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BOUGUER GRAVITY ANOMALY AND ISOSTATIC RESIDUAL GRAVITY MAPS OF THE WALKER LAKE 1° BY 2° QUADRANGLE, CALIFORNIA AND NEVADA

By

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INTRODUCTION

The accompanying gravity anomaly maps are part of a folio of maps of the Walker Lake 1° by 2° quadrangle, California and Nevada, prepared under the Conterminous United States Mineral Assessment Program. The quadrangle encompasses an area of about 19,500 km^2 along and to the east of the east flank of the Sierra Nevada (fig. 1).

The Bouguer gravity anomaly map of the Walker Lake quadrangle was prepared by interpolating gravity values among 3,447 gravity stations established in the quadrangle and additional stations from adjacent quadrangles. An isostatic residual gravity map was prepared in order to reduce the effect of interfering gravity gradients associated with the isostatic root of the Sierra Nevada. Methods of data reduction and factors that limit the accuracy of the gravity values are discussed in the following sections of this report.

The geologic interpretation of the gravity maps is based on previous studies, sample measurements, and correlation with other maps of the folio including a geologic map (Stewart and others, 1982) and a map showing Mesozoic plutonic rocks (John, 1983). The purpose of the interpretative part of this report is to demonstrate the correlation between gravity anomalies and the mapped geology, to assess the continuation of exposed geologic units beneath the surface, and to suggest the location of concealed subsurface bodies with mineral resource potential. A three-dimensional model of the Little Walker caldera (fig. 6) is used to illustrate a possible quantitative interpretation of a gravity anomaly. A concealed 25- by 75-km Cenozoic batholith along the east flank of the Sierra Nevada with possible lateral extensions is suggested in this report. A possible magmatic mechanism is discussed to augment contemporary explanations for the extensional origin of valleys. The possibility of lower gravity anomalies indicating thinner roof rocks in the basement beneath mountain ranges also is discussed. Furthermore, interpretation of gravity anomalies was applied in discussions with W.D. Menzie (oral commun., 1982) as one of the criteria used to identify and to delineate areas of mineral resource potential.

COMPILATION AND REDUCTION METHODS

The set of gravity data consists of 2,283 stations established by the U.S. Geological Survey and 1,164 stations obtained from other sources (fig. 2). Lists of values and an explanation of methods of data collection and anomaly calculation are in Plouff (1982a). The values of observed gravity were tied to the International Gravity Standardization Network of 1971 (IGSN-71)(Morelli, 1974) by tying the tide-corrected gravity observations to base stations at Hawthorne, Mina, Minden, and Yerington, Nev. (Jablonski, 1974; Defense Mapping Agency, written commun., 1980). Ties among base stations of an auxiliary network within the Walker Lake quadrangle established that 14.60 mGal should be subtracted from the observed gravity at stations tied to the California base station network (Chapman, 1966; Robbins and Oliver, 1976) in order to convert to the IGSN-71 datum. Minor adjustments of the observed gravity datums for other previous gravity surveys were determined by multiple gravity values at common stations and extensive repeat measurements during the current study. Minor adjustments of locations or elevations were made for previously established gravity stations, which were mislocated, as indicated on computerized plots, or were compiled before the publication of 7 1/2-minute topographic maps. Redundant stations and stations with doubtful reconciliation of locations with elevations were discarded from the data set. A four-digit code based on location, elevation, and observed gravity (if available) was assigned to the remaining stations, so that the accuracy of calculated gravity anomalies could be individually evaluated.

The source of greatest error in calculating gravity anomalies is the uncertainty of station elevations. The error of the gravity anomaly is 0.2 mGal/m of elevation error. The error is negligible at 1,183 gravity stations that have surveyed elevations or are located near benchmarks. Depending on the methodology used and the topographic contour interval, the error can approach 1.0 mGal for 1,210 gravity stations established near photogrammetrically determined elevations. Elevations were derived from topographic contour interpolation at 694 stations, from altimetry at 127 stations, and from other sources at 111 stations. Unfortunately, most of the published photogrammetrically determined elevations are on hilltops of limited or difficult access. The error of topographic contour interpolation is assumed to be less than or equal to half the contour interval of the map, which corresponds to a 2.4-mGal anomaly error for stations on maps with a contour interval of 24 m (80 ft). As a result of varying barometric conditions in this mountainous area and sparcity of elevation control points, altimetric elevation errors may exceed 10 m, and errors in determining the consequent gravity anomaly may exceed 2.0 mGal.

Conventional circular templates (Hammer, 1939; Swick, 1942) were used to estimate the terrain correction to a distance of 0.9 km for 1,752 stations during the current study and to a distance of 1.28 km for 176 stations by the University of California at Berkeley (M.W. Reynolds, written commun., 1978). Terrain corrections in the remaining distance interval to 166.7 km were determined with a computer program that uses topography digitized with a combination of half-minute, one-minute, and three-minute geographic grids (Plouff, 1977). Terrain corrections for the remaining stations were retained from the original compilations (Robbins and Oliver, 1976; Healey and others, 1980b). The terrain effect of Lake Tahoe, which is about 15 by 35 km and exceeds 400 m in depth, is underestimated by the digital model of surface elevations because the water is treated as rock. Modeling the lake with horizontal layers (Plouff, 1976) shows that the maximum correction in the Walker Lake quadrangle is 0.2 mGal at the shore, and the correction decreases to 0.1 mGal beyond 2 km from the shore. The effect of the lake, however, may need to be considered in interpreting gravity anomalies and gradients in adjacent quadrangles. For example, the effect of the water is 1.4 mGal for a station that is 200 m above lake level near the southwest shore, and the effect exceeds 0.5 mGal at the east shore while persisting at the 0.5-mGal level to a station 1,000 m above the lake level 6 km to the east of the shoreline.

Free-air gravity anomalies were determined using the Geodetic Reference System 1967 formula (GRS 67) for the theoretical value of gravity at sea level (International Association of Geodesy, 1971, p. 60) and Swick's (1942, p. 65) formula for the free-air correction. Bouguer, curvature, and terrain corrections at a standard reduction density of 2.67 g/cm^3 were added to the free-air anomaly at each station to determine complete Bouguer gravity anomalies.

The Bouguer gravity anomaly map (sheet 1) was prepared by interpolation of contours among gravity stations within the Walker Lake quadrangle and nearby stations in adjacent quadrangles. The contours closely match those of the Tonopah 1° by 2° quadrangle to the east (Healey and others, 1981), but small offsets reflecting slightly different data sets and interpolation methods occur along the join with the Nevada part of the Mariposa quadrangle to the south (Healey and others, 1980a). The contours do not merge with the adjacent maps to the south and west published by the California Division of Mines and Geology because the datum of observed gravity on those maps is about 14.6 mGal higher than that of the accompanying map, and the International Formula of 1930 (Lambert and Darling, 1931) was used to calculate the theoretical value of gravity at sea level. The net effect is that the level of the Bouguer gravity anomaly on the accompanying map is lower than those of the adjacent California quadrangles by differences ranging from 2.6 mGal along the south edge to 2.9 mGal along the north edge of the quadrangle. The join is exact within the California part of the Walker Lake quadrangle (Oliver and others, 1982) and along the border of the Mariposa quadrangle to the south (Oliver and Robbins, 1982), but the join with the Sacramento quadrangle to the west (Oliver and Robbins, 1974) is somewhat irregular as a result of new stations established during the present study. The join with the Reno quadrangle to the north (Erwin and Berg, 1977) similarly is irregular. The contour level of the accompanying map is 2.0 mGal lower than that of the Reno quadrangle, which adopted the observed-gravity datum of the U.S. National Gravity Base Net (Schwimmer and Rice, 1969) and the International Formula of 1930 (J.W. Erwin, oral commun., 1978).

ISOSTATIC RESIDUAL GRAVITY MAP

Nearly linear, north-northwest-trending gravity contours near the west edge of the Walker Lake quadrangle (sheet 1) reflect major crustal changes and associated density contrasts in the transition zone between the Sierra Nevada batholith and the Basin and Range province to the east. An approximate isostatic anomaly (fig. 3) was subtracted from the Bouguer gravity anomaly at each station to account for the part of the major gradient associated with the mass deficiency of a crustal downwarp (root) into the upper mantle beneath the Sierra Nevada, which isostatically compensates for the excess topographic mass above sea level. The isostatic correction was made by using the computer program of Jachens and Roberts (1981). Parameters assumed for the isostatic model are a normal crustal thickness of 25 km corresponding to stations located along the Pacific coast, a topographic density of 2.67 g/cm^3, and a density contrast of 0.4 g/cm^3 at the base of the crust. Elevations for the ground surface were obtained from the same geographic 3-minute grid (4.3 km east-west by 5.5 km north-south) used for calculating digital terrain corrections. The digital part of the isostatic correction was carried to a distance of 166.7 km from each station and the remaining correction was interpolated within the program from the worldwide chart of Karki and others (1961). A minor correction was not made for the thinner crust needed beneath Lake Tahoe because water rather than rock is assumed in the topographic model (fig. 4). The net effect would be to slightly lower the values of the isostatic residual gravity shown on sheet 2 near Lake Tahoe.

