The Nevada Bureau of Mines and Geology (NBMG), and the Nevada Mining Analytical Laboratory (NMAL), are charged by state law with the duty of investigating and reporting on the geology and mineral resources of the State. Operated as a unit, NBMG/NMAL are research and public service divisions of the University of Nevada Reno. NBMG/NMAL has no regulatory functions.

NBMG performs research, compiles information, and makes the information available through: 1) published maps and reports; 2) unpublished data files and collections; and 3) talks, correspondence, and personal contacts. NMAL provides assaying and mineral identification services. NBMG, through its affiliation with the National Cartographic Information Center, also provides information and assistance on base maps and airphotos.

NBMG research includes all phases of Nevada's geology and mineral resources: 1) basic geologic mapping and laboratory studies; 2) geophysical and geochemical surveys; 3) engineering geology; 4) geologic considerations in urban and rural planning; 5) the preparation of educational guides and booklets; 6) statewide investigations of mineral commodities; 7) the geology of ore deposits; and 8) the exploration, development, mining, processing, utilization, and conservation of metal ores, industrial minerals, fossil and nuclear fuels, geothermal power, and water.

NBMG/NMAL offices are located in the Scrugham Engineering-Mines building on the University of Nevada Reno campus; office hours are 8:00–4:30, Monday through Friday.

For information concerning the geology and mineral resources of Nevada, contact: Director/State Geologist, Nevada Bureau of Mines and Geology, University of Nevada Reno, Reno, NV 89557-0088. A publication list will be sent upon request.

VADA BUREAU OF MINES & GEOLOGY

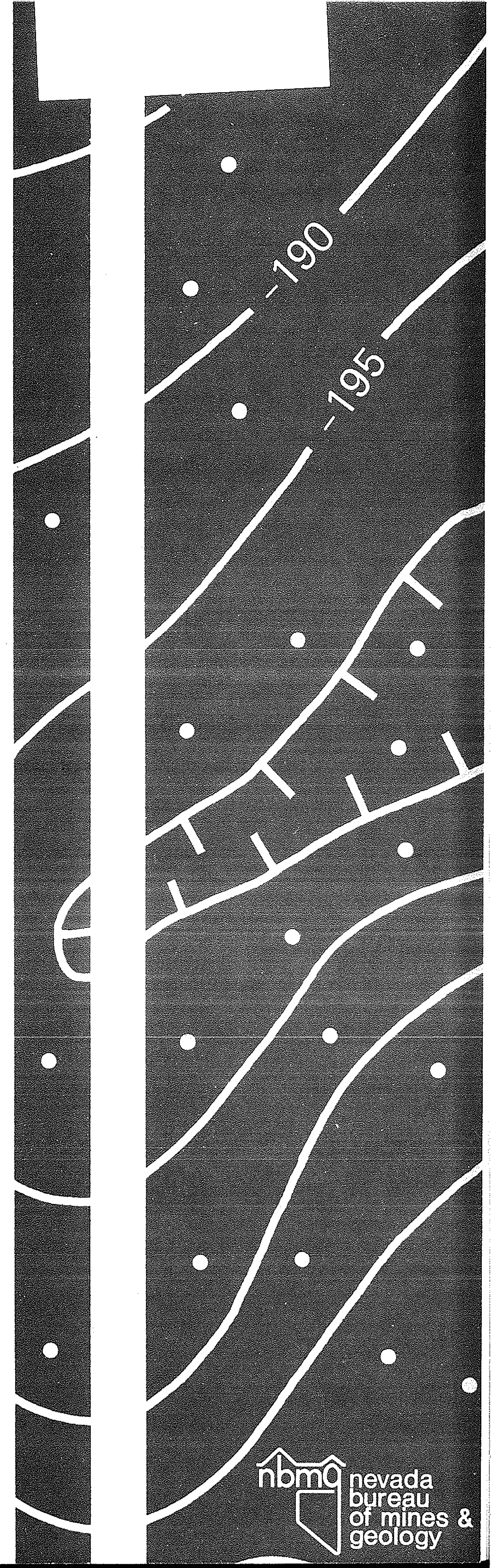
REPORT 38

INTERPRETATION OF THE BOUGUER GRAVITY MAP OF NEVADA

TONOPAH SHEET

DAVID B. SNYDER
DON L. HEALEY

Interpretation of eight local gravity anomalies with sections on gravity and density data, geography and general geology, and regional gravity interpretation. To accompany Nevada Bureau of Mines and Geology Map 73, "Bouguer gravity map of Nevada: Tonopah sheet."



nbmg nevada bureau of mines & geology

NEVADA BUREAU OF MINES & GEOLOGY

REPORT 38

INTERPRETATION OF THE BOUGUER GRAVITY MAP OF NEVADA: TONOPAH SHEET

(Prepared in cooperation with the U.S. Geological Survey)

