support weapon-testing north and east of this area (Diment and others, 1960); only regional reconnaissance, summarized by Healey and others (1980b), encompassed the present study area.

INTERPRETATION

General statement

Of primary concern to this study was to confirm or deny the existence of an intrusive body at Calico Hills. The extent and internal structure of the Eleana argillite are another major interest. Aeromagnetic measurements (fig. 5) reflecting a very distinct magnetic anomaly at Calico Hills first drew attention to the area as a possible location of a deep intrusive body. On the


1 0.5 0 1 MILE
1 0 1 KILOMETER
36° 57′
52′ 30″
36° 48′
116° 24′
22′ 30″
116° 15′

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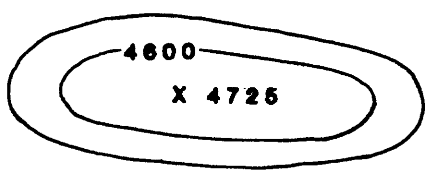


AEROMAGNETIC CONTOURS
CONTOUR INTERVAL IS 10 GAMMAS.
LOCAL MAXIMA AND MINIMA INDICATED.

Figure 5.--Aeromagnetic map of the Calico Hills and vicinity. The three sharp anomalies directly over the Calico Hills are prominent; a broader, lower amplitude anomaly is more subdued. The sharp anomalies are attributed to locally magnetic Eleana argillites (G. Bath, oral commun., 1980). Magnetic contours are residuals with respect to the 1975 IGRF corrected to November 1977 with a 5,000-gamma constant added. Survey was flown 400 ft above the surface (U.S. Geological Survey Open-file Map 79-587).

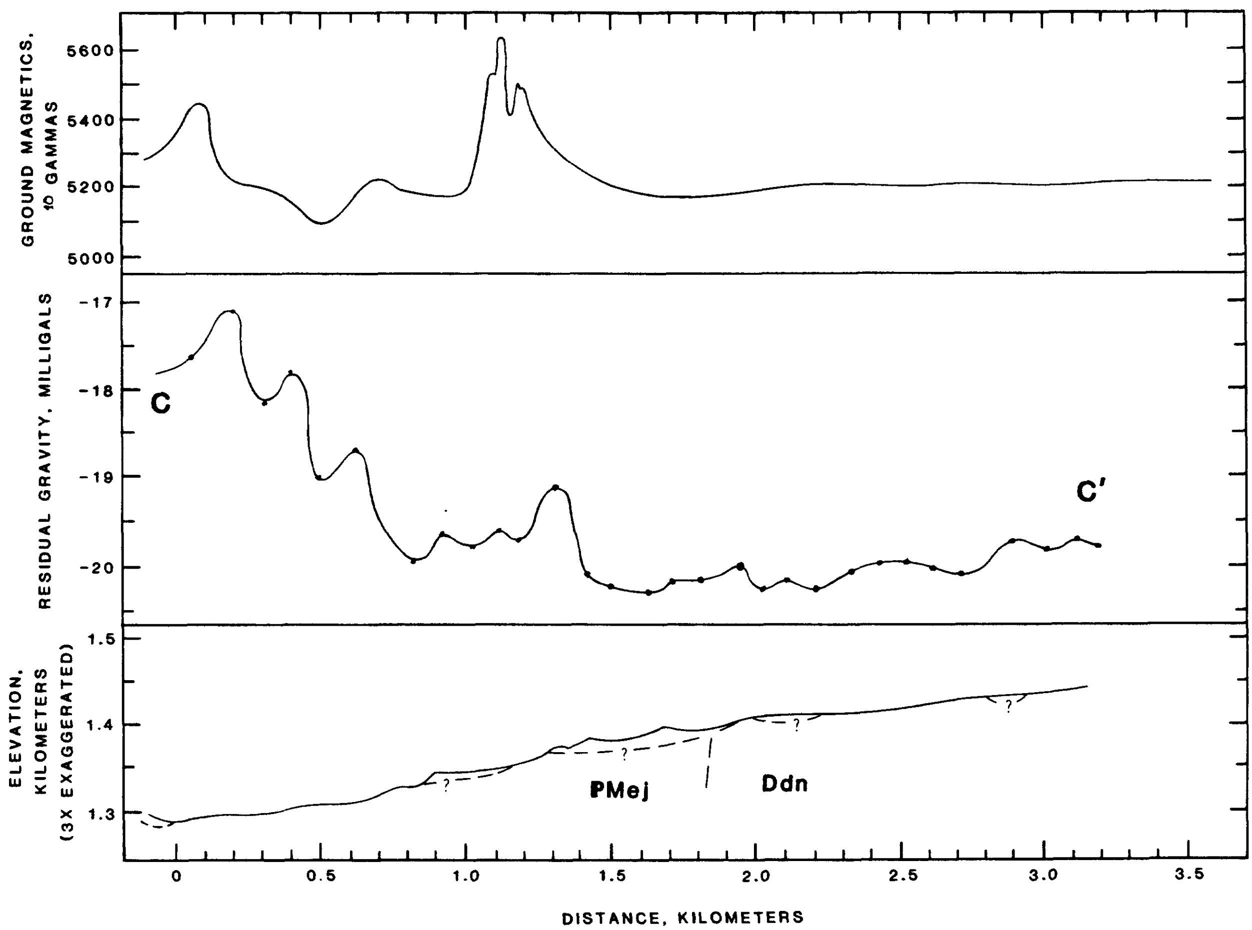


Figure 6.--High resolution north-south geologic cross section C-C' with coincident gravity and ground magnetic profile. Geology is taken from Orkild and O'Connor (1970), PMej represents Eleana argillite, Ddn overthrust limestone. The gravity profile contains the residual Bouguer anomalies for reduction density of 2.67 g/cm^3. The profile is both defined and located by the line of closely spaced stations in figure 8, centered at lat 36°52'30" N, long 116°18'0" W. The total magnetic intensity near ground level was measured with a proton magnetometer (G. Bath, written commun., 1980). Magnetic highs tend to correlate with Paleozoic rock outcrops; gravity lows are associated with surficial lenses of alluvium.

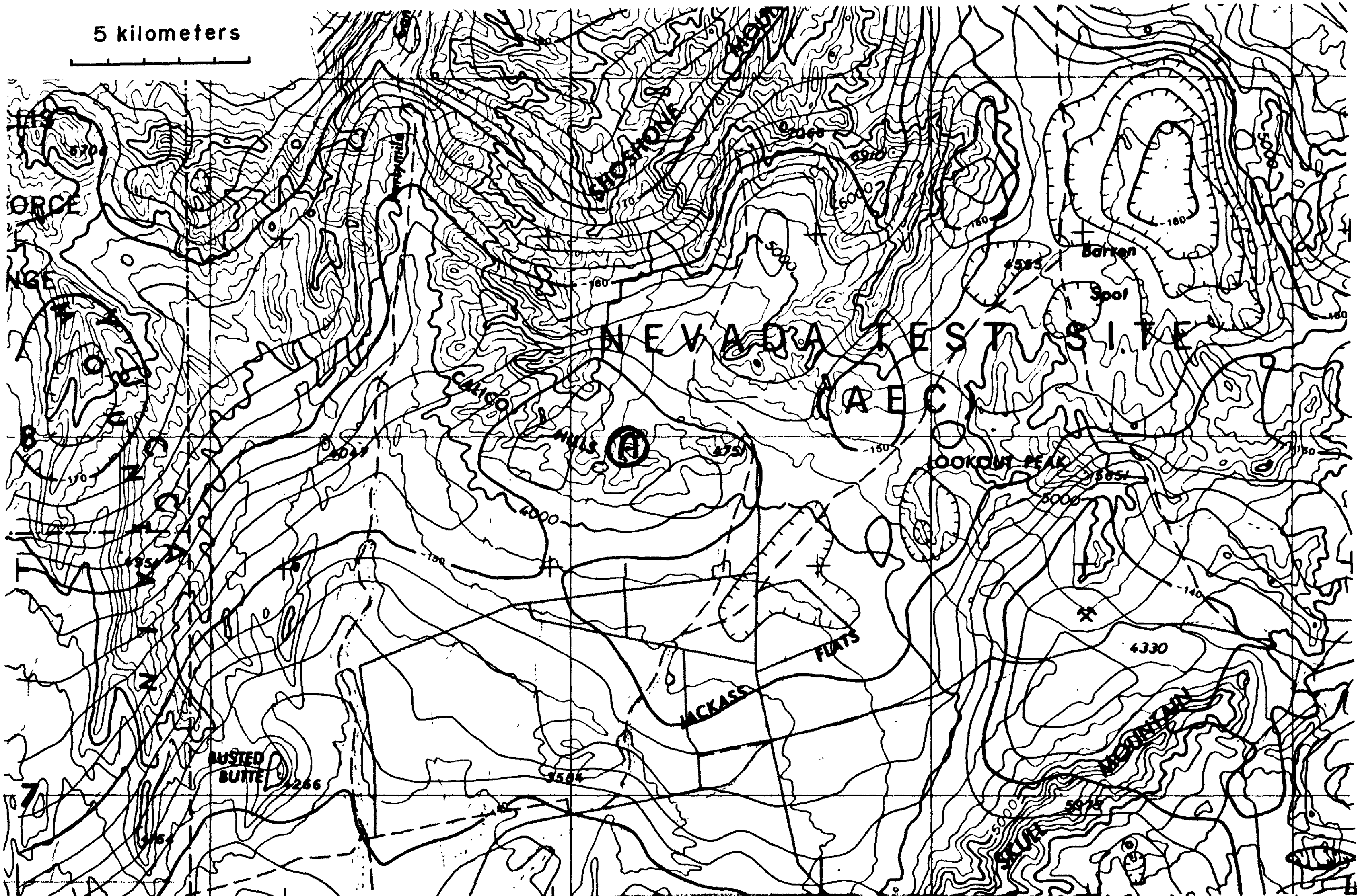
other hand, surface geologic mapping and drill-hole logs indicate that Calico Hills is unusual within the southwestern Nevada Test Site in its surface exposure of Paleozoic argillites. These relatively dense rocks near or directly at the surface are another possible source for the Calico Hills gravity high

In some other areas of southern Nevada, the coincidence of distinct gravity and aeromagnetic highs is associated with known intrusive bodies, as at Wahmonie and Black Mountain (Healey and others, 1980a; 1980b; Spengler and others, 1979, p. 32-35). The gravity high at Calico Hills could possibly result from an intrusive body situated at depth greater than the drill-hole depth of about 800 m beneath the surface. However, intrusive masses do not necessarily produce gravity highs. For example, no local anomalies are associated with the Climax and Gold Meadows (Healey and Miller, 1963) stocks located in the northeastern part of the Nevada Test Site. The quartzite and carbonate country rocks that these stocks intrude themselves produce strong density contrasts with neighboring Cenozoic rocks, whereas the density contrast between the intrusive rock and quartzite is negligible (Healey and Miller, 1963, p. B64; Wahl, 1969, p. 8). Moreover, many felsic intrusions in eastern California are the source of gravity lows because the rocks they intrude, such as schist, amphibolite, and marble, have higher densities (2.8-3.0 g/cm^3) than the intrusions (2.7 g/cm^3) (Oliver, 1977, 1980; Oliver and Robbins, 1980). Thus intrusive magma bodies are observed to have a wide variety of gravity signatures.

