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# A Gravity Model for the Coso Geothermal Area, California

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## Abstract

Two- and three-dimensional gravity modeling was done using gridded Bouguer gravity data covering a 45 × 45 km region over the Coso geothermal area in an effort to identify features related to the heat source and to seek possible evidence for an underlying magma chamber. Isostatic and terrain corrected Bouguer gravity data for about 1300 gravity stations were obtained from the U.S. Geological Survey. After the data were checked, the gravity values were gridded at 1 km centers for the area of interest. centered on the Coso volcanic field. Most of the gravity variations can be explained by two lithologic units: (1) low density wedges of Quarternary alluvium with interbedded thin basalts (2.4 g/cm$^3$) filling the Rose Valley and Coso Basin/Indian Wells Valley, and (2) low density cover of Tertiary volcanic rocks and intercalated Coso Formation (2.49 g/cm$^3$). A 3-D iterative approach was used to find the thicknesses of both units. The gravity anomaly remaining after effects from Units 1 and 2 are removed is a broad north-south-trending low whose major peak lies 5 km north of Sugarloaf Mountain, the largest of the less than 0.3 m.y. old rhyolite domes in the Coso Range. Most of this residual anomaly can be accounted for by a deep, low-density (2.47 g/cm$^3$) prismatic body extending from 8 to about 30 km below the surface. While some of this anomaly might be associated with fractured Sierran granitic rocks, its close correlation to a low-velocity zone with comparable geometry suggests that the residual anomaly is probably caused a large zone of partial melt underlying the rhyolite domes of the Coso Range.

## Introduction

The Coso geothermal area is located at the western margin of the Basin and Range physiographic province in Inyo County, California (Fig. 1). This area is characterized by active extensional tectonics and polygenetic volcanism dating from Tertiary to Recent. The pre-Cenozoic basement rocks are mainly granitic intrusives of Mesozoic age, ranging in composition from granite to gabbro, and containing minor volumes of metamorphic pendants. The area has been extensively faulted, and thick Quaternary alluvial deposits have filled scattered basins. The principal geothermal features are associated with a north-south-trending group of small rhyolite domes and thin tephra deposits that cover the western part of the Coso Range. The geothermal reservoir, being developed by the California Energy Company in association with the U.S. Navy, is related to a magmatic event that produced the rhyolite domes, which are dated at less than 0.3 Ma. The total volume of the domes and their associated flows and pyroclastic deposits is relatively small, probably less than 2 km$^3$ of material was ejected from the 38 individual eruptions (Bacon *et al.*, 1980). On the basis of the eruption distribution and age, Smith and Shaw (1975, 1979) estimated that the volcanism was fed by a 275–1100 km$^3$, shallow magma chamber. Although geophysical studies seem to have ruled out the existence of a present-day high-level magma, seismic evidence points to the possibility of a deeper crustal magma source. Earthquakes as large as M3 occur to depths of 8 km directly below the rhyolite field (Walter and Weaver, 1980), indicating brittle conditions prevail to considerable depth. Reasenberg *et al.* (1980) inverted teleseismic P-wave residual data and mapped out a low velocity body between 5 and 20 km depth which they suggest may be a melt zone. Young and Ward (1980) reached a similar conclusion after finding evidence for a region of high P-wave attenuation below 12 km.

We have taken another look at the gravity data to determine whether these data support the magma chamber concept. This paper reports the progress of those efforts. The reader is referred to the earlier work by Plouff and Isherwood (1980), who gave a general discussion of the gravity features.

## Gravity Data Base

Gravity data for this study was provided to us by the U.S. Geological Survey, Menlo Park. After plotting and examining the data, we selected 1260 stations of corrected data lying between 35° 45' and 36° 20'N latitude and 117° 30' and 118° 10'W longitude (Fig. 1). All gravity values had been reduced to Bouguer gravity and terrain corrected using a terrain density of 2.67 g/cm$^3$, a good approximation to the average density of the crystalline basement rocks. For many stations the data listing showed both the inner zone correction and the total correction. The more recently acquired data were corrected by means of a digital terrain model based on a half-minute grid out to 166.7 km (D. Plouff, pers. commun., 1989). All data were also corrected for earth curvature out to 166.7 km. Lastly, each data point had an isostatic correction, which served as the regional gradient correction, based on an Airy-Heiskanen local compensation model which corrects for the low-density root of the Sierra Nevada (Simpson *et al.*, 1986; Carle, 1988).