DAVID B. SNYDER
DON L. HEALEY
U.S. Geological Survey

1983

ABSTRACT

The complex gravity field of the Tonopah 1 by 2° quadrangle, hereafter called the Tonopah sheet, results from the superposition of numerous gravity highs and lows of differing areal extents; each gravity feature is interpreted as resulting from density distributions in a geologic structure of similar size. Long, narrow gravity highs with north-south trends are correlated with Paleozoic and Mesozoic thrust-and-fold belts along the eastern borders of the Toiyabe, central Monitor, and Hot Creek Ranges. Arcuate gravity highs are correlated with Paleozoic and Mesozoic rocks intruded by plutons in the Paradise Range and at Cedar Mountain. Elliptical gravity lows are correlated with Tertiary calderas and volcanic structures throughout the sheet. North-south-trending elongate gravity lows are correlated with the alluvium in basin-and-range valleys where gravity modeling indicates alluvial thicknesses of 2–3 km (1.2–1.8 mi).

These superposed structures are set in two geologically distinct regions separated in a general way by the northwest-southeast trending Kawich-Toiyabe lineament, a Tertiary left-lateral shear zone. Pre-Cenozoic rocks in the northeast portion of the Tonopah sheet include mostly Paleozoic sedimentary strata with overlapping mid-Cenozoic volcanic rocks; all these rocks commonly are broken by generally north-south-trending, high-angle normal faults. This region is part of the extensional terrane of the Great Basin. Pre-Cenozoic rocks in the southwest portion of the sheet include Paleozoic and Mesozoic sedimentary strata and metavolcanic rocks, Jurassic to Tertiary(?) plutonic rocks, and Tertiary hypabyssal bodies. The rocks locally form oroclinal flexures. This region is part of the Walker Lane.

Contrasting gravity regions are associated with these Great Basin and Walker Lane terranes. Geologic structures northeast of the Kawich-Toiyabe lineament have Bouguer anomalies 20 mGal less than similar structures to the southwest; lower density rock in the crust northeast of the lineament may be the source for the regional gravity change.

INTRODUCTION

The Tonopah sheet of the complete Bouguer gravity map of Nevada includes the portion of central Nevada between lat 38° and 39° N. and long 116° and 118° W. and occupies parts of Nye, Esmeralda, and Mineral Counties (fig. 1). Several mountain ranges within the sheet have been of interest to research geologists over the years, particularly the Hot Creek, Paradise, Toiyabe, and Toquima Ranges. The region has been and continues to be of great mining significance, as witness Tonopah, one of the famous historic silver camps of the American West, and the operating gold mine at Round Mountain. The U.S. Government has had several weapons-testing-related projects nearby. As a result of these activities, many gravity measurements have been made in the past few decades. This field work is summarized in two data reports by Healey and others (1980) and Saltus and others (1981). Those data, in turn, were standardized, plotted, and contoured on the Tonopah gravity map (Healey and others, 1981) and are briefly interpreted in this text.

ACKNOWLEDGMENTS

Several members of the U.S. Geological Survey involved in the Tonopah Conterminous U.S. Mineral Assessment Program (CUSMAP) provided useful textual criticism, particularly G. F. Brem, F. J. Kleinhampl, J. H. Stewart, and D. R. Shawe. P. E. Jansma helped with the data interpretation.

GRAVITY AND DENSITY DATA

The 4548 gravity stations shown on the gravity map of the Tonopah sheet (Healey and others, 1981) were collected by numerous field workers, then edited and compiled by the map authors to form one consistent data set. Fifteen base stations throughout the sheet (Saltus and others, 1981, p. 8–26; Healey and others, 1980, p. 85–91) were used to tie all the stations to a primary base (Tonopah J DoD 0455–1) located at the Tonopah airport. Observed gravity at the primary base is 979,462.25 mGal according to the 1971 International Gravity Standardization Net (IGSN71) (Morelli, 1974). Most measurements were made with LaCoste-Romberg gravity meters with daily drift less than ±0.2 mGal.

Elevation precision varies more widely. Most observations were made at or near U.S. Geological Survey bench marks, spot elevations, and other standard reference points or at points surveyed from such previously established reference marks. These elevations are generally accurate to better than ±6.0 m, resulting in Bouguer anomaly uncertainties of approximately ±1.0 mGal.

A reduction density of 2.67 g/cm³ and the 1967 Geodetic Reference System (International Association of Geodesy, 1971) were used to calculate the simple Bouguer anomaly:

(E = elevation in feet; L = latitude.)

$$\mathrm{SBA} = g_{\mathrm{observed}} - g_t + (9.411549 \times 10^{-2} - 1.37789 \times 10^{-4} \sin^2 L)E$$
$$- 6.7 \times 10^{-9}E^2 - (1.2774 \times 10^{-2})\, 2.67E,$$

where

$$g_t = 978031.85\,(1 + 5.279 \times 10^{-3} \sin^2 L + 2.3462 \times 10^{-5} \sin^4 L).$$

The effect of terrain within 166.7 km (100 mi) of each station was calculated (Plouff, 1977) with a digital terrain model. For stations located in irregular topography, the computer model was supplemented with hand-digitized topographic models and on-site estimates of the nearest terrain. Terrain corrections are generally accurate to less than 10% of the correction, so the accuracy here is within 1 mGal. The complete Bouguer anomalies are therefore generally accurate to well within 1.5 mGal. The Bouguer gravity values were interpolated onto a 1-km (0.62-mi) grid and computer contoured. The resulting map was edited by hand to remove machine errors.