With this fact in mind, the interpretation of the gravity field at Calico Hills must begin by defining the gravity effects attributable to the Paleozoic/Tertiary rock interface. The significant density contrast (0.3-0.5 g/cm^3) existing between these rocks makes this stage of interpretation critical. Once the effect of these relatively near surface structures is removed, source bodies at depth within the Paleozoic rocks can be explored. These deep bodies have low density contrast values (less than perhaps 0.2 g/cm^3) and may be several kilometers below the surface. As a result, perturbations in the measured surface gravity field caused by their presence will be of rather low amplitude and difficult to define. This fact suggests the key question in interpreting the Calico Hills gravity field: Can the subsurface extent of the Paleozoic Eleana argillite be defined precisely enough to permit examination of its internal structure, including the existence of an intrusive body?

Contour-map interpretation

From a regional perspective, the Calico Hills gravity field is an elliptical anomaly of several milligals amplitude located on a northeast-trending shelf between high-gravity regions to the southeast near Wahmonie and Skull Mountain and low-gravity areas at Shoshone and Yucca Mountains (fig. 7). Over the study area, the gravity field, with a regional gravity gradient removed (fig. 8), shows an edge of the large gravity low at Shoshone Mountain to the north, the oval 7-mGal Calico Hills anomaly at the center, and, to the south, 1 to 3-mGal gradients within the northeast-trending band of figure 7. Removal of the regional gradient emphasizes the oval Calico Hills anomaly (fig. 8).



116° 30' Figure 7.--Regional 2-m mGal complete Bouguer anomaly gravity contour map of the southwestern quadrangle of the NEvada Test Site; hachures indicate closed areas of lower gravity. Point A, the Calico Hills, appears as a small positive anomaly within a northeast-trending band that separates a gravity low to the northwest from a gravity high to the southeast near Skull Mountain. The Calico Hills anomaly is rather subdued and irregular in shape. Gravity contours are from D. L. Healey (written commun., 1979). Base from U.S. Geological Survey, Death Valley 1:250,000 quadrangle, 1970.

Regionally, the Calico Hills anomaly is very subdued, especially at its east edge, and somewhat irregular in shape (fig. 7). Irregularly shaped anomalies are characteristic of shallow causative bodies, irregular in shape or distribution. An isolated sizable intrusive body, on the other hand, produces an anomaly noticeable mainly for its continuity and symmetry, although overlying rock units could make critical contributions to the extent and symmetry of the overall anomaly.

The Calico Hills residual anomaly (fig. 8) is roughly defined by the -23 mGal contour. The anomaly opens to the northeast and east beyond the -21 mGal contour in the vicinity of a ridge of tuffaceous rocks in the direction of the northeast-trending band noted earlier. To the north, the limb of the anomaly loses definition as residual anomaly values decrease to -46 mGals because of gradual increase in elevation of rocks having densities less than the 2.67-g/cm^3 reduction density and possibly because of the deepening of the Paleozoic basement northward. In a three-dimensional perspective of the residual gravity map (fig. 9), the 1- to 5-mGal anomalies superimposed on the main anomaly appear clearly. These 0.5- to 1.0-km diameter anomalies do not correlate with changes in surface rock units, but many of them do correlate with local topographic features, and they have been used to estimate the bulk densities of those features relative to the 2.67 g/cm^3 Bouguer reduction density (fig. 2). Some of the small anomalies may also be produced by local hydrothermal alteration causing density contrasts within the rock units.

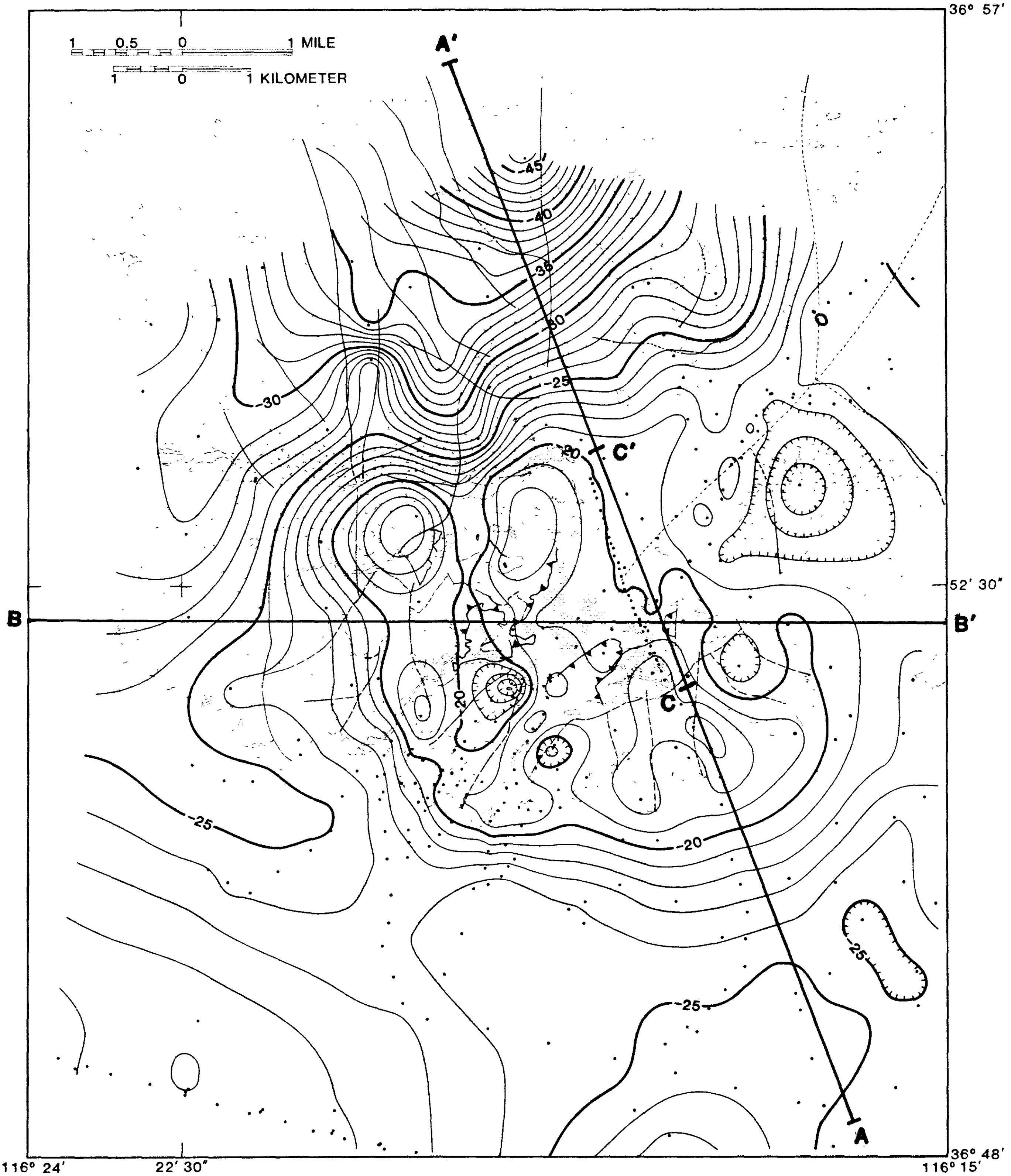
In general, removing the regional gradient enhances the Calico Hills anomaly but does not simplify its outline. The proximity of the large gradient to the north with the generally small changes in gravity to the east further suggests complex near-surface density changes, perhaps masking the effects of more deeply seated causative bodies.

North-south profile interpretation

Gravity- profile modelling along both cross sections discussed in this study utilized a $2\frac{1}{2}$-dimensional computer program (Cady, 1980) wherein source bodies are invariant in cross section but terminate a specifiable finite distance along strike in either direction. This $2\frac{1}{2}$-dimensional approach has the convenience and speed of 2-dimensional calculations yet retains much of the generality of 3-dimensional techniques.

The first interpretive cross section bears slightly west of north (A-A' in figs. 8 and 9). The profile begins over the alluvium in Jackass Flat, passes through a narrow gap in the Calico Hills proper, crosses over alluvium and ends to the north in the Shoshone Mountains. The gravity profile is based on stations at 500 m spacing in the southern third, 75 m spacing in the center, and highly variable spacing in the northern third.

Much of this profile appears in figure 10 along with an aeromagnetic profile and mapped surface geologic units. The 950-gamma magnetic high centered on the profile correlates best with a 1.3-mGal gravity feature rather than the broad 7-mGal high and occurs over an outcrop of Eleana argillite. A broad magnetic high with an amplitude of 150 gammas roughly correlates with the broad gravity feature and also with the overall surface expression of argillite. The 150-gamma correlations suggest that the argillite may be responsible for both geophysical anomalies.



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1 0 1 KILOMETER
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-25
-20
-25
-25
36° 57'
52' 30"
36° 48'
116° 24'
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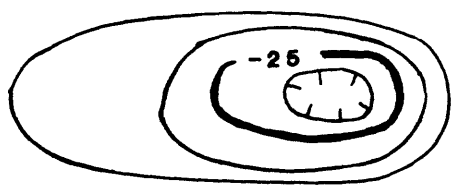
CONCEALED FAULT

GRAVITY STATION



GRAVITY CONTOURS
CONTOUR INTERVAL IS 1 mGal. HACHURED CONTOURS INDICATE AREAS OF LOW GRAVITY CLOSURE.

Figure 8.--One mGal contour residual gravity map of the Calico Hills study area. The Calico Hills gravity anomaly is roughly defined by the -23-mGal contour. The string of gravity highs just northwest of the large closed low northeast of the main anomaly are topographic effects due to an incorrect Bouguer reduction density. The large gravity low at the top of the figure corresponds with the south edge of Shoshone Mountain. The numerous small highs and lows superimpsoed on the main anomaly do not correlate with mapped geologic units and may indicate density variations internal to the Paleozoic rocks.

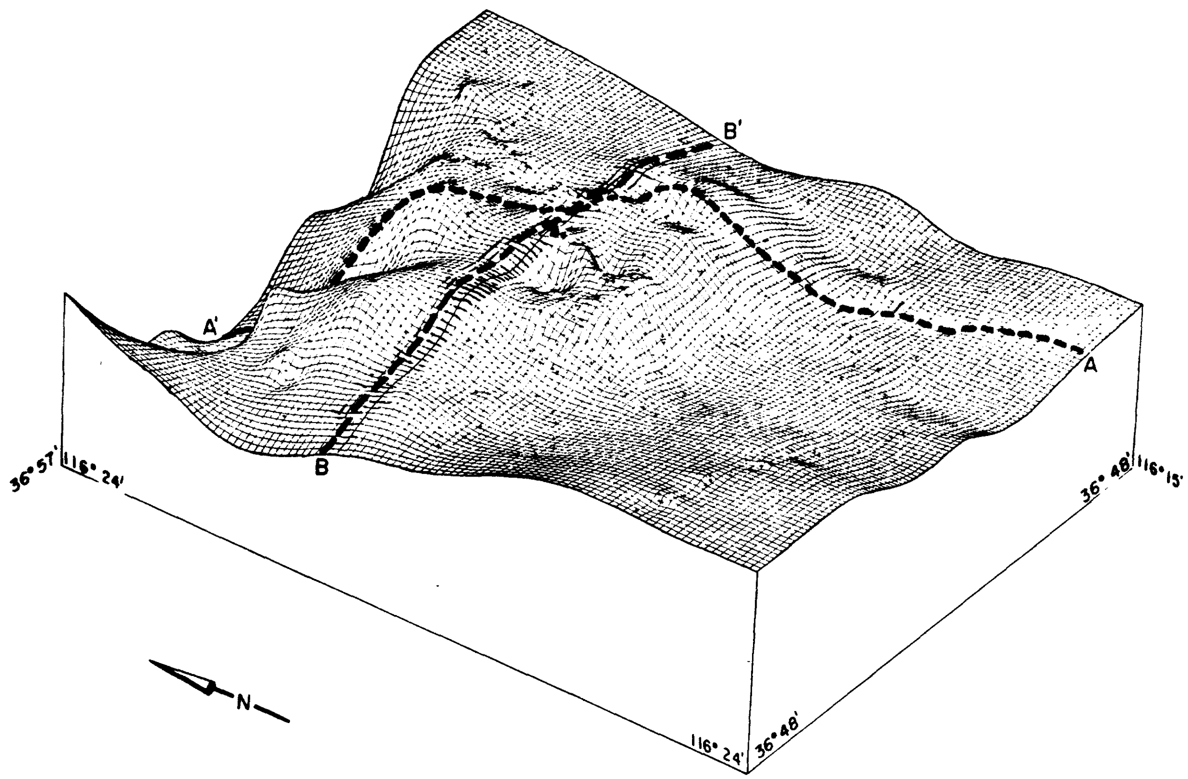


Figure 9.--Three-dimensional perspective of the residual gravity field contoured in figure 8. The modelled profiles A-A' and B-B' are indicated both here and in figures 2 and 8. Drill hole UE25a-3 is indicated by the triangular symbol. The 1 to 5-mGal, 0.5 to 1-km-diameter gravity anomalies superimposed on the Calico Hills main anomaly are rather noticeable in this perspective, as is the steep drop in gravity to the north.