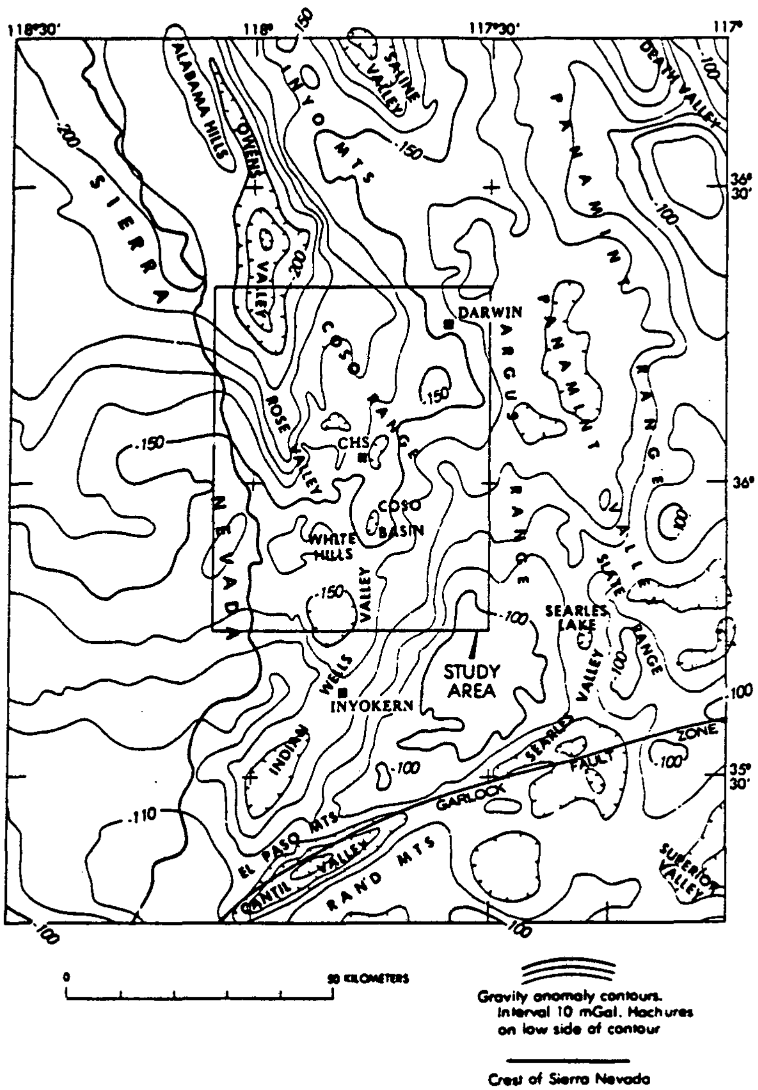

Figure 1. Location map of the study area. Complete Bouguer anomaly map from Plouff and Isherwood (1980). (CHS: Coso Hot Springs)

Additional gravity data for the area was sought from the data base compiled and managed by the National Geophysical Data Center, Boulder, Colorado. Only 12 other data points were found, but as these either did not affect the results or had questionable terrain corrections they were not used. Figure 2 shows the station locations. The crosses are the latitude-longitude intersections, and the scales have been normalized to the UTM 11 coordinate of 35° 45' and 118° 10'. The polygonal outline shown on this and subsequent figures represents the outline of the area of detailed geologic investigations by Duffield and Bacon (1981).