The magnitude of the isostatic correction is large, but the correction generally is a smoothly varying function of position in the Walker Lake quadrangle (fig. 3). The Bouguer gravity anomalies (sheet 1) range from -264 to -129 mGal with an average of -203±19 mGal, where the latter number is the standard deviation. The residual isostatic gravity (sheet 2) ranges from -61 to +12 mGal with an average of -21±13 mGal, corresponding to an average isostatic correction of 182 mGal. Although the isostatic equilibrium cannot be achieved this simply and the assumed isostatic model undoubtedly differs from more complicated crustal structure obtained by seismic refraction measurements (Eaton, 1966) and corresponding two-dimensional gravity models (Oliver, 1977), the isostatic correction provides a simple method to reduce the interfering effect of gradients associated with deep crustal sources. Lateral density changes within the crust, which depart from the assumed isostatic model, still can be interpreted from the residual isostatic gravity map. Alternate methods of removing interfering regional gravity fields, such as best least-squares fits, wave-number filtering, and upward continuation, are not based on physical models and cannot, for example, distinguish between low gradients associated with density contrasts near the surface and larger contrasts at depth. The mathematical methods generally do not account for varying station elevations, and, hence, could not detect that there is a 2- to 3-mGal difference in anomaly between the stations near Twin Lakes (10 km southwest of Bridgeport, Calif.) and the stations on the surrounding hilltops, which are about 1 km farther from mass deficiency associated with the underlying crustal root. The improvement in the ability to perceive local gravity anomalies associated with near-surface density contrasts, which are partly masked by gravity gradients associated with isostasy, is illustrated by a reduction of the gradient of the Bouguer gravity anomaly from about 100 mGal for 45 km east-northeast from the southwest corner of the quadrangle to 45 mGal in 45 km on the isostatic residual gravity map.

DENSITY MEASUREMENTS

Bulk densities were measured for rock samples collected at 74 sites (sheet 1). The average density of metamorphic rocks of Paleozoic and Mesozoic age collected at 11 sites is 2.74 g/cm^3 with a standard deviation of 0.06 g/cm^3. The average density of plutonic rocks generally of Mesozoic age collected at 37 sites is 2.71±0.07 g/cm^3. The average density of Tertiary volcanic rocks collected at 26 sites is 2.57±0.16 g/cm^3. These measurements supplement densities measured for suites of rocks reported by Oliver (1970; 1977, fig. 3) in the Sierra Nevada and density measurements summarized by Erwin (1970) near Yerington, Nev. D.C. Johannesen (written commun., 1982) measured sample densities associated with geologic mapping of an area in the Wassuk Range 10 to 15 km south of Hawthorne, Nev. He determined an average density of 2.61±0.01 g/cm^3 for 112 samples of granodiorite, 2.63±0.02/cm^3 for 50 samples of granite, 2.57 g/cm^3 for 33 samples of metamorphic rock, and 2.65 g/cm^3 for 31 samples of Tertiary andesite. Armin and John (1983) measured an average density of 2.70±0.04

g/cm^3 for 128 samples of granitic rock collected near Lake Tahoe.

Snyder and Healey (1983) compiled bulk densities from gamma-gamma logs of 14 drill holes located in an area about 150 km east of the Walker Lake quadrangle. They obtained average densities of 2.60 g/cm^3 for granite from one hole, 2.31±0.08 g/cm^3 for unspecified kinds of volcanic rocks from 9 holes, and 2.10±0.13 g/cm^3 for Quaternary alluvium from 10 holes. The density of alluvium measured in place is especially valuable because measurement of densities for hand samples of alluvium is difficult.

DISCUSSION

REGIONAL FEATURES

A strong regional gradient is present on the isostatic residual gravity map along the crest of the Sierra Nevada (sheet 2). This gradient reflects a combination of uncertainty of the parameters related to the assumed simple isostatic model, intracrustal density contrasts along the east edge of the Sierra Nevada batholith, and a possible underlying zone of transition between oceanic rocks and less dense continental rocks along a continental border of Mesozoic age (Oliver, 1977, p. 458). The gradient decreases northeastward to a northwest-trending gravity trough between Mono Lake and Lake Tahoe. Regional gravity values increase northeastward from the gravity trough to the complexly shaped crest of a regional gravity high near Hawthorne, Nev. Cogbill (1979, p. 155) attributed this increase to a combination of a northeastward 5- to 10-km thinning of the crust and a northeastward decrease of underlying granitic plutons, which are less dense than rocks of the surrounding basement.

The gravity trough along the east flank of the Sierra Nevada between Bridgeport and Markleeville, Calif., has a northeast boundary near the Nevada-California state line and forms a 25- by 75-km closed low, which is approximately outlined by the -35-mGal contour. In contrast to the Bridgeport-Markleeville gravity low, other elongate gravity lows spaced irregularly over a distance exceeding 300 km along the east flank of the Sierra Nevada have higher amplitudes, have smoother elliptical boundaries, and overlie sedimentary basins. Those gravity lows usually are interpreted as a reflection of thick underlying wedges of sedimentary deposits in downdropped blocks adjacent to the Sierra Nevada range front (Healy and Press, 1964). Plouff and Isherwood (1980), however, interpreted the southeast lobe of a 30- by 80-km gravity low with prominent peripheral gradients centered at Owens Valley as a possible magma chamber near the Coso Range, Calif. An isostatic residual gravity map (not available at the time of their interpretation) now clarifies the boundary. A small part of the Bridgeport-Markleeville gravity low reflects local thickening of sedimentary deposits in Bridgeport Valley. Tertiary and older rocks are predominant within the rest of the anomaly and extend beneath the apparently satellitic gravity lows outside the -35-mGal contour.

Although anomalies within the large gravity low are complex and the periphery of the Bridgeport-Markleeville low is irregularly shaped, segments of fairly continuous gravity gradients centered between the -35 and -30-mGal contours suggest that the gravity low outlines a large body of relatively low density, possibly with steep edges. The amplitude of the gravity low is about 15 to 20 mGal.

The major gravity low may outline the thickest or shallowest part of an underlying batholith of Cenozoic age from which the Tertiary volcanic rocks at the surface were derived. Geologic evidence for the existence of a Cenozoic batholith at relatively shallow depth includes hot springs and small outcrops of rhyolitic intrusive rocks of Tertiary age within and near the large gravity low (sheet 2; Stewart and others, 1982) and the Little Walker caldera (Noble and others, 1974) near the center of the gravity low. The rocks of the proposed Cenozoic batholith that cause the observed gravity low may be less dense than the surrounding basement and roof rocks for at least five reasons. First, the younger rocks of the batholith, although perhaps of similar composition to the surrounding wallrocks, have been subjected to a shorter time of compression associated with tectonic stress and depth of burial. The contrast in density, however, generally would be insignificant. Second, the batholithic rock may partly consist of glass, which can be 0.2 g/cm^3 less dense than crystalline rock of the same composition (Daly and others, 1966, table 4-3). Glass, however, usually forms near the surface under conditions of rapid cooling and is unlikely to be present at depth in substantial amounts. Third, the upper part of the postulated batholith may have relatively low density as a result of vertical zonation within the magma chamber; that is, more felsic, less dense rock components rose buoyantly toward the top of the magma chamber, and dense components sank as a result of chemical differentiation. A process of thermogravitational diffusion was suggested by Hildreth (1979) to explain zonation in the magma chamber from which the Bishop Tuff was erupted. Fourth, upper levels of the former magma chamber may be depleted of mafic components, which were largely extruded as Tertiary andesite now prevalent at the surface. Fifth, the batholith may still contain substantial amounts of magma. Heat and whatever convective-transfer process, including buoyancy, that caused and distributed the initial melt, however, would need to have been replenished until nearly the present time in order to maintain the liquid state.

No quantitative modeling of the batholith configuration, such as was attempted for a postulated batholith beneath the San Juan Mountains, Colo. (Plouff and Pakiser, 1972), is feasible because of the irregular shape of the anomaly and the unknown contribution of density contrasts associated with major intracrustal changes along the flanks of the Sierra Nevada. Assuming that the upper part of the batholithic rocks are 0.15 g/cm^3 less dense than the surrounding wallrocks, and the amplitude of the anomaly is 15 mGal, the upper part of the batholith has a thickness of 2.4 km.

VALLEYS

Elongated gravity lows with amplitudes ranging from 10 to 20 mGal associated with wedges of Quaternary deposits on the downdropped side of basin-range faults include Carson River, Smith, Mason, Walker Lake, and Soda Springs Valleys. An apparently fault-associated gravity low also overlies Quaternary deposits in Alkali Flat of Gabbs Valley in the northeast corner of the quadrangle. The prominent elongated gravity low in the eastern part of Gabbs Valley overlies Tertiary sedimentary rocks.

The gravity map provides a method to estimate the configuration of the interface between sedimentary deposits and bedrock underlying valleys. Generally, the location of the thickest deposits would coincide with the location of the lowest gravity values. Greater anomaly amplitudes reflect greater thicknesses of sedimentary deposits, and the highest gravity gradients would overlie the steepest flanks of the valley. For example, Erwin (1970) estimated the thickness of fill in Smith and Mason Valleys on the basis of gravity data. A gravity profile of closely spaced stations near Hawthorne, Nev. (fig. 5), reveals the concealed edge of the pediment aligned with the range-front scarp (Dohrenwend, 1982) at the west flank of Walker Lake Valley. The profile also has a change in slope that may overlie an older fault formerly at the edge of the valley or the northeast edge of a distributed fault system that starts at the location labeled "edge" on figure 5. Quantitative modeling of the subsurface configuration of valleys based on gravity data, however, is uncertain because of the wide possible variation of density within the sedimentary deposits and the unknown effect of the lateral variations of densities in the underlying basement rocks, which may be related to the valley-forming process.