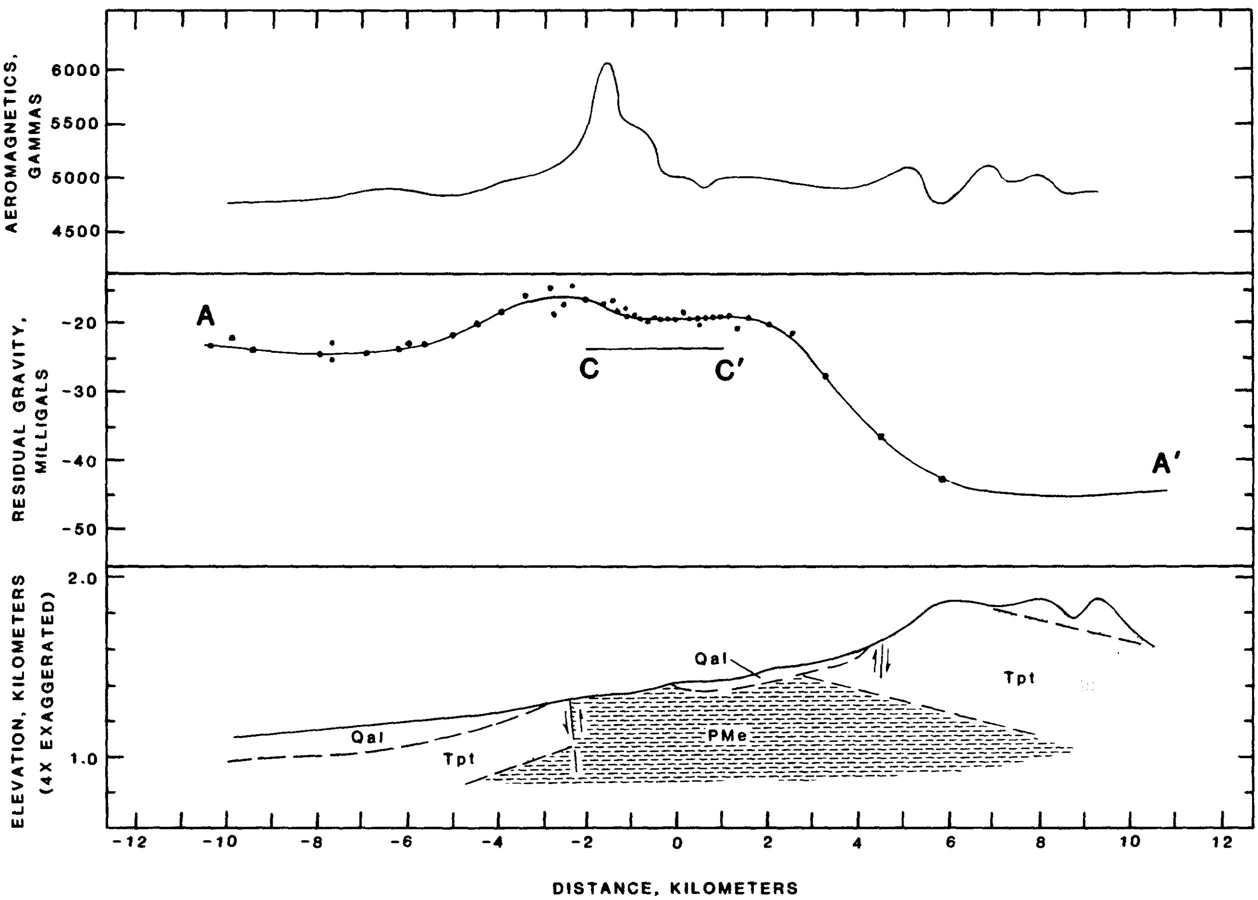


Figure 10.--North-south geologic cross section A-A' with coincident residual gravity and aeromagnetic profiles. Tpt represents tuffs, PMe the Eleana argillite, and Qal alluvium. Gravity is from figure 8, aeromagnetic profile from figure 5. The large aeromagnetic spike correlates with the highest gravity values and Paleozoic outcrops. The main positive gravity anomaly matches a low-amplitude swell in the aeromagnetic profile and the structural dome.

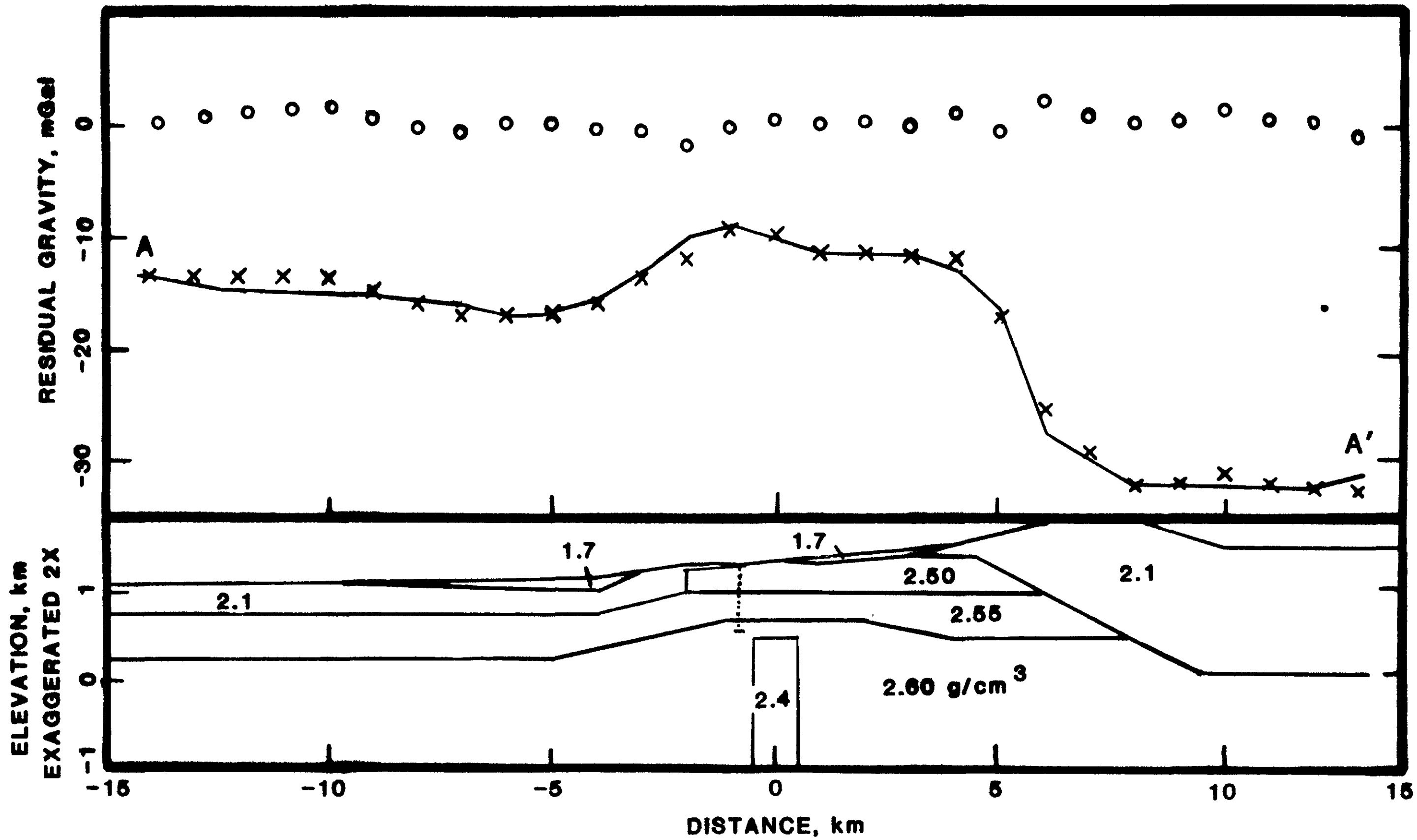
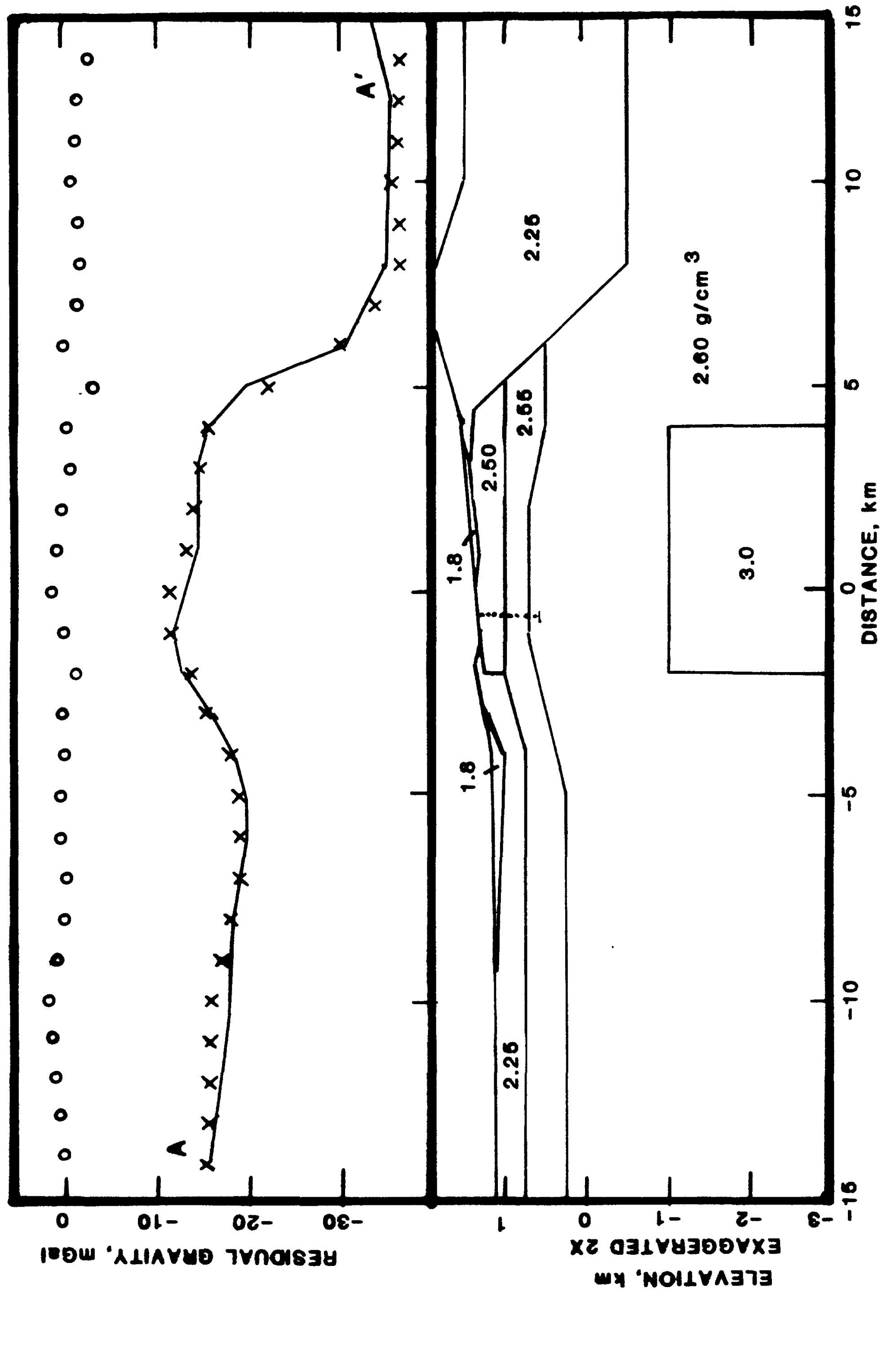