Figure 3 is the complete Bouguer anomaly, Fig. 4 is the isostatic correction as calculated by the USGS, and Fig. 5 is the difference plot showing the isostatic residual plot which was used in the interpretation.

## Interpretation

The 3-D modeling code used was developed by Carle (1988), who based his algorithm on an earlier, less general inversion approach discussed by Cordell and Henderson (1968). The details of the method will not be discussed in this paper. However, it is appropriate to at least mention that the earth is represented by a grid of square prisms, each measuring 1 × 1 km, and each prism being a stack of density units. The density of each unit is presumed known on the basis of rock density measurements, which for this paper are based on the work of Plouff *et al.* (1980). The spatial distribution of each unit is initially specified in the model on the basis of geologic mapping (Duffield and Bacon, 1981), and drill hole information if available. The program performs an automated, iterative calculation to find the thicknesses of the density units within each of the prism stacks. Convergence of the observed to calculated gravity is usually rapid. Acceptably small residual

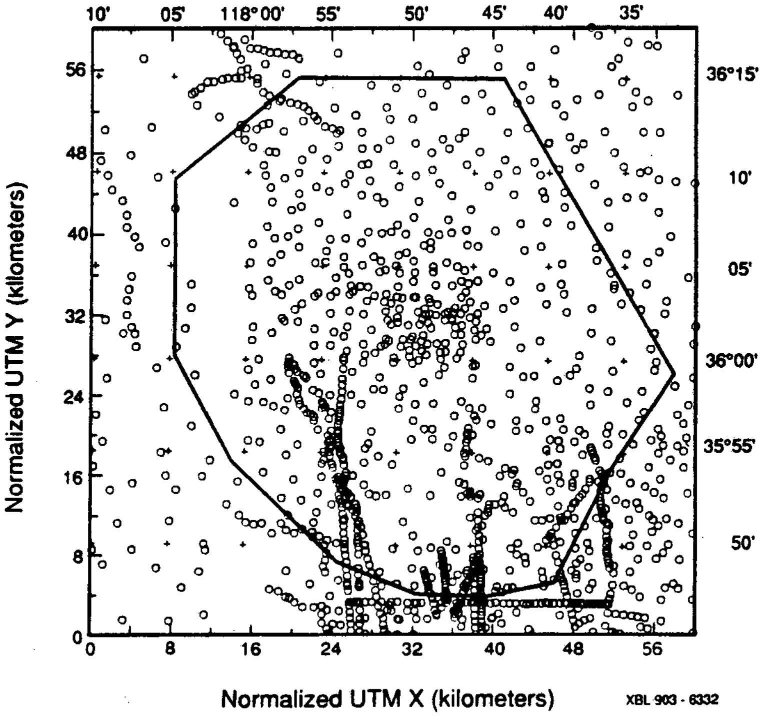

Figure 2. Location of gravity stations used in the interpretation.