The gravity low near Walker Lake may reflect rocks of relatively low density in the basement beneath the valley as well as the thickness of sedimentary deposits because electrical measurements indicate that high surface conductivities observed farther north in the valley may extend beneath the valley to a total depth of about 7 km near Schurz, Nev. (Lienert and Bennett, 1977, p. 544). The inference, based on geologic mapping, that calderas exist beneath Pueblo Valley, Ore., and Quinn River Valley, Nev. (Rytuba and McKee, 1984, fig. 1), shows that rocks of relatively low density with igneous origins may be found beneath other valleys of the Great Basin.

Substantial disparities between gravity-anomaly levels on opposite sides of valleys confirm that there are significant changes of density and associated changes of rock type beneath valleys. For example, the difference in gravity-anomaly level is about 28 mGal across Owens Valley, which is about 19 km wide (Kane and Pakiser, 1961, fig. 5). The change in level was attributed to unknown changes of density within the basement and was removed from the interpretative profile by subtracting a regional gravity anomaly that was assumed to be linearly distributed across the valley. The remaining 43-mGal gravity anomaly still may include a substantial contribution from contrasts of density within basement rocks beneath Owens Valley as well as variation in thickness of sedimentary deposits. Comparison of the gravity-anomaly levels on opposite sides of Warner Valley, Ore. (Plouff and Conradi, 1975), shows that only 7 mGal of a total relief of 19 mGal on the faulted west side of this basin-range valley can be attributed to the effect of a wedge of Quaternary sedimentary deposits in the valley. Other evidence that there are substantial density contrasts within basement rocks beneath valleys includes rapid changes of gravity values along the strike of valleys and larger gravity gradients over pediments along the edges of valleys that cannot be explained by changes of sediment thickness. Conventional models of the origin of basin-range valleys, as summarized by Stewart (1983, p. 34), emphasize extensional tectonics and do not incorporate underlying magmatic processes except for one model that has buoyant blocks floating on a substratum of presumable magma. Thompson and Burke (1974, fig. 16), however, suggested a dikelike body beneath Dixie Valley, Nev., to accomodate surface extension. On the basis of seismic refraction interpretation, Burke (1980, fig. 4.2) proposed a model incorporating a thinned lithosphere, a thick axial dike at a shallow level, listric faults, volcanic rocks, and sedimentary deposits associated with active intracontinental rift valleys.

A north-south-elongated gravity low with an amplitude of about 5 mGal is associated with the sediments that underlie Bridgeport Valley. Sharp (1972) observed that Bridgeport Valley is downwarped relative to the Sierra Nevada range front to the west and relative to a higher area to the south, through which a stream formerly flowed southward into Mono Lake. The vertical displacement in the area to the south may have occurred along the edges of a horstlike, northeast-trending basement block outlined by the gravity high between Bridgeport Valley and Mono Lake. The inner part of the gravity low at Twin Lakes reflects thickened sedimentary deposits along Robinson Creek. Plouff (1982b) suggested that the remaining part of the Bouguer gravity low may reflect the subsurface extent of plutonic rocks surrounded by denser metamorphic rocks. That initial interpretation was uncertain, because a magnetic low with about the same dimensions as the gravity low (3 by 15 km) is displaced markedly southward from the gravity low and trends more easterly. The portrayal by the isostatic residual gravity map (sheet 2) more clearly seems to suggest that the gravity low reflects an apophysis or tongue of the Cenozoic batholith.

BASINS

Gravity lows that are nearly circular are associated with bowl-shaped accumulations of sedimentary deposits at several locations in the Walker Lake quadrangle. The most prominent circular gravity low overlies Mono Lake and was the subject of the earliest detailed gravity and seismic studies in the quadrangle (Pakiser and others, 1960). Initially, the interpreted maximum thickness of basin fill beneath Mono Lake associated with a presumed 50-mGal gravity anomaly varied between 1 or 1.5 km (Christensen and others, 1969) and 5.5±1.5 km (Pakiser and others, 1960), depending on the assumed density contrast. Later estimates based on seismic measurements suggested a thickness of 2 to 2.5 km (Pakiser, 1976). Oval gravity lows of 5 to 20 mGal in amplitude overlie Lake Tahoe, Rhodes Salt Marsh, Teels Marsh, Columbus Salt Marsh, Garfield Flat, and Whisky Flat.

Seismic evidence indicates that the basin beneath Mono Lake is a structural depression formed by a combination of downwarping and faulting (Pakiser, 1976). Pakiser and others (1960, p. 445) postulated that the subsidence may have resulted from the removal of support by extrusion of volcanic material from an underlying magma chamber in this area of extensive volcanic activity. They stated that the mechanism of basin-range faulting seems inadequate to explain the origin of Mono Basin and its associated gravity low because the gravity low is equidimensional in plan view, which implies nearly equal gravity gradients on all sides, and lacks typical north to northwest elongation for block-faulted valleys in this part of the Basin and Range province. Christensen and others (1969) obtained a shallower model than Pakiser and others (1960) by assuming a larger density contrast between the basin fill and the subjacent bedrock, and, consequently, inferred that the subsidence could be accomplished by warping as well as faulting. They concluded that the "basin appears to be the product of a regional pattern of warping and faulting" (p. 5221) by explaining that the northeast elongation of the outer part of the gravity low "reflects a regional zone of northeast-southwest structural trends, extending far east of the...junction of this zone with northwest-trending structures" (p. 5225-5226). They further stated that the "basin...is not to be regarded as a volcano-tectonic depression, as has been suggested" (p. 5221), in contrast to the Long Valley caldera (Pakiser, 1961; Bailey and others, 1976; Kane and others, 1976) centered about 35 km to the southeast, which has an associated gravity low of similar size and amplitude to that of Mono Basin. They explained that "...the Mono Basin has not been the center of even approximately comparable volcanism and no direct relation of the basin to eruptive events is evident...Some irregularity in that geometry [of Mono Basin] may perhaps have been influenced by movements of magma at depth." (Christensen and others, 1969, p. 5238). This explanation seems to be based on the restrictive assumption that underlying magma chambers the size of Mono Basin must evolve into volcanic centers.

Kane and others (1976, p. 759) suggested that an irregular 10-mGal band outside a 35-mGal gravity low over the Long Valley caldera reflects an underlying magma source centered at a depth of 8 to 16 km. If a magma chamber exists beneath Mono Basin, the shallowest part may be within the associated gravity low because contours of a seismic delay-time map (Pakiser, 1976, fig. 2), which reflect the near-surface thickness of a combination of volcanic rocks and fill, nearly coincide with the outermost contours of the closed, 30-mGal low. On the basis of P-wave teleseismic delays, VanWormer and Ryall (1980, p. 1569) outlined a crustal low-velocity zone in the southeastern 30 minutes of the Walker Lake quadrangle and, consequently, defined a possible source area for late Quaternary volcanism. Focal depths for earthquakes in this east-west zone are shallower (2 to 7 km) under Mono Lake and deeper (5 to 15 km) to the east (VanWormer and Ryall, 1980, p. 1561).

Prominent gravity lows that are nearly circular apparently reflect the bowl-like configuration of thick fill associated with subsidence beneath Mono Basin, Rhodes Salt Marsh, Teels Marsh, and Columbus Salt Marsh. However, it is difficult to establish whether subsidence of the basins is localized by "a regional pattern of warping and faulting" (Christensen and others, 1969) or, alternatively, by collapse of underlying rocks into a hydrostatically deflated or an extrusively depleted cupola of a Cenozoic magma chamber. Upper-level magma reservoirs that were sources of the prevalent Cenozoic volcanic rocks most likely existed and perhaps still exist in partially molten or crystalline states in forms similar to the plutons and batholiths of Mesozoic age that are now exposed in and near the Sierra Nevada. Emplacement of magma through denser rocks toward higher levels in the crust probably occurred preferentially near former conduits or along tectonic zones of weakness such as folds and faults. On the other hand, if a magma chamber has reached the upper crust, relief of regional tectonic stress later might preferentially occur at that locality in the form of a combination of faulting and warping, which depends on the competence of the rocks under stress, the confining pressure, and the magnitude and direction of the applied stress. Therefore, the alternate tectonic or magmatic origins of Mono basin and other areas of subsidence in the Walker Lake quadrangle can be closely interwoven. The gravity effect of underlying magma reservoirs or batholiths, however, may be masked by the effects of overlying roof rocks or sedimentary deposits unless the igneous body has a sufficiently large density contrast and volume or has steep edges with associated peripheral gravity gradients. The existence of igneous bodies beneath gravity lows also may be deduced from other geophysical observations such as the electrical resistivity low near Schurz, Nev. (Lienert and Bennett, 1977), and seismic shear-wave attenuation near Long Valley (Sanders, 1984).

Gravity lows that are located over sedimentary deposits of Tertiary or early Quaternary age may reflect thick accumulations of sedimentary deposits in basins that are no longer subsiding or in some places that are not subsiding as rapidly as adjacent Quaternary basins. The largest of these gravity lows is located in Gabbs Valley (northeast corner of the quadrangle), the southern part of Mason Valley (south of Yerington), and between Carson River Valley and the Pine Nut Mountains. Gravity minima over older sedimentary deposits in Gabbs and Mason Valleys suggest that the deposits are thicker and, presumably, the subsidence was greater at those locations compared to the adjacent parts of the valley covered by Quaternary deposits unless there was a significant contribution to the amplitude of the anomalies from basement rocks of relatively low density beneath the valleys. The southeast part of the gravity low at Rhodes Salt Marsh overlies sedimentary deposits of Tertiary and Quaternary age. Other broad lows that incorporate older sedimentary deposits are located 18 km southeast of Yerington and along the west flank of Wellington Hills (north of Sweetwater Mountains). The latter low does not extend westward into Antelope Valley, possibly because the Quaternary sedimentary deposits are thin over Mesozoic rocks in the roof over the northeast edge of the postulated batholith.