Figure 11.--Modelled interpretation of gravity profile A-A'. The central dotted line indicates the extent of drill holeUE25a-3. X is calculated gravity, O, residual gravity, and the line, observed gravity. A, "Best" interpretive model uses 1.7-g/cm^3 bodies to represent alluvium, 2.1-g/cm^3 bodies to represent Tertiary tuff. The 2.50-g/cm^3, 2.55-g/cm^3, and 2.60-g/cm^3 bodies represent the argillite, altered argillite, and remaining bulk of the Eleana Formation, respectively. The 2.40-g/cm^3 body represents an intrusive rhyolite dike. B, a limiting interpretive model in which tuff densities are 2.25 g/cm^3 and a 3.0-g/cm^3 pluton replaces the rhyolite dike. The smaller density contrast between tuff and argillite required a thicker tuff section and a positive density contrast between intrusive and Paleozoic rocks.


RESIDUAL GRAVITY, mGal
0
-10
-20
-30
A
A'
ELEVATION, km
EXAGGERATED 2X
1
0
-1
-2
-3
2.25
1.8
1.8
2.50
2.55
2.25
2.60 g/cm3
3.0
-15
-10
-5
0
5
10
15
DISTANCE, km

The detailed profiles of figure 6 cover roughly the central third of the entire north-south cross section. Ground magnetics and gravity correlate nicely, matching 200 to 300-gamma and 1-mGal anomalies respectively. Surface geology generally indicates alluvium near gravity lows; Paleozoic rock crops out near gravity highs. The broad gravity high toward the left end of the profile is not readily explainable by any mapped rock units.

Modelling along profile A-A' started with the published geologic cross section for the area (McKay and Williams 1964; Orkild and O'Connor, 1970). Drill hole UE25a-3 provided geologic control for the top 800 m near the center of the profile, including the density suite of 2.50 g/cm^3, 2.55 g/cm^3, and 2.60 g/cm^3 for the Eleana rocks. The seven bodies in the models (figs. 11A, B) are based on these constraints plus a seismic profile (fig. 4) that nearly parallels this profile between the 0 and 5 km values (fig. 2). This seismic profile indicated much complexity in velocity structure and was simplified when applied to gravity modelling. The shapes of all modelled bodies above 0.5 km elevation and between 0 and 5 km on the profile line were influenced by the results of the seismic interpretation. The 1.7- (1.8) g/cm^3 body is noticeably thickened for gravity modelling. This body incorporates the 0.8 and 1.2- km/s bodies of the seismic profile, probably grouping fine alluvium with highly fractured and weathered bedrock. The 2.10- to 2.25-g/cm^3 density range chosen for the tuff bodies represents median values of many density values determined for the many tuff and flow units represented by these bodies (Carr, 1966). The lower contact of the northern tuff body follows from some preliminary magnetic modelling in the area (D. Jefferis, oral commun., 1978). The southern structure copies published cross sections (McKay and Williams, 1964) and is a logical extension of exposed rock units in the Calico Hills and Little Skull Mountain to the south. One fault is modelled at -3.0 km, as suggested by surface geologic mapping and electrical studies.

The seven body model (fig. 11A) produces a very reasonable fit between calculated and observed gravity curves. The match is especially striking between the -9 to -4 and -1 to 9 km values on the horizontal scale. The discrepancy between -4 and -1 km may result from approximating a structually complicated hillside with simply shaped bodies. The overall fit is rather good and cannot be much altered within the drill hole, seismic, and surface geologic constraints discussed.

The model bodies contributing most to the calculated profile are those representing tuffaceous rocks with 2.10-g/cm^3 modelling densities. The northern and southern bodies produce gravity effects of about -28 and -7 mGals, respectively. For comparison, the two alluvium bodies (ρ = 1.7 g/cm^3) produce effects less than 5- mGal. Thus, the lower boundaries of the tuff bodies are very important, for slight adjustments in their location produce sizable shifts in the gravity profile. Unfortunately, there is no dependable control at appropriate depths near the edge of this cross section, and one must resort to geologic interpretations. Without control of these critical contacts, a number of equally close gravity profile matches could be generated by elevating the lower tuff boundaries while simultaneously injecting a high-density body near the center of the cross section, or by thickening the tuff and adding low-density bodies within the Eleana Formation. The injecting of one such body, a rhyolite dike, is warranted by mapped surface expressions of such a dike near the center of the profile. In figure 11A, this rhyolite dike is represented by the 2.40- g/cm^3 density body.

Another possible variation in modelling is indicated in figure 11B. Here the bulk densities of the tuffs is 2.25 g/cm^3. In addition, the dike-size body is enlarged and located deeper to represent the top of a pluton or some other large intrusive body. In order to achieve a match between calculated and observed gravity, the lower contact of the northern tuff body needed to be steepened and deepened. As with the dike, the modelling program used a least squares match of the gravity curves to determine the density of the intrusive body. In this case the pluton was assigned a density of 3.00 g/cm^3. This value, undoubtedly too great, is intended to represent an extreme of modeling, as is figure 11B in general. A large dense intrusive is required to compensate the denser, though thickened, tuffs modelled in figure 11B with respect to those modelled in figure 11A.

For perspective, the several variations of spheres and upright rectangular prisms indicated in figures 12 and 13, respectively, produce maximum gravity effects of 1 to 11 mGals. The rectangular prism modelled in figure 11a had a maximum amplitude of -1.2 mGal; that in figure 11B, a maximum amplitude of +2.2 mGal.

East-west profile interpretation

The second interpretive cross section (fig. 14) shown as B-B' on figures 8 and 9, runs due east-west just south of lat 36°52'30" N. It extends from the edges of Yucca Mountain in the west, across Forty Mile Canyon, through the Calico Hills, to Kiwi Mesa. Because no planned magnetic or gravity lines were established in this direction, randomly spaced gravity stations define the observed gravity curve. The gravity map, figure 8, indicates no striking correlations between surface geology and gravity values. Notably, no clear gradient defines the Calico Hills anomaly on its eastern flank.

Modelling drew heavily upon the first interpretive profiles (fig. 11) for depth of contacts and densities. All nonalluvial bodies in the first model are included in this cross section. A higher density, 2.3 g/cm^3, for the tuffs near Kiwi Mesa, 2.3 g/cm^3, was thought appropriate (D. Ponce, written commun., 1980). Body shapes resemble those of the geologic interpretations of McKay and Williams (1964) with three proposed faults represented at -3.75, -2.5, and 3.3 km on the distance scale. A rhyolitic dike of 2.62 g/cm^3 density was included in the modelling to approximate the observed gravity values better. This higher density, when compared with profile A-A' partly reflects the latitude in choosing the density of such an intrusive body.

The overall fit between observed and calculated gravity is reasonable. Terrain corrections based on an incorrect reduction density of 2.67 g/cm^3 undoubtedly contribute to the mismatch at -6 km. The tuff must also thicken west of this value and beyond the area of interest of this study. To the east, the nearly constant observed gravity suggests interesting structures.

Geologic interpretation of the surface contact between argillite and tuff mapped near the 3-km mark in the cross-section suggests at least a 0.5 km thickness of tuff, as do gravity interpretations of the west edge of the Wahmonie/Skull Mountain horst (D. A. Ponce, written commun., 1980). Such tuff thicknesses would produce about -10 mGal of computed gravity in profile B-B' yet variation in the observed values is no greater than 3 mGals. The interpretation of profile B-B' in figure 14 assumed less than 0.2-km thickness of tuff to accommodate the small variation observed. An increase in density

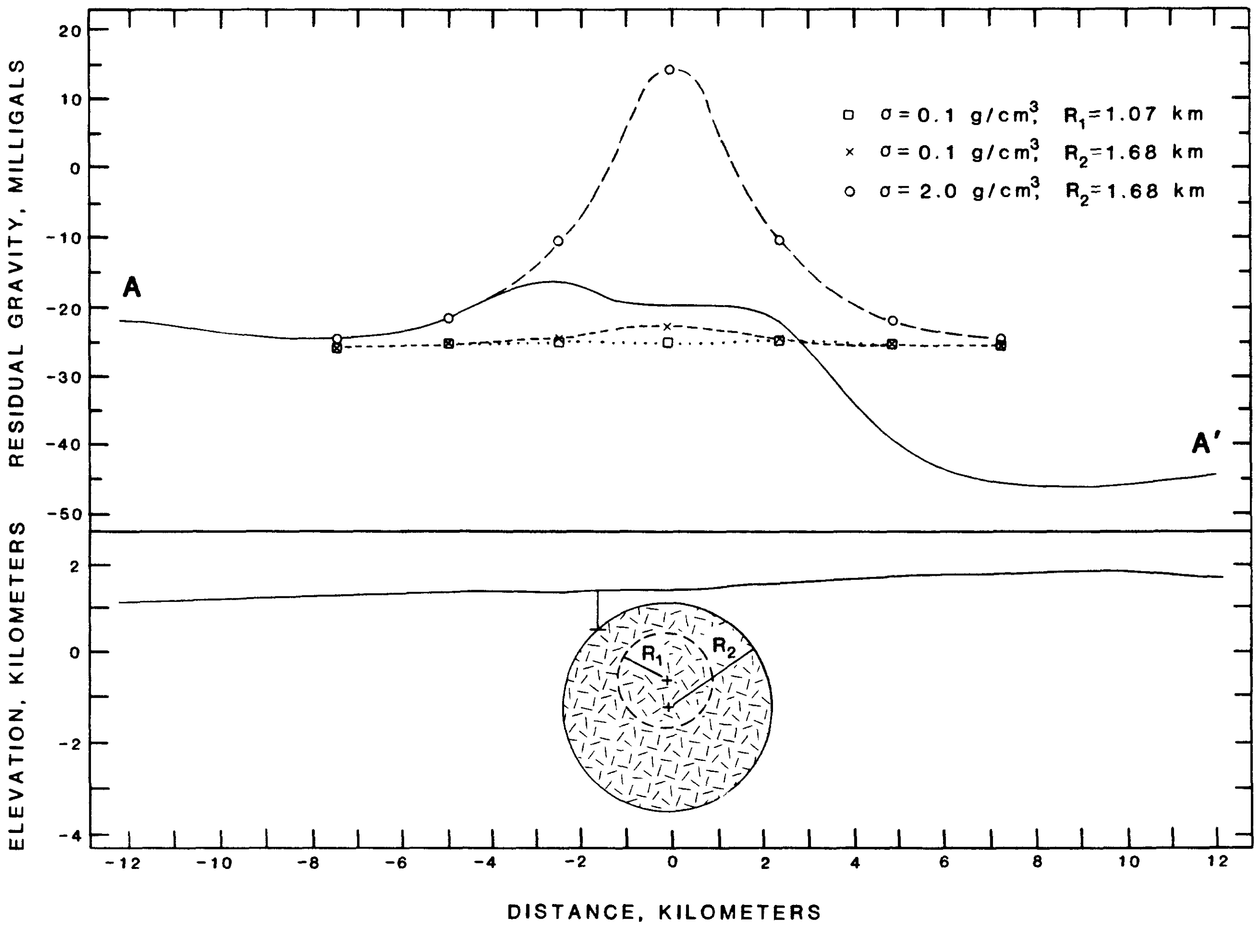


Figure 12.--Resulting gravity anomalies for spheres of 1.07- and 1.68-km diameter compared with observed gravity profile A-A'. Density contrasts of 0.1 g/cm^3 and 2.0 g/cm^3 are indicated for the larger sphere. Only the large sphere and large contrast produce an anomaly of significant amplitude to affect the modelling, and that effect is too great. The short vertical line at -2 km again represents the drill hole.