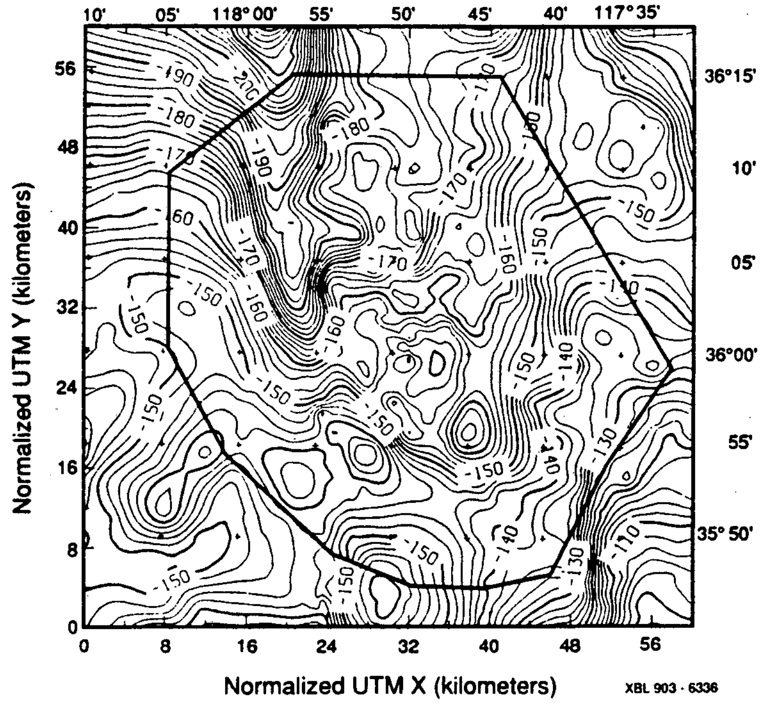

Figure 3. Complete Bouguer gravity map (contour interval: 2 mGal).

fields remain after 3–10 iterations, at which point the results are reviewed to make sure they are geologically consistent and plausible. Drill hole data, if available, can be used to constrain density unit thicknesses within the grid block of the hole. The area used in the modeling measures 45 × 45 km. As no provision was made for the effects of mass outside the grid, interpreted results near the grid boundary are expected to be in error.

The Quaternary rhyolite domes and their associated

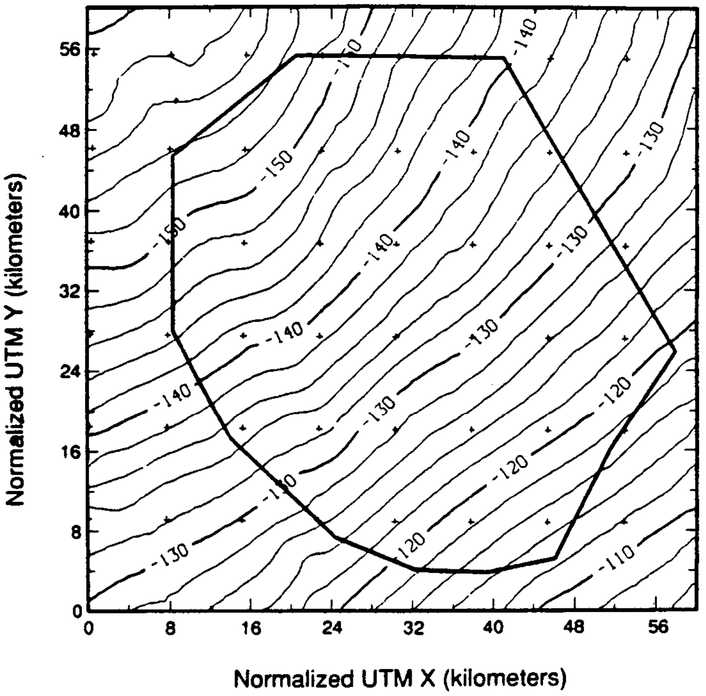

Figure 4. Isostatic gravity correction subtracted from the complete Bouguer gravity anomaly (contour interval: 2 mGal).