Gravity lows are associated with six structural basins of Miocene and Pliocene age described by Gilbert and Reynolds (1973) in the central part of the quadrangle. These are Fletcher Valley (and Baldwin Canyon), Coal Valley, Wichman Valley, East Walker River Valley, Pine Grove Flat (southern part of Mason Valley), and the southern part of Smith Valley. Gilbert and Reynolds (1973, p. 2493) stated that stratigraphic relations show that the sedimentary deposits now preserved in the six basins originally accumulated in a single large basin, which was later subdivided by Quaternary warping and minimal faulting.

CALDERAS AND GRAVITY ANOMALIES OVER VOLCANIC ROCKS

The Little Walker caldera, roughly outlined by a -45-mGal contour (sheet 2) located about 20 km northwest of Bridgeport, Calif., is believed to have been formed by collapse in response to the withdrawal of magma from an underlying magma chamber following the eruption of the Miocene Eureka Valley Tuff of the Stanislaus Group (Noble and others, 1974). Oliver (1974) reported that W.R. Dickinson and his students from Stanford University, Palo Alto, Calif., used gravity measurements to estimate the subsurface configuration of the downdropped wedge of tuffaceous sediments associated with the Little Walker caldera. Three-dimensional modeling (Plouff, 1976; 1982b) later demonstrated that a wedge of tuffaceous sedimentary rocks with a thickness of 1.4 km and averaging 0.47 g/cm^3 less dense than the surrounding rocks can account for the observed gravity low (fig. 6). A gravity high reflects the intrusive volcanic rocks forming the core of Mount Emma, a large stratovolcano (G.F. Brem, written commun., 1981) to the southwest of the caldera.

Other closed gravity lows in the Walker Lake quadrangle, including those over the previously discussed Cenozoic basins, similarly could reflect underlying calderas. None of the lows overlie pre-Tertiary rocks except the large Bridgeport-Markleeville gravity low, which encompasses rocks of diverse ages. The -45-mGal contour (sheet 2), which roughly outlines the subsurface extent of the Little Walker caldera, encloses tuffaceous rocks of the Stanislaus Group. The 6- by 14-km gravity low, which is centered over Lost Cannon Creek about 14 km to the northwest of the Little Walker caldera, also encloses rocks of the Stanislaus Group (Stewart and others, 1982) and similarly may reflect an underlying caldera. No gravity lows enclose or are near other remnants of the Stanislaus Group in the Sierra Nevada, but the station coverage may be too sparse and the regional gravity gradient may be too large to identify a gravity low near the cluster of outcrops of the Stanislaus Group located about 12 km northeast of Pinecrest, Calif. A few outcrops mapped as the Stanislaus Group are located between two prominent gravity lows centered 10 to 12 km northeast of the state line near Bald Mountain and Fletcher, Nev.

Local accumulations of tuff or underlying tuffaceous sedimentary deposits may be too small in volume or the gravity coverage may be too sparse to reveal significant gravity lows within extensive outcrops of tuff in Nevada near the south edge of the Walker Lake quadrangle except at a southeast-trending gravity low near Miller Mountain (8 km northeast of Basalt). Prominent gravity lows that possibly may identify calderas are located at Teels Marsh, Rhodes Salt Marsh, and Columbus Salt Marsh near the north and east margins of extensive outcrops of tuff. Small erosional remnants of tuff are found to the east and west of the elongated gravity low in Soda Spring Valley near Luning, Nev. A large, elongated gravity low in Walker River Valley near Schurz, Nev., which is near an electrical resistivity low, is located to the west of the northwest end of nearly continuous outcrops of tuff that extend 60 km southeast along the Gillis and Gabbs Valley Ranges. A broad gravity low centered over Alkali Flat in the western part of Gabbs Valley is near the northeast margin of the same band of tuff. The gravity low southeast of Schurz for the most part may reflect a volcano-tectonic depression or the site of a large, formerly active magma chamber suggested by Ekren and others (1980, p. 48-51), which is the source of enormous volumes of tuff and flows exposed in the Gabbs Valley and Gillis Ranges. Gravity lows centered at long 119°0'W. (13 km south of the north edge of the Walker Lake quadrangle) and in Mason Valley (south of Yerington) are located near large outcrops of tuff and, hence, may identify concealed Tertiary calderas. Proximity of the eastern of the two lows to a volcanic center is further supported by the occurrence of two outcrops of Tertiary breccia (Stewart and others, 1982) at the southwest edge of that low.

The criterion of proximity of a gravity low to an outcrop of tuff, although suggestive, does not prove a genetic relation to the eruption of the nearby tuff because ash-flow tuff is mobile and can be found far from its eruptive source. Rhyolitic flows and intrusive rocks shown on the generalized geologic base are relatively viscous and hence are more likely to be found closer to their sources than ash-flow tuff or basalt. For example, the outcrops of Quaternary rhyolite and dacite that form most of the islands in Mono Lake are probably near their source.

Large outcrops of Pliocene rhyolite (Gilbert and others, 1968, p. 293) underlie a prominent gravity low at the Mt. Hicks volcanic center (35 km east of Bridgeport). The large 8- by 15-km areal extent of the anomaly suggests a deep source, although a substantial part of the amplitude of the observed anomaly may reflect rocks of the topographic edifice that have markedly lower densities than the reduction density of 2.67 g/cm^3. Within the limits of sparse gravity-station coverage, a gravity low apparently is not associated with a similar volcano (Gilbert and others, 1968, p. 293) near Beauty Peak 14 km to the west of Mt. Hicks. A 4- by 9-km gravity low occurs at a major complex volcano (Kleinhampl and others, 1975, p. 18) at Bodie Mountain (13 km east-southeast of Bridgeport). A gravity low of similar dimensions, which is located 9 km north of Bodie Mountain, has a 2- by 5-km outcrop of rhyolite along its southwest edge. A small gravity low centered 7 km west of Bodie Mountain overlies the Big Alkali caldera (Chesterman, 1968), a collapse feature 3 km in diameter, "from which pyroclastic materials and lavas issued and into whose interior and rim zone plugs of rhyodacite and rhyolite were later emplaced" (Kleinhampl and others, 1975, p. 18). C.W. Chesterman and R.H. Chapman ran gravity traverses and estimated that a maximum thickness of 150 m of sedimentary deposits underlies the Big Alkali caldera (Chesterman, 1968).

Extensive outcrops of rhyolite along the east flank of the Sweetwater Mountains generally seem to underlie irregular gravity lows within the border of the postulated batholith. The gravity-station coverage is too sparse to determine if the gravity low in Wickman Valley extends significantly northwestward into outcrops of rhyolite that cover a 5- by 10-km area along the east flank of the Pine Grove Hills. These rocks crop out just north of a 10- by 12-km gravity low over "a major collapsed andesitic vent centered southeast of Bald Mountain" (Kleinhampl and others, 1975, p. 31). The prominent gravity low seems to reflect a bowl-shaped accumulation of volcanic rocks surrounded by denser Mesozoic rocks with an arcuate fault pattern along the southeast edge. The gravity low partly may reflect a former magma chamber, into which volcanic rocks, sedimentary deposits, and basement rocks subsided.

A horseshoe-shaped combination of outcrops of rhyolite covering a 4- by 8-km area midway between Markleeville and Topaz Lake partly encloses the northern lobe of the Bridgeport-Markleeville gravity low. The closed 5- by 15-km gravity low centered 3 km northeast of Markleeville may reflect a local apophysis of the postulated underlying batholith. The faults mapped over the closed gravity low lack the arcuate pattern that might suggest a concealed caldera, and no pyroclastic rocks are present. Gravity gradients along the south edge of the low reveal a steep boundary at less than 3-km depth that separates rocks of sharply contrasting densities. Several north-northeast-trending faults are enclosed by the low and a major fault (Dohrenwend, 1982) underlies the northwest edge of the gravity low.

Interfering gravity gradients are too large or the gravity station coverage is too sparse near exposures of rhyolite in the eastern part of the Walker Lake quadrangle to define gravity anomalies that might be associated with them. Gravity lows, however, may be associated with outcrops of rhyolite near Pilot Cone at the north edge of the quadrangle, the north flank of the Gabbs Valley Range between the eastern and western parts of Gabbs Valley, and the west flank of the Garfield Hills.

The subsurface volumes of rhyolitic intrusive rocks (small triangles on sheet 2) generally are too small and the gravity-station spacing is too large to produce a consistent correlation between the gravity pattern and the locations of rhyolitic intrusive rocks. There are three locations where relative gravity highs might reveal underlying Tertiary stocks or plutons that intrude less dense volcanic rocks, as in the case of the San Juan Mountains, Colo. (Plouff and Pakiser, 1972, p. B188). These locations are near Highland Lakes (in the Sierra Nevada 36 km northnortheast of Pinecrest), South Sister (northeast side of the Sweetwater Mountains), and Bodie. The location of outcrops of Tertiary intrusive rocks near lobes at the north, south, and east edges of the large T-shaped gravity high over and to the south of the Garfield Hills may be significant. Assuming that the gravity effects of overlying veneers of sedimentary deposits and Cenozoic volcanic rocks are negligible, the large gravity high appears to outline a block of pre-Cenozoic basement rocks. The Tertiary intrusive rocks probably ascended along paths of least resistance such as contacts near the margin of the basement block, and, as indicated in the western part of the block, near paths previously penetrated by Mesozoic plutons.