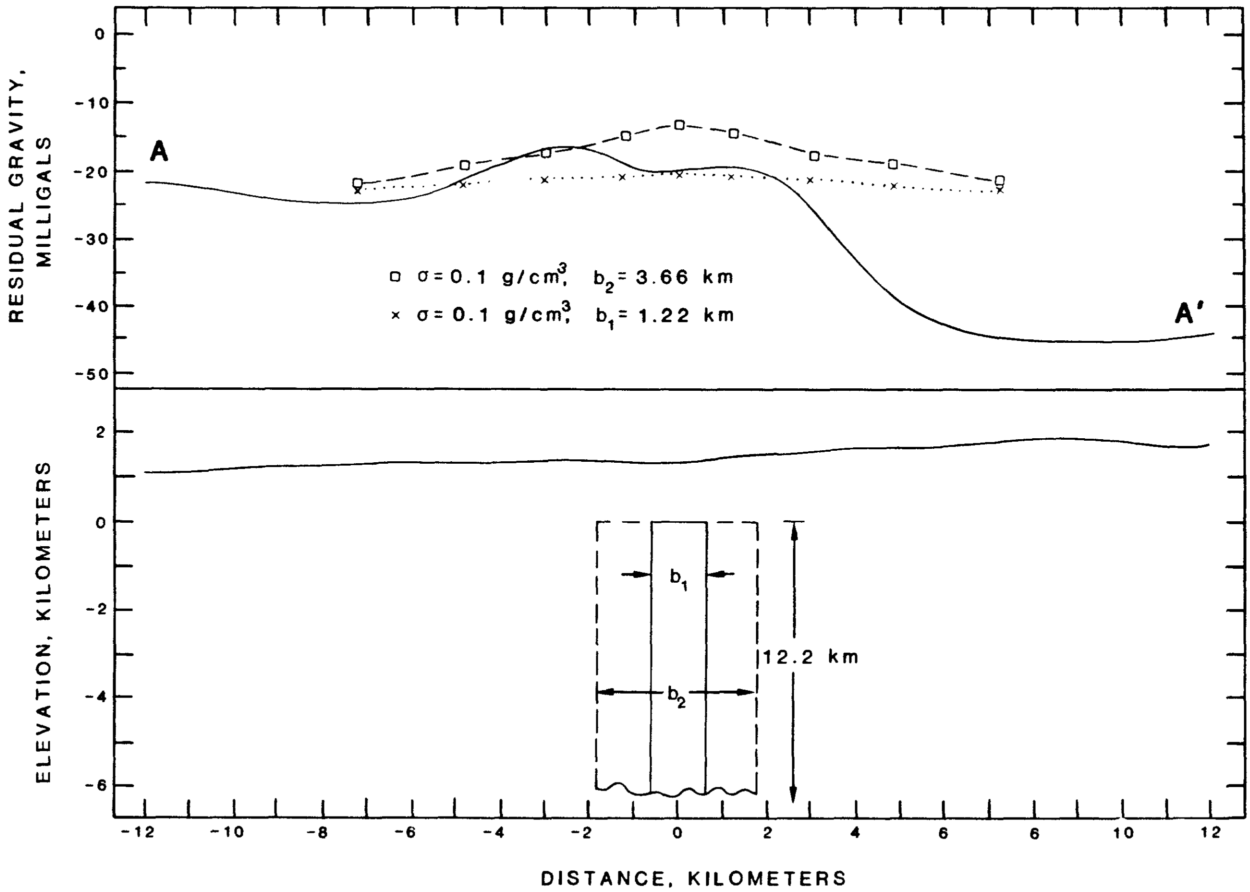


Figure 13.--Resulting gravity anomalies for upright rectangular prisms of 0.1-g/cm^3 density contrast and 1.22- and 3.66-km thicknesses and infinite extent. Anomalies are small, though noticeable, when compared with the observed gravity profile A-A'.

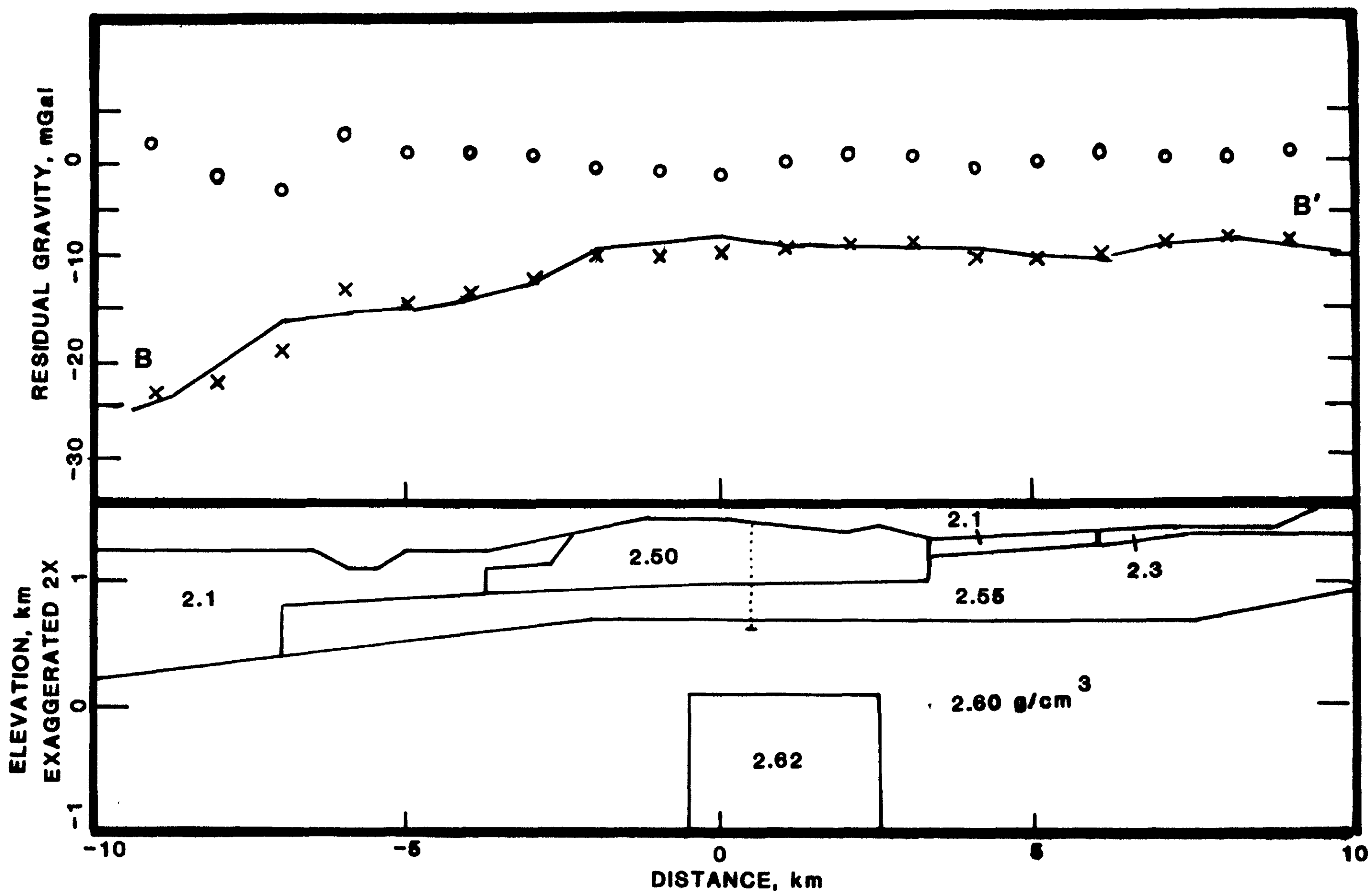


Figure 14.--Modelled interpretation of gravity profile B-B'. Bodies with densities identical to those in Figure 11 represent the same geologic units. The 2.3 g/cm^3 body represents somewhat denser volcanic rocks near Kiwi Mesa; the 2.62-g/cm^3 body is another example of an intrusive dike, viewed toward the wide cross section of the 2-1/2-dimensional body. The calculated anomaly at -6 km is produced by the topographic effect of Forty Mile Wash. The vertical dotted line represents the drill hole. Symbols as in figure 11.

to the eastward at depth seems more appropriate, yet unproven. Thermal alteration associated with the Wahmonie intrusive body could either massively or locally increase density. Alternatively, greater coherence and fewer fractures away from the Calico Hills dome could lower effective porosity and increase density.

Conclusions

A 770-m drill hole log and complete surface geologic mapping provide unusally good geologic control for the Calico Hills study area. In addition, a seismic refraction line provided independent constraints on density variation within the top kilometer of the central Calico Hills. This control plus geologic interpretation of the structures at the edges of the study area were used to produce a modelling profile through the Calico Hills trending N 10° W. Interpretation of this profile suggests that the Calico Hills gravity anomaly can be entirely attributed to topography on the surface between the Paleozoic Eleana argillite and overlying Tertiary tuff. The 0.35- to 0.50-g/cm^3 contrast at this boundary produces gravity variations of several milligals for vertical changes of several hundred meters in the depth of the boundary. Spherical and prismatic bodies near 0 m elevation (sea level) produce 2- to 11- mGal anomalies depending on density contrasts and the extent of the bodies. Only with precise control of the depth of basement rocks beneath Jackass Flats and Shoshone Mountain such as a drill hole or seismic soundings could provide, can the existence of intrusive bodies be excluded or confirmed. The east-west-trending modelling profile produced similar conclusions with one exception. As before, no deep high-density body was required under the Eleana outcrops. To the east, beneath Kiwi Mesa, however, high-density rocks at depth must balance the 2.1- to 2.3-g/cm^3 tuff mapped at the surface to produce the lack of gravity gradient in this region. Those high-density rocks may be an intrusive body, marbleized or hydrothermally altered rocks, or more coherent tuff and argillite than the highly fractured rock immediate to Calico Hills. This study does define the domical shape of the Paleozoic rock/tuff boundary but produces no convincing evidence of an intrusive body, although its existence cannot be ruled out at this time.

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Appendix 1. Principal facts of the 339 gravity stations used in this study.

Explanation of tables:

STATION - An alphanumeric combination of up to eight characters for station identification.

LAT. and LONG. - Latitude and longitude of the station in degrees and minutes to the nearest hundredth of a minute.

ELEV - Station elevation, in feet, to the nearest tenth of a foot.

ACC - One letter and three digits indicating elevation, location, and reading accuracies, see Appendix A. The remaining columns contain gravity values in milligals, to the nearest hundredth of a milligal.