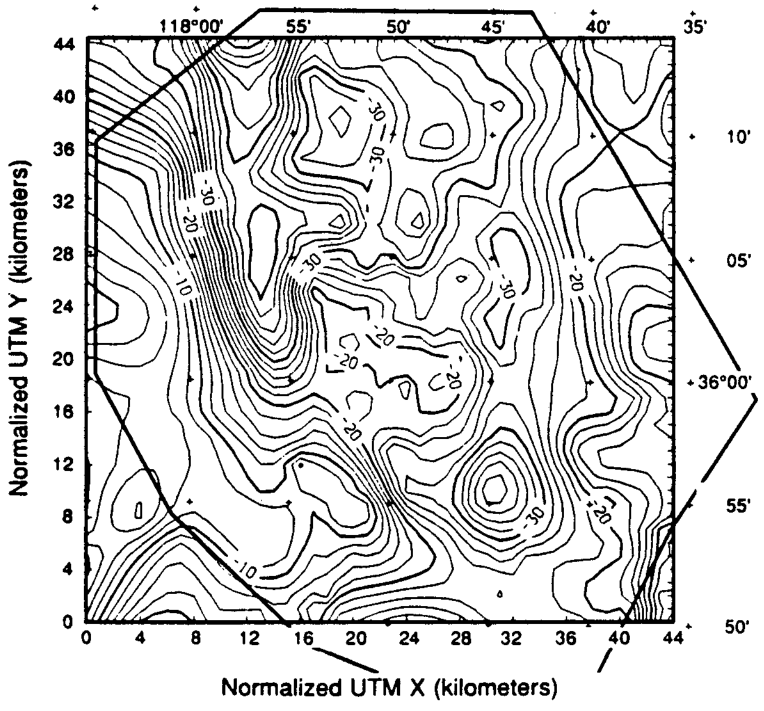

Figure 5. Isostatic residual Bouguer gravity used for the interpretation (contour interval: 2 mGal).

tephra deposits were found not to have a significant effect on gravity, and so these were ignored. The two most significant density units needed to explain the observed gravity are:

Unit 1: Quaternary alluvium and thin (<100m-thick) basalts filling Rose Valley and the Coso Basin (2.0 g/cm$^3$).

Unit 2: Undivided Tertiary volcanics; densities are variable but an average of 2.49 g/cm$^3$ was used. A thin veneer

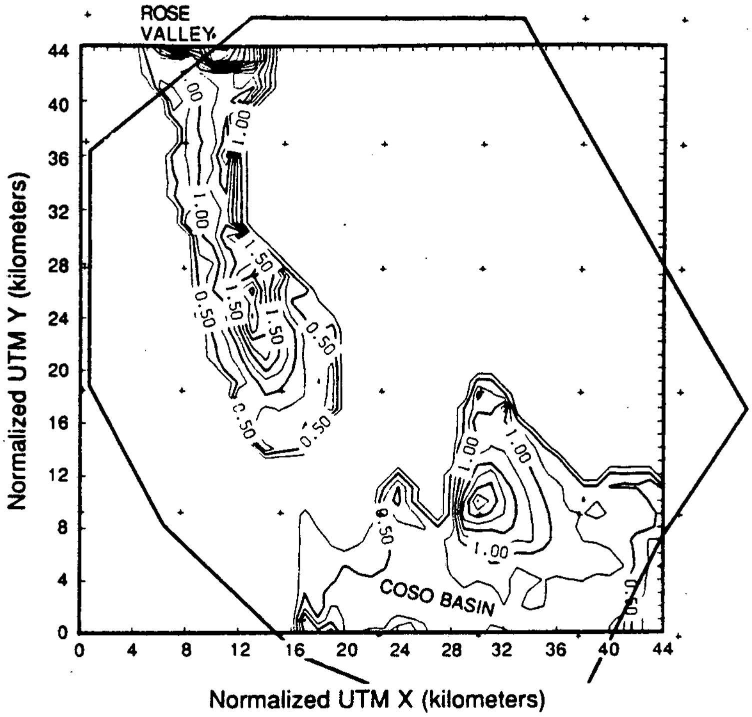

Figure 6. Estimated thickness of Unit 1 consisting of Quaternary alluvium and thin basalt flows filling Rose Valley and the Coso Basin (contour interval: 0.25 m).

of Unit 2 outcrop is widely distributed over Mesozoic basement rocks. Most of Unit 2 is preserved in basins where it underlies Unit 1 (M. Erskine, pers. commun., 1989).

The modeling was done in two steps. First, we estimated Unit 1 thicknesses (Fig. 6). After this was done the effect of the alluvium was subtracted from the isostatically corrected Bouguer anomaly and the iterative process was repeated to find the Unit 2 thicknesses.