BASEMENT ROCKS

Mountain ranges that have deep-seated cores of pre-Cenozoic basement rocks, including the west flank of the Sierra Nevada, the Wassuk Range, and the Singatse Range (west of Yerington), have associated gravity highs that express the contrast in density between rocks of the mountain ranges and less dense sedimentary deposits and Cenozoic volcanic rocks at comparable depths in the surrounding areas. On the other hand, gravity highs evidently are not as prominent over mountain ranges such as the Sweetwater Mountains and the Gillis Range because the underlying, relatively dense basement rocks are not "deep seated". The additional effect of large-scale density anomalies such as might be associated with a Cenozoic batholith within basement rocks will be discussed later when applied to specific mountain ranges.

Oliver (1977, fig. 3) determined that the average density of 418 samples of the Sierra Nevada batholith collected between lat 36° and lat 38° is 2.68±0.06 g/cm^3 and the average density of 121 samples of wall-rocks and roof pendants is 2.75±0.14 g/cm^3. He concluded that this small but significant density contrast causes observable gravity highs where metamorphic rocks in roof pendants are surrounded by younger plutonic rocks. The prominent gravity high of about 15 mGal between Bridgeport and Mono Valleys, with a faultlike boundary along the northwest edge of Mono Valley, reflects a basement block bounded to the north and southeast by sedimentary deposits, Cenozoic volcanic rocks, and presumed Cenozoic batholithic rocks. Oliver (1977, p. 454) interpreted the southward prolongation of this gravity high near Saddlebag Lake and Tioga Pass, located 3 and 10 km south of the quadrangle, respectively, as the effect of a roof pendant with an average density of 2.86 g/cm^3. There is a small saddle between this high and a northwest-trending high, which has a crest over basement rocks 10 km northwest of Bodie. The relative gravity high over Buckeye Creek (8 km west of Bridgeport) mostly may reflect a septum of basement rocks between the Little Walker caldera and a cupola of the postulated Cenozoic batholith beneath Robinson Creek. The gravity high in the Wassuk Range 8 km southwest of Hawthorne, Nev., reflects an exposed underlying metamorphic roof pendant.

The Sweetwater Mountains probably do not have an associated gravity high because pre-Cenozoic roof rocks are thin over the presumed underlying Cenozoic batholith, which is delineated by the Bridgeport-Markleeville gravity low. Outcrops of basement rock near Masonic Mountain and outside the Bald Mountain gravity low similarly do not have associated gravity highs.

Steep gravity gradients along the linear east flank and the arcuate northwest flank of the Pine Nut Mountains and along most edges of the Singatse Range overlie steep, probably faulted edges of the respective basement blocks. No northeast-trending faults have been mapped at the edges of the prominent southwest prolongation of the basement block associated with the Singatse Range. Only the northeast and west edges of the basement block beneath Pine Grove Hills seem to be steeply dipping or fault controlled. The smooth elliptical shape of the anomaly associated with this block suggests that the gravity high outlines a Mesozoic pluton, which nearly surrounds a pendant underlying the west crest of the gravity high.

Roof rocks are exposed at the crest of the prominent gravity high associated with the Wassuk Range and at a minor crest 8 km southwest of Hawthorne, Nev. Steep gravity gradients around most edges of the Wassuk Range indicate that this deep-seated block of basement rocks is largely fault bounded. Although pre-Cenozoic basement rocks are prevalent in the Gillis Range, the absence of an associated gravity high perhaps indicates that the basement rocks are allocthonous and seem to be deeply rooted only near the southeast edge of the range. Associated gravity highs indicate that the dense basement rocks beneath the Gabbs Valley Range and the Pilot Mountains to the southeast are relatively deep seated. The exceptionally sharp gravity high over the Monte Christo Mountains in the northeast corner of the quadrangle and its subsurface extension to the southwest reflects a fault-bounded, deep-seated wedge of basement rocks. The sharpness of this gravity high is accentuated because Cenozoic deposits of low density in the adjacent Gabbs Valley are thick.

The gravity low indicated by the closed 25-mGal contour 10 km to the south of Hawthorne overlies the narrowest part of the valley between the Wassuk Range and the Garfield Hills. The valley fill is too thin to substantially affect the amplitude or the horizontal extent of the gravity low. Therefore, the gravity low reflects rocks within the basement beneath the valley, which have average densities lower than basement rocks beneath the Garfield Hills and the Wassuk Range. The gravity low might reveal an underlying Cenozoic pluton beneath the valley, because gravity lows have been observed in other areas over outcropping masses of relatively young plutonic rocks surrounded by denser basement rocks (Case, 1967; Witkind and others, 1970).

VanWormer and Ryall (1980, fig. 5) mapped an area of low velocity in a 30-minute area of the southeast corner of the Walker Lake quadrangle by studying the relative arrival times of *P*-waves from teleseisms. Inasmuch as they also recorded clusters of local microearthquakes with focal depths of 2 to 7 km beneath Mono Lake and depths of 5 to 15 km at locations farther to the east, they interpreted the low-velocity zone as a reflection of an underlying zone of partial melt in an area of volcanism and geothermal activity. The low-velocity zone extends from an area of maximum time delays at the north flank of the Adobe Hills northeastward through Teels Marsh to Luning. Delay times also increased southeastward along the southeast flank of the Candelaria Hills toward Columbus Salt Marsh. Anomalous delays were not observed at Garfield Flat or Rhodes Salt Marsh, perhaps because station coverage was too sparse and no valley sites were occupied. Mono Valley and Walker Lake are outside the network of seismometers used by Van Wormer and Ryall (1980), but the low-velocity zone is apparently absent or relatively thin beneath the Wassuk Range, Garfield Hills, and Candelaria Hills. If a gravity map is contoured by using data points only at sites from the seismic delay-time study, a gravity low is produced, which is somewhat larger than the delay-time anomaly and has lower values to the west. Although correlation of the delay-time anomaly with a regional version of the gravity map is not clear, the perception of an underlying zone of partial melt associated with the delay-time anomaly and associated with local seismicity suggests plutons of Cenozoic age as sources for some local gravity lows. Furthermore, Cenozoic plutons and, during a stage of active volcanism, calderas are more likely to be located in the basement beneath valleys than elsewhere because the near-surface crust would be vulnerable to intrusion at sites with histories of normal faulting or subsidence.

GRAVITY ANOMALIES AND MINERAL RESOURCE POTENTIAL

The gravity maps primarily were used during the resource assessment phase of this study to find or to delineate calderas, volcanic centers, plutons, and roof pendants, and to provide approximate borders along range fronts where the alluvium might be too thick to profitably recover ore from underlying potential mineral deposits. No attempt was made to directly locate ore bodies, but interpretation of gravity anomalies and simultaneous interpretation of magnetic anomalies (Plouff, 1987) helped to identify features in the regional geologic framework that might be favorable to ore deposition. The gravity and magnetic maps also can provide constraints for future studies of resources, such as water, geothermal energy, and petroleum, and constraints for studies of geologic hazards including volcanic eruptions and earthquakes.

Ash-flow tuffs that erupted from calderas such as the McDermitt caldera, Nev. and Ore., may be enriched in elements including mercury and uranium (Rytuba, 1981). Sedimentation and hydrothermal mobilization may further concentrate minerals to form ore deposits at these highly fractured sites. Sedimentary deposits filling calderas may act as thermal insulators (Grose and Keller, 1979, p. 366) above radioactive and magmatic sources of heat. Therefore, water-saturated sedimentary deposits near the bottoms of Cenozoic calderas, similar to the Valles caldera, N. Mex. (Goff and Grigsby, 1982) may have abnormally high temperature gradients and consequently may form geothermal reservoirs. As previously discussed, calderas can be detected as gravity lows (fig. 6) because they consist of tuffaceous sedimentary deposits of relatively low density that fill basins formed in roofs subsiding into underlying magma chambers. Sedimentary deposits in calderas formed before Cenozoic time probably have been compacted, indurated, and perhaps crystallized, so that there would be little contrast in density with the surrounding rocks, hence no detectable gravity anomaly.

Many mineral deposits in Nevada are located near Cenozoic volcanic centers (Albers and Kleinhampl, 1970). Wallace (1979) discussed the specific case of porhpyry-copper deposits that may underlie young volcanic centers in Nevada. Two volcanic centers, active less than 6 m.y. ago, located near Bald Mountain and Mount Hicks (Stewart and Carlson, 1976) are correlated with prominent gravity lows (sheet 2). The gravity lows may reflect underlying calderas. A gravity low of similar dimensions located to the north of Markleeville, Calif., also may reflect a concealed caldera. Extensive deposits of tuff, however, were not found near any of the three gravity lows. Alternatively, one or more of these gravity lows may reflect local accumulations of previously erupted volcanic rocks of relatively low density or may reflect satellitic Cenozoic plutons within denser basement rocks located just outside the hypothetical batholith delineated by the Bridgeport-Markleeville gravity low.