OB GRAV - Observed gravity relative to the prime base Merc,
g = 979,518.80 mGal.

FA - Free air anomaly.

SB - Simple Bouguer anomaly for a crustal density of 2.67 gcm^{-3}.

NEAR- Terrain corrections to a distance of 0.59 km using cylindrical ring templates (Hammer, 1939) and field measurements.

TC - Computer calculated total terrain corrections out to 166.7 km using digitized terrain values.

CBA - Complete Bouguer anomaly for crustal density of 2.67 gcm^{-3}.

Computer terrain corrections carried from station to 166.7 kilometers
Densities are 2.67 and 2.50. Density of 2.67 used for values in columns labelled TC, (NEAR). (NEAR) represents inner zone hand corrections, TC represents computer corrections

Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
10a	365212	1161792	43818	97948010		-122	-15067	12	151	-15049	10a
b-5	365034	1162028	38808	97950766		-1819	-15055	5	111	-15067	b-5
a-6	365094	1161955	42865	97948557		-301	-14920	96	257	-14794	a-6
c1	365213	1161828	44543	97947631		179	-15013	40	185	-14962	c1
c2	365200	1161863	45328	97947216		520	-14939	14	168	-14906	c2
c3	365175	1161890	45453	97947194		652	-14850	30	192	-14793	c3
c4	364943	1161992	36445	97952093		-2582	-15012	4	90	-15041	c4
c5	364975	1161975	37339	97951498		-2383	-15118	5	98	-15140	c5
x-10	365092	1161993	41412	97949573		-648	-14772	15	154	-14746	x-10
x-11	365091	1161980	41335	97949601		-691	-14789	17	157	-14760	x-11
x-12	365084	1161970	41277	97949677		-659	-14737	17	155	-14711	x-12
x-14	365086	1161997	40820	97949823		-946	-14868	13	146	-14850	x-14
x-15	365078	1162017	40282	97950032		-1231	-14970	9	134	-14962	x-15
x-16	365093	1162021	40862	97949715		-1024	-14961	13	145	-14943	x-16
x-17	365093	1162034	40855	97949670		-1076	-15010	11	141	-14997	x-17
x-18	365086	1162052	40501	97949733		-1336	-15149	7	130	-15146	x-18
x-19	365100	1162051	41021	97949456		-1144	-15135	9	139	-15124	x-19
x-2	365119	1161982	43017	97948511		-240	-14912	30	191	-14852	x-2
x-20	365115	1162051	41605	97949134		-939	-15129	6	144	-15113	x-20
x-21	365126	1162044	42132	97948850		-743	-15113	14	160	-15082	x-21
x-22	365115	1162027	41696	97949226		-761	-14982	15	158	-14953	x-22
x-23	365111	1162013	41529	97949392		-746	-14910	16	161	-14878	x-23
x-24	365126	1161972	44506	97947481		120	-15060	80	269	-14924	x-24
x-25	365141	1161961	45775	97946715		525	-15087	62	276	-14947	x-25
x-26	365158	1161946	49402	97944026		1221	-15629	239	645	-15124	x-26
x-27	365141	1161942	47007	97945828		796	-15236	93	359	-15014	x-27
x-28	365075	1161975	40505	97950122		-927	-14742	12	142	-14727	x-28
x-29	365062	1161985	39952	97950367		-1183	-14809	8	130	-14805	x-29
x-3	365112	1161975	42616	97948772		-346	-14881	41	198	-14813	x-3
x-30	365052	1161997	39533	97950496		-1433	-14917	5	121	-14921	x-30
x-31	365043	1162007	39194	97950618		-1617	-14985	4	116	-14994	x-31
x-32	365046	1162026	39219	97950549		-1667	-15043	7	118	-15050	x-32
x-33	365056	1162027	39581	97950360		-1530	-15030	9	123	-15031	x-33
x-34	365071	1162011	40166	97950111		-1251	-14950	14	137	-14939	x-34
x-35	365081	1162008	40140	97950215		-1186	-14876	20	150	-14853	x-35
x-37	365077	1161933	41070	97949798		-723	-14730	9	145	-14713	x-37
x-38	365074	1161919	41036	97949878		-670	-14666	19	154	-14640	x-38
x-39	365071	1161898	41137	97949771		-678	-14708	14	148	-14689	x-39
x-4	365104	1161975	42226	97949013		-460	-14862	31	182	-14809	x-4
x-40	365074	1161878	41275	97949597		-727	-14804	19	154	-14778	x-40
x-41	365088	1161880	42104	97949112		-452	-14813	38	182	-14761	x-41
x-42	365104	1161881	43588	97948115		-77	-14944	64	228	-14848	x-42
x-43	365114	1161898	44854	97947234		217	-15081	68	264	-14951	x-43
x-44	365123	1161884	47433	97945277		671	-15506	304	627	-15017	x-44
x-46	365094	1161905	42605	97948812		-290	-14821	32	183	-14769	x-46
x-47	365079	1161908	41550	97949552		-520	-14691	19	158	-14662	x-47
x-48	365089	1161931	41491	97949564		-578	-14729	17	161	-14697	x-48
x-49	365093	1161921	42143	97949135		-400	-14774	30	178	-14725	x-49
x-50	365104	1161923	42121	97949125		-447	-14813	49	202	-14740	x-50

Computer terrain corrections carried from station to 166.7 kilometers
Densities are 2.67 and 2.50. Density of 2.67 used for values in columns labelled TC, (NEAR). (NEAR) represents inner zone hand corrections, TC represents computer corrections

Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
x-51	365116	1161923	42642	97948791		-308	-14852	94	254	-14729	x-51
x-52	365126	1161911	43122	97948507		-155	-14863	64	226	-14768	x-52
x-53	365136	1161905	43540	97948331		47	-14803	99	263	-14672	x-53
x-54	365071	1161939	40816	97949997		-754	-14675	7	138	-14664	x-54
x-55	365063	1161947	40445	97950218		-870	-14664	11	136	-14655	x-55
x-56	365053	1161952	40228	97950186		-1091	-14812	9	129	-14809	x-56
x-57	365039	1161949	39669	97950381		-1402	-14931	7	121	-14936	x-57
x-58	365026	1161952	39325	97950436		-1651	-15064	5	114	-15075	x-58
x-59	365013	1161949	38889	97950605		-1873	-15137	4	108	-15153	x-59
x-6	365101	1161985	41516	97949446		-690	-14850	19	165	-14814	x-6
x-60	365010	1161963	38808	97950649		-1901	-15137	11	114	-15147	x-60
x-61	365019	1161936	39221	97950435		-1740	-15117	6	113	-15128	x-61
x-62	365027	1161929	39285	97950492		-1634	-15033	9	119	-15039	x-62
x-63	365033	1161923	39669	97950282		-1492	-15022	9	122	-15026	x-63
x-64	365044	1161932	40038	97950190		-1253	-14909	10	127	-14907	x-64
x-65	365059	1161916	40572	97950055		-908	-14745	14	139	-14733	x-65
x-66	365072	1161910	41041	97949851		-690	-14687	17	151	-14665	x-66
x-67	365147	1161895	44447	97947778		331	-14829	82	243	-14719	x-67
x-68	365160	1161891	44898	97947439		397	-14916	85	245	-14805	x-68
x-69	365169	1161894	45038	97947445		522	-14839	56	217	-14757	x-69
x-7	365103	1161994	41889	97949186		-602	-14889	23	169	-14849	x-7
x-70	365171	1161926	50280	97943120		1121	-16028	367	799	-15370	x-70
x-71	365189	1161929	48892	97944734		1405	-15271	169	449	-14962	x-71
x-72	365173	1161888	45243	97947323		587	-14844	47	207	-14772	x-72
x-73	365178	1161888	45486	97947191		676	-14838	18	180	-14793	x-73
x-74	365214	1161895	47957	97945531		1286	-15070	63	270	-14939	x-74
x-5	365095	1161972	41379	97949584		-672	-14785	12	156	-14757	x-5
x-9	365092	1162002	41260	97949553		-811	-14883	21	158	-14854	x-9
x-78	365000	1161765	38295	97951077		-1941	-15002	2	96	-15029	x-78
x-76	365080	1161800	41021	97949941		-630	-14621	12	136	-14613	x-76
x-75	365135	1161825	44132	97947902		176	-14876	40	193	-14816	x-75
x-77	365048	1161783	39720	97950525		-1223	-14770	6	115	-14780	x-77
c-9	364972	1161720	37752	97951265		-2223	-15099	2	88	-15133	c-9
x-83	365285	1161783	45126	97947146		138	-15253	3	154	-15234	x-83
x-82	365302	1161765	45083	97947077		3	-15373	3	158	-15349	x-82
x-81	365330	1161736	45284	97946924		0	-15446	2	171	-15410	x-81
x-84	365262	1161815	45696	97946817		378	-15208	7	157	-15186	x-84
x-85	365243	1161836	45742	97946887		518	-15083	11	164	-15054	x-85
x-86	365222	1161861	45910	97946812		632	-15027	19	178	-14985	x-86
x-87	365207	1161882	46080	97946757		758	-14958	20	184	-14910	x-87
x-88	365095	1162208	37721	97951267		-2428	-15293	6	113	-15302	x-88
a-3	365094	1162180	38724	97950669		-2082	-15289	7	117	-15296	a-3
x-89	365115	1162133	40270	97949811		-1517	-15251	12	135	-15243	x-89
x-93	365175	1162057	44068	97947826		-18	-15048	63	237	-14944	x-93
x-90	365127	1162135	40629	97949551		-1456	-15314	25	153	-15288	x-90
x-91	365155	1162102	41901	97948924		-928	-15219	17	164	-15184	x-91
x-92	365170	1162083	43187	97948167		-498	-15228	37	202	-15157	x-92
hc1	365263	1161932	53280	97941755		2443	-15729	304	791	-15082	hc1
hc2	365302	1162020	53270	97942081		2703	-15465	354	846	-14764	hc2