Unit 1 attains a thickness of nearly 2.5 km in the center of Rose Valley, east of the geothermal area, and is over 2 km thick to the southeast in the Coso Basin. These thicknesses are consistent with other geophysical results (Plouff and Isherwood, 1980). Unit 2 thicknesses are shown in Fig. 7. For Unit 2, the program assigned all of the remaining gravity anomaly to this layer and produced an unreasonably large unit thickness of 10 km or more in some grid blocks. From a cross-section by M. Erskine (pers. commun., 1989) the Unit 2 layer thickness was on the order of 1 km or less, and we made a decision to limit Unit 2 thickness to 1 km. Subtracting the effects of both units from the complete Bouguer anomaly gives the residual anomaly of Fig. 8 which shows a broad 20 to 30 mGal low centered over the geothermal area. While some of this effect is undoubtedly due to the fractured and hydrothermally altered condition of near-surface crystalline rocks hosting the geothermal system, the width of the residual gravity anomaly indicates a much deeper source. To get a feeling for what this source might be we used an interactive 2-D gravity modeling program to give us the approximate depth, dimensions, and density contrast for the deep source body. The result is a roughly tabular body extending from 8 to 30 km below the surface with a density of 2.47 g/cm$^3$ (Fig. 9).

Because the low density zone conforms surprisingly well with the low velocity zone previously reported by Reasenberg *et al.* (1980), it is very likely that the two are related. We found a density contrast of 7.5 percent, while the 3-D inversion of travel-time residuals (Reasenberg *et al.*, 1980) gave a maximum velocity contrast of 8.4 percent, and a source extending from 5 to 20 km below the surface.

## Conclusions

A combination of 2-D and 3-D gravity modeling reveals that a large, deep low density region underlies the Coso geothermal system and the Quaternary rhyolite domes of the Coso volcanic field. To a first approximation, the low-density zone extends from 8 to 30 km below the surface, or below the region of active seismicity, and is roughly coincident with previously reported low-velocity and a high attenuation zone found from an inversion of teleseisms. The cause of both the gravity and seismic anomalies is probably a large volume of partial melt in a north-south-trending zone up to 10 km in width and centered below the Coso volcanic field. The gravity interpretation sug-

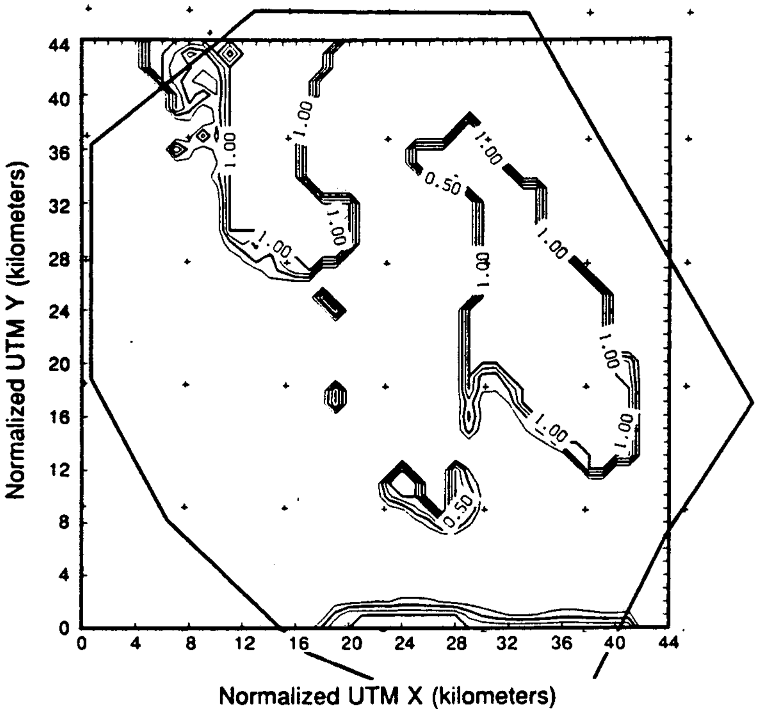

Figure 7. Estimated thickness of Unit 2 consisting of undivided Tertiary volcanics. The thickness was limited to a maximum of 1 km (contour interval: 0.25 m).