Although the evidence for identifying present or former sites of underlying magma chambers is inconclusive, the concept of an underlying Cenozoic batholith along the east flank of the Sierra Nevada with separate plutons to the north and east plays an important role in evaluating geologic models of mineral deposition. Mineral-rich fluids formed by differentiation and mobilized by heat can create a metasomatic aureole around a magma chamber (for example, Proffett, Jr., 1979, fig. 5; Beane, 1983). Moore (1969) stated that the greatest mineral production in Lyon, Douglas, and Ormsby Counties, Nev., has come from contact metasomatic deposits, vein deposits, and deposits formed within granitic rocks. Wallace (1979, p. 74) suggested that for future exploration the Markleeville and the Masonic mining districts in the Walker Lake quadrangle have some of the characteristics of upper levels of porphyry systems. Both mining districts and the Patterson mining district near the southeast edge of the Sweetwater Mountains are located near the edge of the Bridgeport-Markleeville gravity low. All three mining districts in the Walker Lake quadrangle, for which Silberman and others (1976) obtained ages of hydrothermal, precious-metal mineralization, are located near the edge of the Bridgeport-Markleeville gravity low. The ages, which are among the youngest determined for deposits in the Great Basin, are 5, 7, and 10 Ma for the Monitor, Bodie, and Aurora mining district samples, respectively. The younger the age of mineralization, the more likely that the plutonic source, from which heat, fluids, or propulsive force emanated, can be detected as a gravity low because the density of a pluton later would increase by crystallization. Case (1967) and Curtin and King (1974) suggested that gravity lows may reveal concealed Tertiary intrusive bodies and associated ore deposits in the Front Range mineral belt of the Colorado Rocky Mountains.

Older plutons such as the intrusive body that contains the porphyry-copper ore near Yerington, Nev. (Ware, 1979) may not significantly differ in density from the surrounding country rock and, consequently, are unlikely to be detected on a gravity map. As discussed earlier, roof pendants of metamorphic rocks may be denser on the average than adjacent plutonic rocks. For example, a west-northwest-elongated gravity high in the Singatse Range 8 km southwest of Yerington probably reflects the extent of the underlying mass of roof rocks that were engulfed by later Mesozoic plutonic rocks. Therefore, contact-metasomatic deposits that are found near a contact between intrusive rocks and older carbonate rocks might be located along the gravity gradient that follows the contact.

Evaporite mineral deposits are found in basins of the region. Evaporite commonly contains zeolite (Surdam, 1979), borate (Noble, 1926), lithium-bearing brine (Davis and Vine, 1979), or a variety of saline minerals such as those found in Searles Lake basin, Calif. (Mabey, 1956). The gravity map of the Walker Lake quadrangle provides an estimate of the subsurface extent of sedimentary deposits that contain evaporite deposits being extracted from Teels Marsh, Rhodes Salt Marsh, and Columbus Salt Marsh (Kleinhampl and others, 1984). Other geophysical methods such as seismic soundings (Mabey, 1956, fig. 4) and electrical soundings (Bisdorf and Smith, 1976) can be used to supplement estimates based on interpretation of the gravity map.

Gravity models of the subsurface extent of sedimentary deposits also have been used to evaluate the ground-water potential of valleys in the Walker Lake quadrangle. Blum (1979) estimated the total ground-water storage of the South Lake Tahoe Basin by using gravity analysis, and D.K. Maurer (written commun., 1981) of the U.S. Geological Survey established more than 300 gravity stations in order to estimate the ground-water potential of Carson River Valley.

Many valleys in the region have been studied for their geothermal potential (Garside and Schilling, 1979). Hose and Taylor (1974) explained that hot springs and other geothermal manifestations could result from a hydrothermal system in which meteoric waters percolate downward to a depth at which rocks are normally hot, are heated, and ascend to the surface along deeply penetrating basin-range faults. The highest temperatures for hot springs in Mineral County were measured at Wedell Springs near the west flank of the Monte Christo Mountains (Garside and Schilling, 1979, p.47). Wedell Springs are located on the down-dropped side of the inferred southward continuation of a mapped normal fault (Stewart and others, 1982; Dohrenwend, 1982) with an associated steep gravity gradient, which might provide conduits for deep circulation suggested by Hose and Taylor (1974). The explanation of Hose and Taylor, however, may not fully account for the magnitude of an exceptionally high heat flow of 7.2 HFU (300 mW/m^2) determined in a drillhole 3 km southwest of Luning, Nev. (Munroe and Sass, 1974, p. 3-116) without a heat source at an abnormally shallow depth. The closest mapped range-front fault is a major fault about 7 km from the drillhole on the east side of Soda Spring Valley. The steepness of the gravity gradient, however, suggests that there also is a concealed major range-front fault on the west side of the valley. Furthermore, coincidence of a relatively high seismic delay time (VanWormer and Ryall, 1980, fig. 5) and the lowest part of a gravity low in Soda Spring Valley suggests that the anomalous heat may be derived from a magma chamber or a partly molten Cenozoic pluton buried at shallow depth to the east of or beneath the drillhole. As discussed in the previous section, nearby clusters of microearthquakes with shallow focal depths and a history of repeated volcanism suggest that magma chambers occur at shallow depths in the area. Furthermore, convective hydrothermal systems surrounding magma chambers or plutons may localize epithermal ore deposition and cause anomalous heat flow (White and Heropoulos, 1983; Bonham and Giles, 1983).

Hydrothermal systems play an important role in the maturation and mobilization of organic matter during the formation and localization of petroleum and epithermal mineral deposits (Simoneit, 1983, p. 215). The discovery of oil in Railroad Valley, Nev., has renewed exploration interest throughout the Great Basin. Duey (1983) stated that conditions favorable to generation of petroleum in Railroad Valley and elsewhere include immature shaly source rocks near a valley heated by underlying intrusive rocks. Although drilling for oil or gas in the Walker Lake quadrangle has been limited to one well abandoned in about 1920 (Garside and Schilling, 1977), areas with conditions favorable for oil generation similar to those in Railroad Valley may now be evaluated. Gravity anomaly maps have been used in conjunction with seismic exploration to determine the thickness of sedimentary deposits and to locate faults, for example, in Railroad Valley (Guion and Pearson, 1979) and Fallon Basin (Hastings, 1979, fig. 2).

The gravity anomaly map also can be used to assist in interpreting ground movements recorded by seismometer nets that monitor volcanic activity (Miller and others, 1982) and earthquakes (VanWormer and Ryall, 1980). For example, the possibility that the gravity anomaly map reveals a Cenozoic batholith should have a strong influence on interpreting seismic data. Movement over cupolas of an underlying Cenozoic batholith may account for interruptions of the major fault pattern along the east flank of the Sierra Nevada (Dohrenwend, 1982), which otherwise might be continuous or en echelon in response to basin-range extension and general Sierra Nevadan uplift. Interpretations based on fault-plane solutions obtained from the directions of first motions of earthquakes consequently should incorporate possible movement of underlying magma near calderas and Cenozoic plutons as well as basin-range extension. Knowledge of the geologic framework derived from the gravity anomaly map also can be used to position seismometers, to estimate local velocity corrections needed to determine hypocenters, and to estimate interstation time and near-surface amplitude corrections needed for teleseismic studies.