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Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
hc3	365333	1161947	54350	97941066		2658	-15878	206	635	-15389	hc3
hc4	365363	1162015	56800	97938839		2691	-16682	299	993	-15836	hc4
hc5	365417	1161998	60960	97935347		3031	-17761	254	1209	-16702	hc5
hc6	365370	1162107	52250	97941525		1090	-16731	412	944	-15930	hc6
hc7	365330	1162178	47330	97944590		-412	-16554	395	779	-15913	hc7
hc8	365365	1162233	41350	97948319		-2355	-16458	257	461	-16125	hc8
hc9	365288	1162245	40020	97949415		-2398	-16047	86	250	-15923	hc9
hc10	365223	1162243	40410	97949380		-1972	-15755	109	257	-15625	hc10
hc11	365230	1162172	43870	97947337		-773	-15735	181	391	-15477	hc11
hc12	365282	1162113	45420	97946845		117	-15374	165	373	-15136	hc12
hc13	365185	1161703	47760	97945051		663	-15626	229	537	-15228	hc13
hc14	365235	1162017	50480	97943605		1702	-15515	279	655	-15002	hc14
hc15	365230	1162108	47190	97945276		287	-15808	356	667	-15278	hc15
hc16	365457	1162213	44140	97946617		-1567	-16622	314	558	-16197	hc16
hc17	365498	1162170	48410	97943590		-640	-17151	472	737	-16552	hc17
hc18	365452	1162067	57850	97937392		2102	-17629	231	967	-16810	hc18
hc19	365502	1162083	54420	97939597		1011	-17550	427	798	-16898	hc19
hc20	365512	1161958	58750	97937043		2512	-17526	146	577	-17098	hc20
hc21	365583	1161913	66330	97931133		3623	-19000	191	951	-18201	hc21
hc22	365475	1161950	59220	97936760		2724	-17474	136	688	-16935	hc22
gm01	365181	1161780	42813	97948883		-149	-14751	8	150	-14732	gm01
gm02	365186	1161782	42980	97948668		-215	-14874	10	152	-14853	gm02
gm03	365190	1161784	43249	97948551		-85	-14835	9	148	-14818	gm03
gm05	365200	1161790	43448	97948300		-163	-14982	14	155	-14959	gm05
gm04	365195	1161790	43442	97948350		-111	-14928	9	149	-14911	gm04
gm06	365205	1161794	43577	97948184		-165	-15028	11	152	-15007	gm06
gm07	365211	1161797	43852	97947968		-131	-15087	17	157	-15063	gm07
gm08	365216	1161800	43978	97947924		-64	-15063	15	156	-15040	gm08
gm09	365221	1161801	44233	97947772		17	-15070	7	147	-15056	gm09
gm10	365225	1161805	44410	97947681		86	-15060	6	147	-15047	gm10
gm11	365230	1161807	44564	97947579		122	-15077	8	150	-15061	gm11
gm12	365236	1161809	44944	97947417		308	-15021	6	149	-15006	gm12
gm13	365240	1161811	45174	97947169		271	-15137	6	150	-15121	gm13
gm14	365245	1161815	45355	97947052		317	-15152	7	153	-15134	gm14
gm15	365250	1161817	45411	97947013		323	-15165	6	154	-15146	gm15
gm16	365255	1161819	45461	97946996		346	-15159	5	155	-15140	gm16
gm17	365261	1161821	45691	97946857		414	-15169	7	159	-15146	gm17
gm18	365266	1161822	45902	97946736		484	-15171	7	161	-15146	gm18
gm19	365271	1161825	46107	97946592		526	-15200	4	160	-15175	gm19
gm20	365277	1161827	46130	97946592		539	-15194	2	160	-15170	gm20
gm21	365281	1161829	46318	97946471		589	-15209	3	163	-15182	gm21
gm22	365286	1161831	46487	97946387		656	-15199	4	166	-15169	gm22
gm23	365292	1161833	46643	97946305		712	-15196	4	168	-15164	gm23
gm24	365297	1161834	46743	97946248		742	-15200	2	168	-15169	gm24
gm25	365301	1161836	46896	97946144		776	-15218	3	171	-15185	gm25
gm26	365307	1161839	46997	97946074		792	-15237	3	174	-15200	gm26
gm28	365317	1161843	47366	97945886		937	-15218	6	181	-15174	gm28
gm29	365322	1161845	47388	97945869		933	-15229	4	181	-15185	gm29
gm30	365328	1161847	47530	97945783		972	-15239	7	187	-15190	gm30

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Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
gm31	365332	1161849	47799	97945603		1039	-15263	7	189	-15212	gm31
x-94	365398	1161672	47211	97945686		474	-15628	5	204	-15562	x-94
x-95	365395	1161650	47365	97945610		547	-15607	3	201	-15545	x-95
x-96	365390	1161633	47478	97945542		593	-15601	3	202	-15536	x-96
x-97	365390	1161609	47780	97945342		676	-15620	9	216	-15542	x-97
x-98	365392	1161593	48289	97945060		870	-15600	26	235	-15504	x-98
x-99	365402	1161575	48893	97944766		1129	-15546	24	238	-15448	x-99
x100	365417	1161553	49693	97944278		1372	-15577	20	243	-15475	x100
x101	365425	1161555	49790	97944189		1362	-15619	8	227	-15533	x101
x102	365403	1161761	47280	97945625		471	-15655	16	222	-15570	x102
x103	365428	1161767	47802	97945138		438	-15866	22	246	-15758	x103
x104	365445	1161777	48368	97944667		475	-16022	24	264	-15897	x104
x105	365485	1161792	50257	97943265		790	-16351	33	255	-16237	x105
x106	365482	1161807	49398	97943792		514	-16334	28	264	-16210	x106
x107	365378	1161753	46361	97946315		333	-15479	3	193	-15423	x107
x108	365355	1161745	45852	97946583		156	-15483	2	178	-15440	x108
x109	365463	1161630	49630	97944296		1264	-15663	9	222	-15582	x109
x113	365470	1161615	49817	97944243		1376	-15614	5	217	-15538	x113
x112	365477	1161593	49923	97944163		1386	-15641	4	218	-15564	x112
x110	365487	1161578	50335	97943911		1507	-15661	6	224	-15578	x110
x111	365500	1161562	51111	97943477		1783	-15649	7	228	-15563	x111
x115	365488	1161532	51381	97943343		1920	-15604	3	225	-15521	x115
x116	365285	1161772	44969	97947193		37	-15300	3	153	-15282	x116
x117	365300	1161798	45676	97946812		299	-15280	4	161	-15254	x117
x118	365320	1161813	46340	97946414		496	-15309	5	171	-15274	x118
x119	365348	1161836	47476	97945772		881	-15311	7	189	-15260	x119
x120	365362	1161858	48356	97945187		1103	-15389	8	204	-15324	x120
x121	365373	1161892	49725	97944288		1475	-15484	22	245	-15380	x121
x122	365378	1161922	51237	97943134		1735	-15740	37	295	-15587	x122
x-79	365132	1161648	41218	97949635		-826	-14884	19	144	-14868	x-79
x123	365013	1161820	38722	97950815		-1820	-15027	8	109	-15041	x123
x124	365048	1161817	39829	97950420		-1225	-14810	8	121	-14814	x124
x125	365098	1161853	42739	97948765		-217	-14794	34	183	-14742	x125
x126	365177	1161811	43631	97948284		26	-14855	35	174	-14813	x126
x127	365203	1161738	44830	97947358		190	-15100	24	163	-15071	x127
tg2e	364762	1161854	34167	97953408		-3147	-14800	0	59	-14855	tg2e
bmr3	364765	1161858	34130	97953451		-3143	-14784	0	60	-14838	bmr3
tg1e	364771	1161892	34098	97953495		-3138	-14768	0	60	-14822	tg1e
bmd5	364777	1161906	34089	97953489		-3161	-14788	0	60	-14841	bmd5
tg1w	364777	1161917	33984	97953552		-3197	-14788	0	61	-14840	tg1w
tg2w	364784	1161961	33792	97953699		-3240	-14766	0	63	-14816	tg2w
tg3w	364791	1161985	33610	97953874		-3247	-14710	0	65	-14758	tg3w
tg4w	364798	1162018	33577	97953963		-3199	-14651	0	65	-14699	tg4w
tg4a	364798	1162018	33577	97953964		-3198	-14650	0	65	-14698	tg4a
tg5w	364806	1162051	33572	97954034		-3144	-14594	0	65	-14642	tg5w
bmd7	364809	1162056	33631	97954012		-3115	-14585	0	65	-14634	bmd7
tg6w	364814	1162090	33556	97954113		-3092	-14536	1	65	-14584	tg6w
tg6a	364836	1162100	33900	97953899		-3014	-14576	1	67	-14622	tg6a
tg6b	364788	1162076	33262	97954317		-3126	-14471	1	63	-14520	tg6b

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Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
h757	365347	1161707								-15378	h757
h758	365369	1161684								-15442	h758
h759	365398	1161671								-15560	h759
h760	365412	1161824								-15848	h760
h761	365382	1161725								-15618	h761
h762	365323	1161718								-15375	h762
h763	365015	1161609								-15248	h763
h764	364816	1161772								-15210	h764
h795	364888	1161776								-15161	h795
h796	364902	1161754								-15168	h796
h797	364916	1161733								-15160	h797
h798	364931	1161717								-15160	h798
h799	364949	1161698								-15175	h799
h800	364971	1161697								-15158	h800
h801	364992	1161695								-15115	h801
h802	365013	1161702								-15049	h802
h803	365033	1161710								-14973	h803
h804	365055	1161714								-14867	h804
h805	365076	1161721								-14740	h805
h806	365098	1161722								-14670	h806
h807	365120	1161731								-14625	h807
h808	365155	1161760								-14798	h808
h809	365137	1161748								-14604	h809
h810	365174	1161776								-14779	h810
h811	365195	1161786								-14856	h811
h812	365215	1161795								-14978	h812
h813	365236	1161783								-15121	h813
h814	365254	1161760								-15074	h814
h815	365267	1161751								-15307	h815
h816	365280	1161732								-15356	h816
h817	365301	1161734								-15439	h817
h818	365323	1161718								-15334	h818
h819	365343	1161710								-15345	h819
h820	365361	1161700								-15402	h820
h821	365381	1161686								-15468	h821
h822	365401	1161675								-15520	h822
h823	365398	1161649								-15499	h823
h824	365396	1161633								-15490	h824
h825	365404	1161702								-15576	h825
h826	365408	1161731								-15620	h826
h827	365411	1161758								-15575	h827
299	365171	1161925	50320	97943416		1455	-17163		676	-1517	299
300	365146	1162015	44750	97947231		70	-15263		659	-1466	300
301	365120	1162024	42240	97948879		-604	-14407		316	-1482	301
302	364920	1162033	35780	97952570		-2697	-12203		136	-1488	302
309	364810	1162055	33640	97954030		-3090	-11474		115	-1456	309
310	364820	1162100	33610	97954089		-3074	-11463		104	-1454	310
311	364837	1162170	33450	97954246		-3092	-11409		105	-1450	311
312	364853	1162242	33350	97954332		-3123	-11375		119	-1449	312

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Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
313	364907	1162233	34240	97953750		-2946	-11678		122	-1461	313
314	364803	1162020	33650	97953879		-3222	-11477		126	-1468	314
315	364853	1161550	36490	97951907		-2596	-12446		115	-1504	315
316	364918	1161528	37530	97951191		-2428	-12800		132	-1521	316
317	364945	1161529	37910	97950937		-2364	-12930		145	-1527	317
318	364998	1161510	38990	97950431		-1931	-13298		162	-1519	318
319	365015	1161542	38980	97950356		-2040	-13295		175	-1528	319
320	365132	1161542	41810	97948842		-1062	-14260		212	-1524	320
321	365174	1161532	42940	97948125		-778	-14646		231	-1532	321
322	365061	1161608	39560	97950226		-1692	-13493		181	-1512	322
323	365018	1161654	38710	97950711		-1943	-13203		174	-1509	323
324	364943	1161615	37760	97951153		-2286	-12879		130	-1515	324
325	364842	1161645	36100	97952058		-2796	-12313		110	-1511	325
326	364853	1161707	35990	97952085		-2888	-12275		120	-1516	326
327	364865	1161766	35860	97952214		-2899	-12231		120	-1512	327
328	364877	1161825	35600	97952469		-2905	-12142		123	-1504	328
329	364889	1161890	35350	97952656		-2970	-12057		125	-1501	329
330	364901	1161949	35620	97952554		-2836	-12149		124	-1497	330
331	364908	1162008	35670	97952613		-2740	-12166		135	-1488	331
344	365025	1162223	36340	97952204		-2689	-12394		144	-1505	344
566	365167	1162201	39500	97950264		-1863	-13472		200	-1526	566
567	365332	1162177	47330	97944607		-398	-16143		844	-1583	567
568	365425	1162064	58740	97937096		2681	-20035		1579	-1592	568
569	365482	1162026	57420	97937807		2069	-19584		837	-1682	569
572	365477	1161726	57500	97938017		2362	-19612		1086	-1631	572
573	365327	1161643	54200	97940226		1686	-18486		1196	-1575	573
815	365127	1161609	40840	97949679		-1131	-13929		143	-1504	815
816	365105	1161902	43950	97947873		20	-14990		270	-1483	816
817	364994	1161870	38049	97951070		-2170	-12978		133	-1513	817
818	365000	1161854	38310	97950935		-2069	-13066		133	-1512	818
819	364983	1161855	37720	97951263		-2271	-12865		132	-1512	819
821	365107	1162239	37150	97951473		-2776	-12671		242	-1532	821
822	365103	1162078	40970	97949373		-1279	-13974		183	-1519	822
1036	364941	1162042	36310	97952234		-2565	-12384		110	-1495	1036
1037	364965	1162053	36850	97951882		-2444	-12568		122	-1501	1037
1038	364983	1162046	37420	97951520		-2296	-12763		133	-1504	1038
1039	365005	1162044	37820	97951297		-2175	-12899		155	-1504	1039
1040	365033	1162048	38779	97950697		-1914	-13227		156	-1510	1040
1041	365055	1162050	39540	97950266		-1661	-13486		169	-1510	1041
1042	365080	1162055	40370	97949770		-1413	-13769		170	-1513	1042
1043	365098	1162058	41060	97949383		-1178	-14004		183	-1512	1043
1044	365082	1162092	39960	97949899		-1672	-13629		169	-1525	1044
1045	365055	1162103	39040	97950429		-1968	-13315		167	-1524	1045
1046	365040	1162123	38300	97950900		-2172	-13063		156	-1520	1046
1047	365023	1162155	37490	97951446		-2362	-12787		123	-1514	1047
1048	365007	1162182	36740	97951972		-2518	-12531		111	-1505	1048
1049	365015	1162204	36510	97952115		-2603	-12452		99	-1507	1049
1153	365082	1161522	40210	97949757		-1580	-13714		141	-1527	1153
1154	365109	1161557	40640	97949638		-1333	-13861		131	-1519	1154