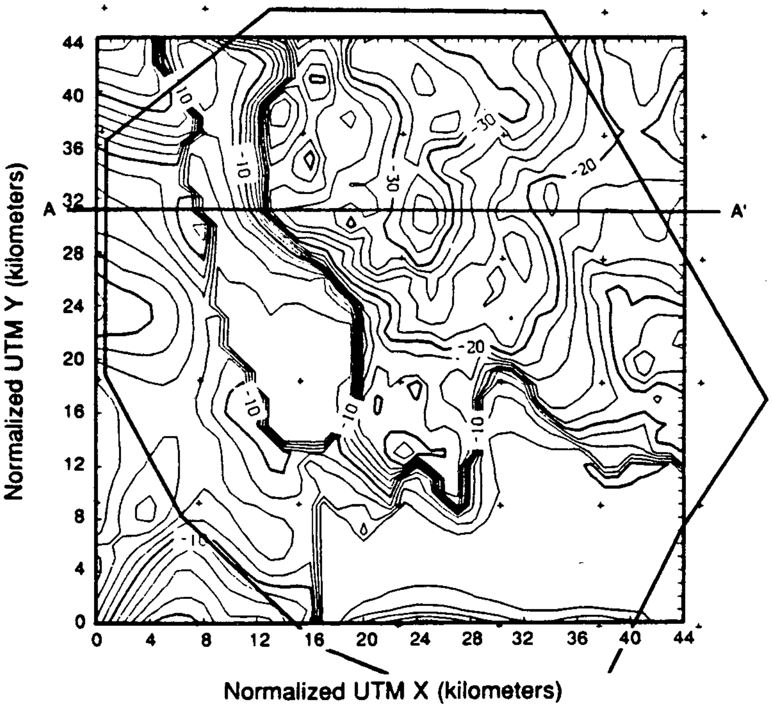

Figure 8. Residual anomaly remaining after stripping off the effects of Units 1 and 2 (contour interval: 2 mGal).

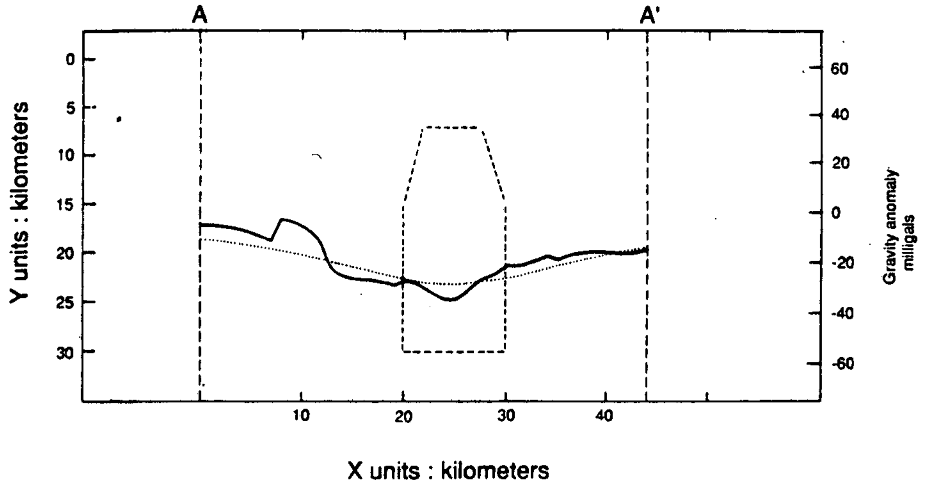

Figure 9. A two-dimensional fit of the residual anomaly shown in Fig. 8 along the east-west profile A–A'. The solid line is the residual anomaly after removal of the effects of Units 1 and 2. The dotted curve is the calculated anomaly considering the crustal low density zone (density contrast = –0.2) shown in the figure.

gests a volume of melt of about 2600 $km^3$, or larger than the Smith and Shaw (1975, 1979) estimates. However, due to errors and uncertainties in the gravity interpretation, the Smith and Shaw volume may be closer to reality.

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