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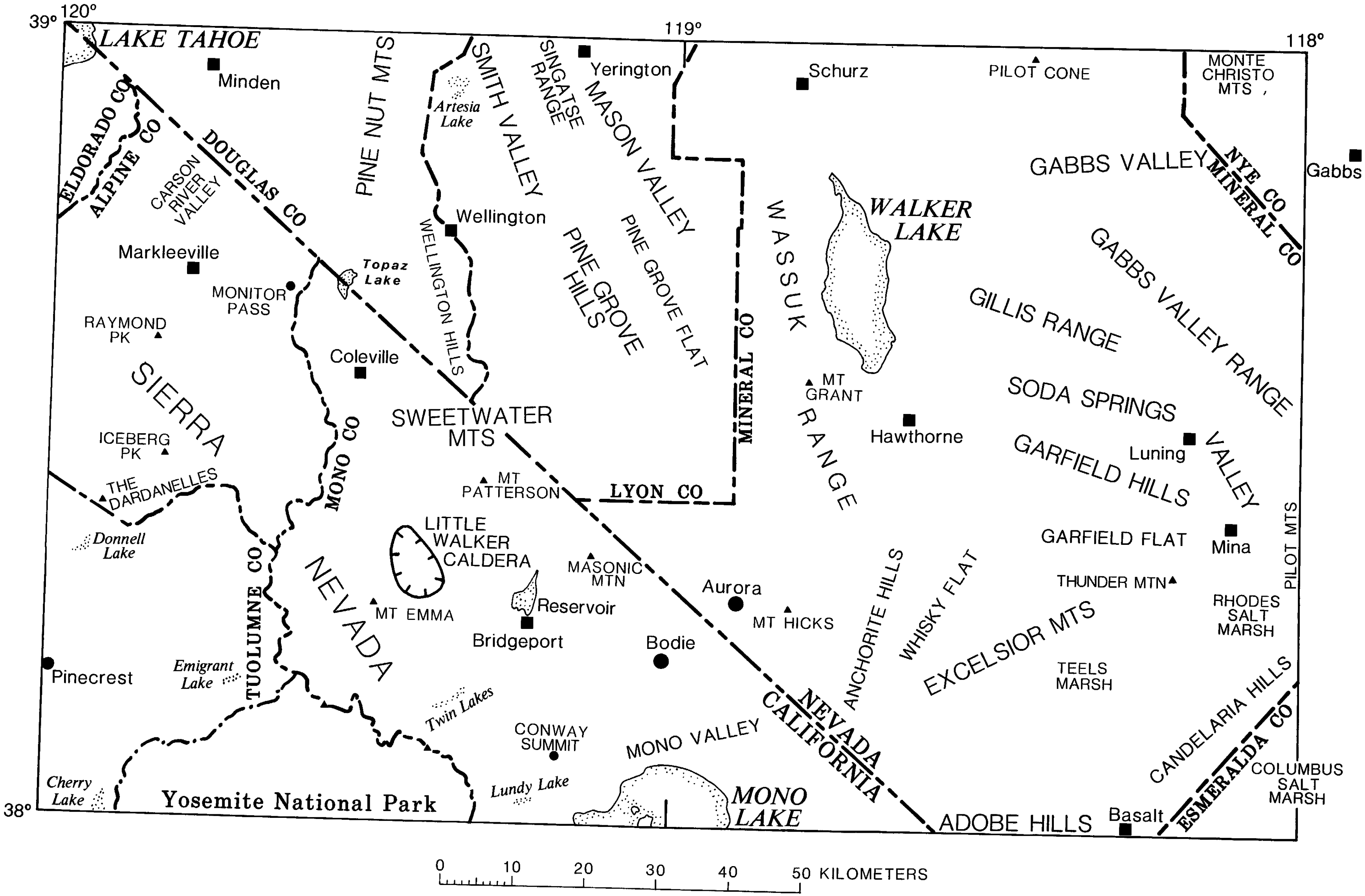
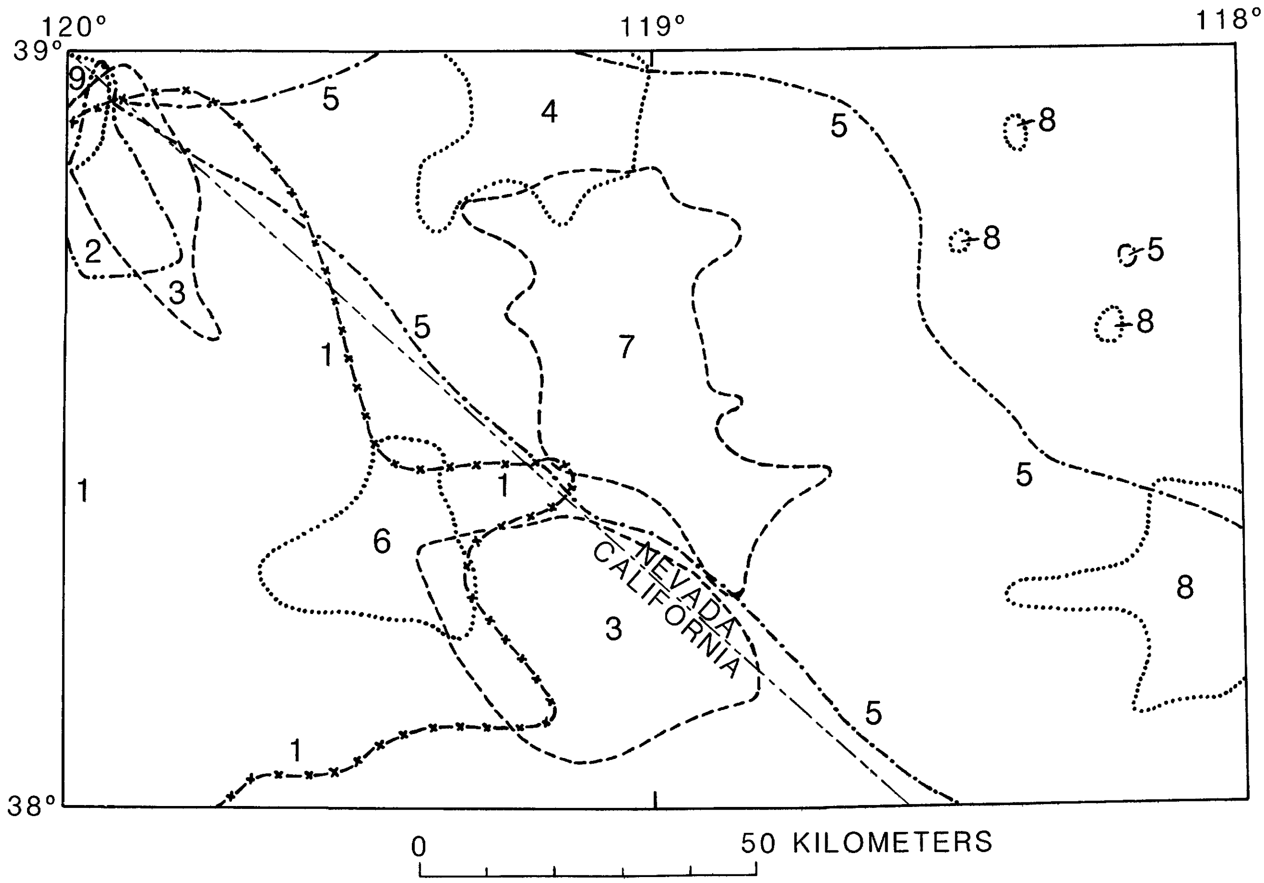


Figure 1.--Index map showing locations discussed in text.



EXPLANATION

A, area in figure; N, number of gravity stations obtained from contributor

A	N	Contributor
1	34	University of California, Berkeley, Calif., (J.F. Evernden, written commun., 1961; Robbins and Oliver, 1976)
2	9	Jet Propulsion Laboratory, Pasadena, Calif., (A.A. Loomis, written commun., 1967; Robbins and Oliver, 1976)
3	150	California Division of Mines and Geology (Robbins and Oliver, 1976; R.H. Chapman, written commun., 1980)
4	45	Nevada Bureau of Mines and Geology (Erwin, 1970; J.W. Erwin, written commun., 1978)
5	125	Aeronautical Chart and Information Center (written commun., 1978)
6	148	Stanford University, Stanford, Calif., (Oliver, 1974; Oliver and Robbins, 1976)
7	383	University of California, Berkeley, Calif. (C.M. Gilbert and M.W. Reynolds, written commun., 1978)
8	207	Northwestern University (Healey and others, 1980b; A.H. Cogbill, Jr., written commun., 1980)
9	63	Blum (1979)
	2,283	U.S. Geological Survey (Pakiser and others, 1964; Robbins and Oliver, 1976; Healey and others, 1980b; D.K. Maurer, written commun., 1981; Plouff, 1982a) located throughout the quadrangle

Figure 2.--Locations of gravity data. Data collected by the U.S. Geological Survey are distributed throughout quadrangle.

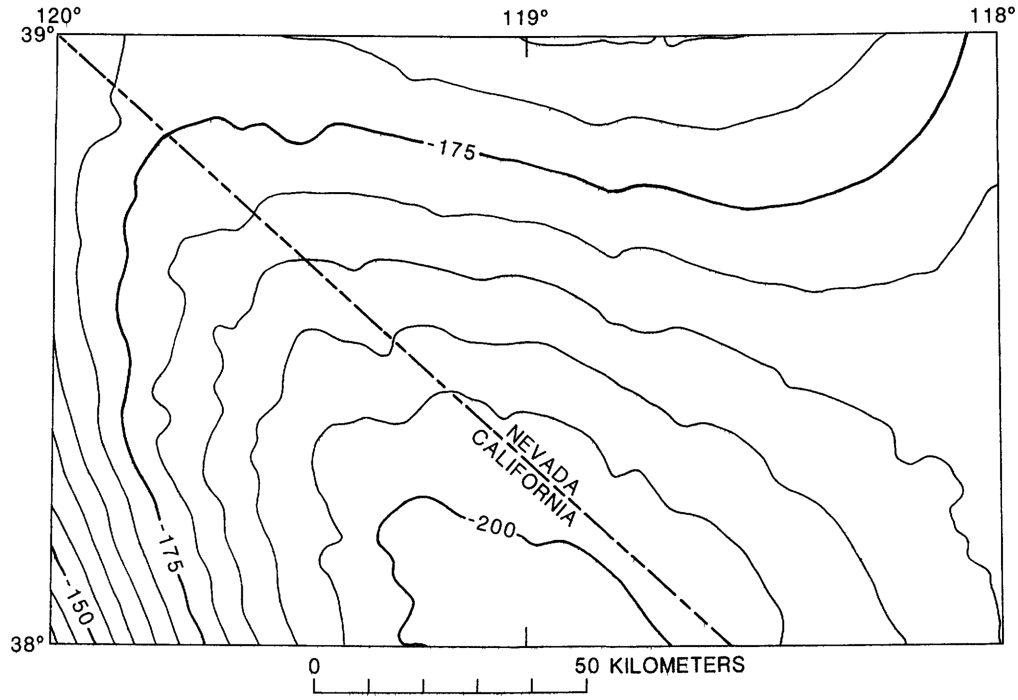


Figure 3.--Gravity anomaly of crustal downwarp caused by local isostatic compensation of the mass above sea level. Contour interval, 5 mGal.