Computer terrain corrections carried from station to 166.7 kilometers
Densities are 2.67. Density of 2.67 used for values in columns
labelled TC, (NEAR). (NEAR) represents inner zone hand corrections,
TC represents computer corrections

Station	Lat.	Long.	Elev	Ob Grav	ACC	FA	SB	NEAR	TC	CBA	Sta
1156	365184	1161613	41990	97948975		-836	-14322		169	-1511	1156
1157	365217	1161655	42440	97948722		-714	-14475		226	-1509	1157
1158	365239	1161692	43270	97948188		-499	-14758		173	-1521	1158
1159	365267	1161721	44080	97947611		-355	-15034		156	-1536	1159
1160	365316	1161720	44960	97947137		73	-15335		192	-1535	1160
1161	365348	1161700	46120	97946403		238	-15730		187	-1544	1161
1162	365385	1161678	47240	97945665		499	-16112		183	-1556	1162
1163	365426	1161655	48510	97944862		830	-16545		279	-1557	1163
1164	365462	1161629	49910	97944166		1399	-17023		277	-1548	1164
1266	364836	1161806	35230	97952608		-3055	-12016		95	-1509	1266
1267	364898	1161745	36350	97951956		-2743	-12398		84	-1517	1267
1268	364928	1161648	37290	97951325		-2534	-12719		83	-1529	1268
1269	364986	1161583	38370	97950706		-2221	-13087		96	-1533	1269
1270	365066	1161551	39710	97949999		-1784	-13544		129	-1532	1270
1554	364808	1161611	35860	97952307		-2723	-12231		71	-1500	1554
1555	364840	1161620	36220	97952043		-2695	-12354		70	-1509	1555
1556	364877	1161632	36640	97951709		-2687	-12497		71	-1523	1556
1557	364915	1161643	37130	97951446		-2545	-12664		72	-1525	1557
1710	365215	1161727	45250	97946995		204	-15433		273	-1509	1710
1711	365220	1161758	47250	97945475		557	-16116		647	-1504	1711
1712	365195	1161836	48160	97945066		1040	-16426		524	-1500	1712
1713	365177	1161753	44490	97947512		61	-15174		335	-1491	1713
1714	365121	1161765	44010	97947921		100	-15010		268	-1477	1714
1715	365113	1161752	43070	97948498		-194	-14690		165	-1485	1715
1716	365213	1161925	50150	97944069		1887	-17105		432	-1492	1716
1717	365265	1161933	53280	97941757		2442	-18172		1038	-1483	1717
1718	365287	1161959	55830	97939802		2852	-19042		1111	-1522	1718
1719	365333	1161946	54350	97941073		2666	-18537		840	-1517	1719
1720	365363	1161959	55410	97940001		2546	-18899		567	-1593	1720
1721	365403	1161948	54720	97940427		2266	-18663		492	-1605	1721
1722	365411	1161908	52220	97942221		1699	-17811		303	-1595	1722
bmd8	364818	1162102	33612	97954089		-3069	-14533	1	65	-14580	bmd8
tg7w	364820	1162120	33470	97954202		-3092	-14508	1	66	-14554	tg7w
tg8w	364827	1162148	33386	97954280		-3103	-14490	1	67	-14536	tg8w
bmd9	364835	1162172	33446	97954252		-3086	-14494	1	67	-14539	bmd9
tg9w	364834	1162183	33384	97954291		-3104	-14490	0	66	-14537	tg9w
tg10	364841	1162214	33320	97954324		-3142	-14506	1	67	-14551	tg10
tg11	364848	1162245	33277	97954378		-3138	-14488	0	68	-14532	tg11
bm10	364851	1162245	33342	97954341		-3118	-14490	0	68	-14535	bm10
tg12	364857	1162280	33234	97954425		-3145	-14479	0	69	-14522	tg12
tg13	364865	1162318	33276	97954414		-3128	-14477	0	71	-14518	tg13
tg14	364871	1162341	33338	97954388		-3104	-14474	0	73	-14514	tg14
bm11	364869	1162353	33352	97954397		-3079	-14454	0	74	-14493	bm11
tg15	364877	1162370	33409	97954394		-3040	-14435	5	82	-14465	tg15
tg17	364887	1162412	33470	97954420		-2971	-14386	7	96	-14404	tg17
tg18	364890	1162430	33600	97954309		-2964	-14424	3	101	-14436	tg18

LOCATION CODE (1st digit)

Code	Station Location Method (vertical and horizontal)
	A) Survey marks (vertical) - Topo Maps (horizontal)
	1) Base plate directly on bench mark
B	a) USGS or USC&GS level-line bench mark.
M	b) Level line bench marks other than a) such as USCE, BPR, CDH, private companies, etc.
V	c) Vertical angle (VABM) bench marks.
	2) Base plate near bench mark.
N	a) USGS or USC&GS level-line bench mark.
E	b) Level-line bench marks other than a) such as USCE, BPR
H	c) Vertical angle (VABM) bench marks.
P	3) Base plate on or near other reference marks (such as stakes, paint, etc.) that have been surveyed by the group doing the gravity survey or other known people.
X	4) On or near Section Corners, 1/4 section marks, 1/8 section markers, and other property boundary markers.
D	5) Destroyed or not found bench or reference marks.
	B) Map locations (vertical and horizontal)
F	1) Black spot elevations - field checked.
G	2) Brown spot elevations and elevations taken off original manuscripts - not field checked.
W	3) Blue lake elevations.
R	4) Lake or reservoir elevations determined from leveling to bench marks, and water level is determined from gauging stations.
S	5) Sea level elevations.
C	6) Contour line interpolation.
Q	7) River gradient interpolation.
	C) Air Photographs (vertical and horizontal)
T	1) Elevations determined by U.S. Geological Survey Topographic Division by Kelsh plotter or least squares computer system.
K	2) Elevations determined by other groups by Kelsh plotter or least squares computer system.
L	3) Elevations determined by Laser methods.
J	4) Elevations determined by other methods.
	D) Altimetry (vertical) - Topo Maps (horizontal)
A	1) Good control (Leap frog, double loop, two or more altimeters, etc.)
Y	2) Poor control.
	E) Special sources
Z	1) Elevations determined by methods such as mobile elevation recorders - horizontal control from Topo Maps.
I	2) Other special sources.
	F) Unknown Elevation Sources
U	1) Elevation data sources unknown (this would include reference marks with unknown ties).

SUBJECTIVE NUMERICAL ACCURACY CODE FOR 2nd, 3rd & 4th DIGITS

Elevation Accuracy Code (2nd digit)

Relative to 1929 USC&GS mean sea level datum

Code	Elev. Acc. feet	Typical types of Elevation Data	Approx. Gravity Effect mgal
1	±0.2	On leveled B M	±0.01
2	±1/3	Beside B Ms	±0.02
3	±1	Transit and good alidade surveys	±0.05
4	±2	VABMs most black map elevations	± .1
5	±4	Black elevations on old maps, good photogrammetry	± .2
6	±10	Brown elevations on 20' contour maps	± .5
7	±20	Brown elevations on 80' contour maps, good altimetry	±1.0
8	±40	Contour interpolation; 50' contour map may be used in Alaska	±2.0
9	±80	Poor altimetry; data from 200' contour	±5.0
0	≥80	Altimetry in very bad weather or equipment failures	>5.0

Latitude Accuracy Code for California Data (3rd digit)

(based on mean value of 1.45 mgal/min. at 37° Latitude)

Code	Lat. Acc. min.	Nec. Dist. Acc. feet	Typical Map Measurement Requirements in inches	Approx. Gravity Effect mgal
1	±.003/4	±42	Triangulation or special survey data	±0.01
2	±.01½	±84	.04 (1:24,000) map; special location care	±0.02
3	±.03½	±210	.10 (1:24,000) normal survey; .04 (1:62,500) maps	±0.05
4	±.07	±420	.21 (1:24,000) map; .08 (1:62,500) normal survey	± .1
5	±.14	±840	.42 (1:24,000) map; .16 (1:62,500) map	± .2
6	±.35	±2100	.4 (1:62,500) map; .1 (1:250,000) map	± .5
7	±.70	±4200	.8 (1:62,500) map; .2 (1:250,000) map	±1.0
8	±1.4	±8400	1.6 (1:62,500) map; .4 (1:250,000) map	±2.0
9				±5.0
0				>5.0

Station O.G Accuracy (4th digit)

(relative to local base shown on lead card)

Code	Observ. Grav. Acc. mgal	Suggested types of Gravity Measurements
1	±0.01	Local surveys with special meters
2	±0.02	Multiple readings with LaCoste
3	±0.05	Average LaCoste and Multiple Worden
4	± .1	LaCoste data with small vibrations etc. Most USGS Worden data
5	± .2	Data from loops with closure errors this large
6	± .5	" " " " " " " "
7	±1.0	" " " " " " " "
8	±2.0	" " " " " " " "
9	±5.0	" " " " " " " "
0	>5.0	" " " " " " " "

Appendix 2. Laboratory density measurements of the Calico Hills Tuff

Paintbrush tuff - Topopah Springs member

13 samples, unsaturated	2.27 ± 0.17 g/cm^3
13 samples, saturated with water	2.34 ± 0.14 g/cm^3

Rhyolite flows and tuffaceous beds of Calico Hills

Rhyolite flows

4 samples, unsaturated	2.06 ± 0.09 g/cm^3
4 samples, saturated	2.17 ± 0.04 g/cm^3

Tuffaceous beds

45 samples, unsaturated	2.08 ± 0.26 g/cm^3
17 of these, altered tuff	2.21 ± 0.28 g/cm^3
9 of these, unaltered	2.00 ± 0.09 g/cm^3
41 samples, saturated	2.24 ± 0.19 g/cm^3
16 of these, altered tuff	2.34 ± 0.20 g/cm^3
9 of these, unaltered	2.15 ± 0.08 g/cm^3

Totals

71 samples, unsaturated	2.12 ± 0.26 g/cm^3
70 samples, saturated	2.26 ± 0.17 g/cm^3