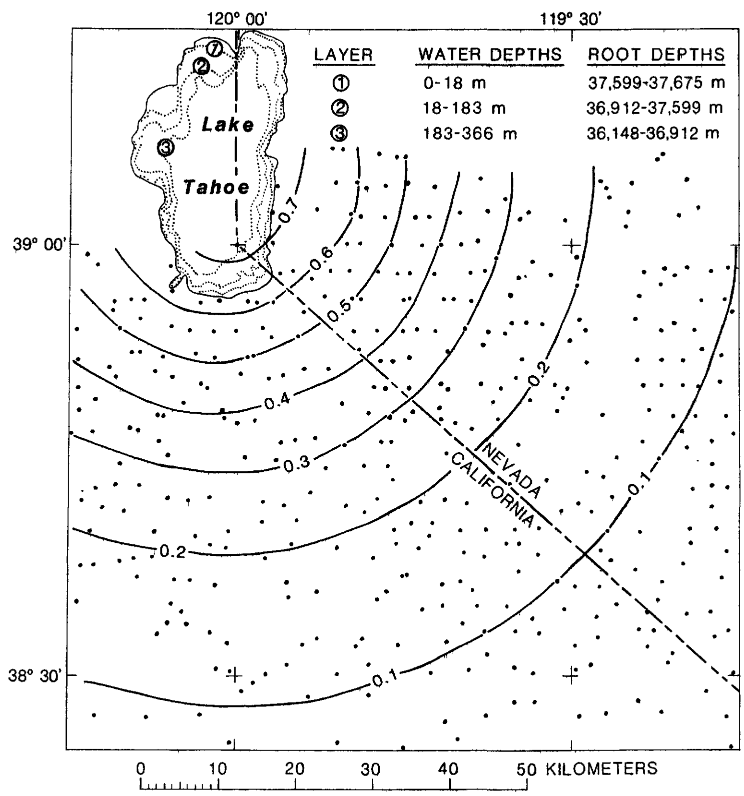


Figure 4.--Gravity anomaly to be added to the values of isostatic compensation (fig. 3) or to be subtracted from the isostatic residual gravity anomaly (sheet 2) in order to account for the mass of water in Lake Tahoe rather than rock. Contour interval, 0.1 mGal. Dots indicate gravity stations. Depths of root are relative to sea level.

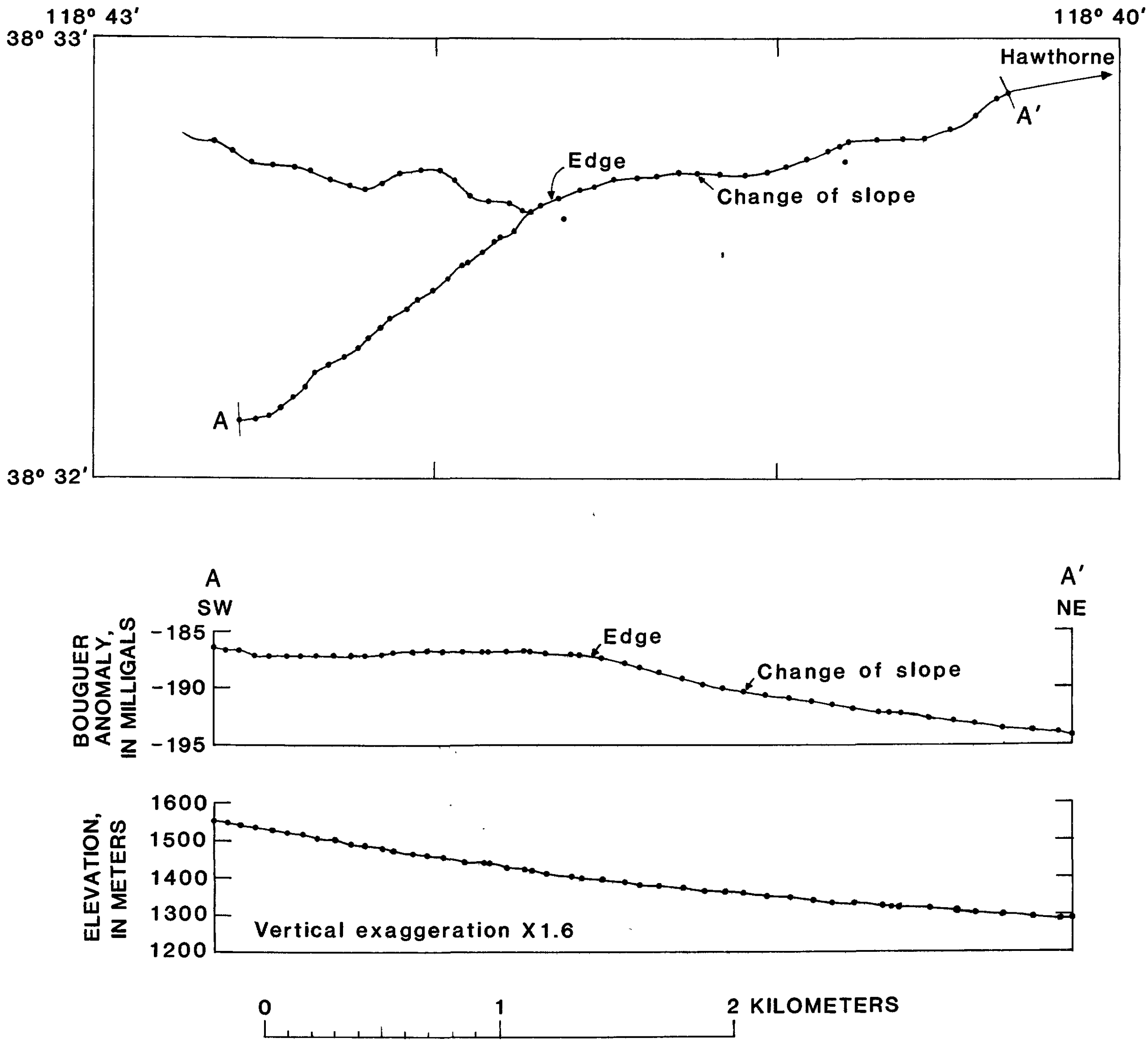


Figure 5.--Location of gravity stations and gravity profile A-A' near east edge of Wassuk Range. See sheet 1 for location of profile. Dots indicate gravity stations.

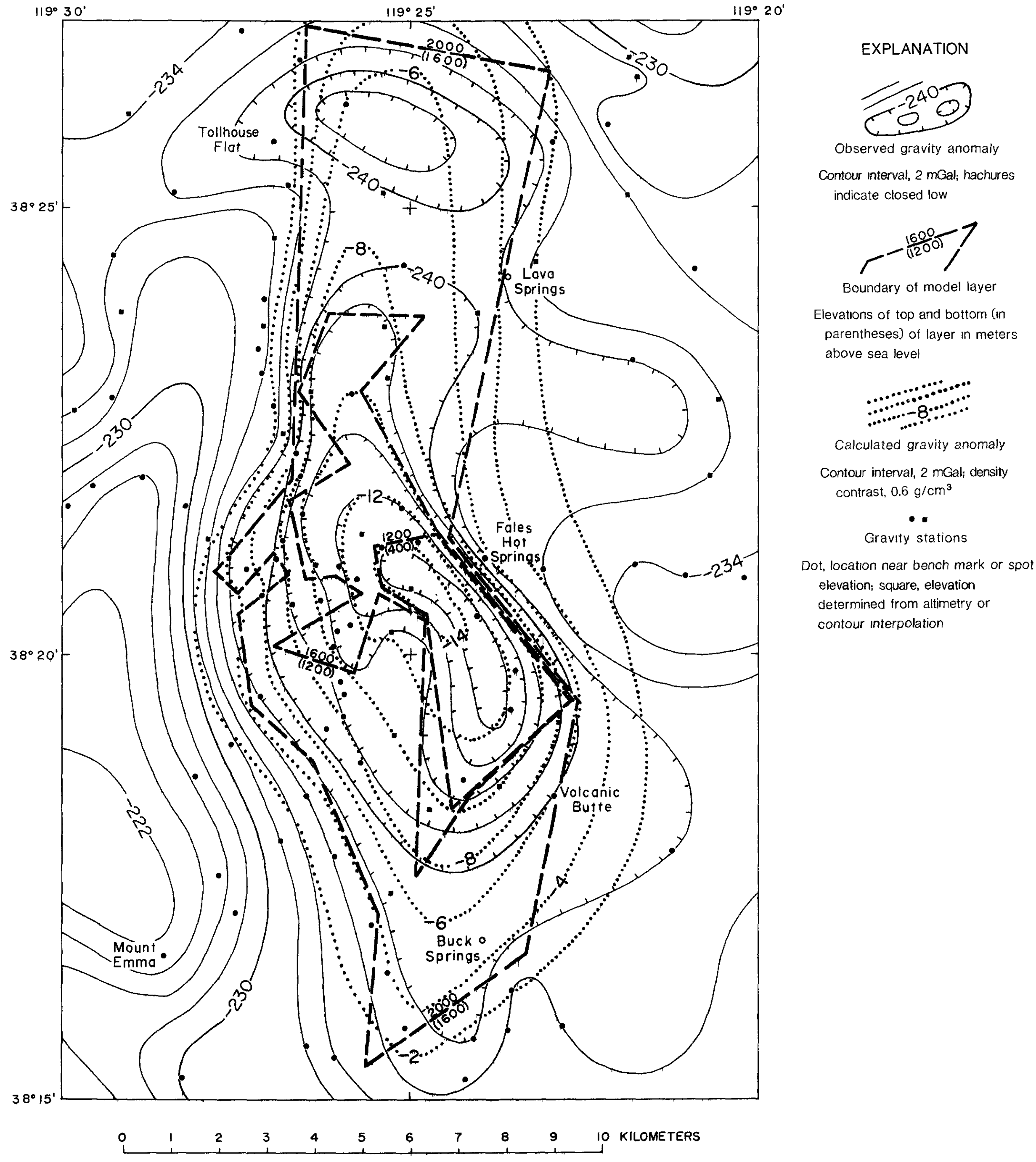


Figure 6.--Gravity model of the Little Walker caldera.