Bulk density data are available from density logs taken in holes drilled in Monitor, Little Fish Lake, Stone Cabin, and Hot Creek Valleys (pl. 1; U.S. Geological Survey, 1969). These holes were drilled during an extensive investigation of the area for the Central Nevada Supplemental Test Site project.

Density data from 14 holes are summarized in table 1. The density of Quaternary alluvium, based on continuous gamma-gamma logs from 10 widely scattered holes, averages 2.10 ±0.13 g/cm³. This compares with a value of 2.18 g/cm³ reported by Healey (1970, p. B61) for six holes located within Hot Creek Valley. Included in Healey's value are the data for more than 1280 m (4200 ft) of alluvium logged by a borehole gravity meter in drill hole UCE–18.

TABLE 1. Rock densities (in g/cm³) from subsurface sampling, eastern part of the Tonopah 1 x 2° sheet.

Location	Quaternary alluvium	Tertiary rocks	Pre-Cenozoic rocks	USGS well[1]
Belmont (38°34.5'N.,116°55.5'W.)	—	—	[2]2.60 (granite) [3]2.57 ±.04(17)	UCE-1
Monitor Valley (38°52.4'N.,116°13'W.)	1.92 1.98(1)	2.34 2.36 ±.11(11)	—	UCE-16
Monitor Valley (38°58.1'N.,116°38.1'W.)	—	2.34 2.26 ±.17(28)	—	UCE-3
Big Sand Springs Valley (38°43.1'N.,116°16'W.)	2.05 [4](2.03-2.09)	—	—	UCE-14
Little Fish Lake Valley (38°48.6'N.,116°26.9'W.)	2.08	2.06 2.14 ±.18(3)	—	UCE-9
Little Fish Lake Valley (38°41.3'N.,116°27.8'W.)	1.94 (1.96-2.00)	—	2.84 (dolomite)	UCE-10
Little Fish Lake Valley (38°54.7'N.,116°20.2'W.)	1.99	2.39 2.35 ±.17(8)	—	UCE-12a
Stone Cabin (38°18.2'N.,116°35.5'W.)	—	2.31 2.32 ±.12(36)	—	UCE-2
Hot Creek Valley (38°35.9'N.,116°13.5'W.)	2.31 (2.27-2.56)	2.43	—	UCE-11
Hot Creek Valley (38°40.75'N.,116°13'W.)	2.13 2.22 ±.10(2)	2.32 2.33 ±.17(20)	—	UCE-17
Hot Creek Valley (38°35.2'N.,116°11.5'W.)	—	2.33 ±.11(28)	—	UCE-18
Hot Creek Valley (38°35.7'N.,116°13.1'W.)	2.27	2.31 2.36 ±.11(19)	—	UCE-20
Hot Creek Valley (38°37.6'N.,116°12.9'W.)	2.23	2.20	—	HTH-1
Hot Creek Valley (38°38.1'N.,116°12.9'W.)	2.08 2.07 ±.02(4)	2.28 ±.07(4)	—	UC-1
Averages	2.10 ±0.13	2.31 ±0.08		

[1] U.S. Geological Survey (1969).
[2] Average density from gamma-gamma log.
[3] Mean specific gravity ± standard deviation (number of samples).
[4] Range in specific gravity in parentheses.

Tertiary volcanic rock densities average 2.31 ±0.08 g/cm³ based on gamma-gamma logs from nine holes, supplemented by averages of core sample specific gravity for holes UCE-18 and UCE-1. In drill hole UCE-18, the average specific gravity value is 2.33 g/cm³, and the borehole gravity meter density value is 2.35 g/cm³ as reported by Healey (1970, p. B55).

Massive dolomite in UCE-10 had a density of 2.84 g/cm³ and granite in UCE-1 had a density of 2.60 g/cm³ as measured by the gamma-gamma technique.

GEOGRAPHY AND GENERAL GEOLOGY

The Tonopah sheet lies within the Basin and Range physiographic province and straddles the boundary between the Walker Lane (Locke and others, 1940; Walker belt of Stewart, 1980, p. 86) to the southwest and the extensional terrane of the western Great Basin to the northeast. The topography is characterized by north-northeast-trending mountain ranges with intervening alluviated basins. In Mineral and Esmeralda Counties several arcuate mountains interrupt the north-northeast-trending pattern and create a more diverse drainage system. Elevations within the quadrangle vary from 1370 m (4540 ft) at the Columbus Salt Marsh in the southwest corner of the sheet to 3640 m (11,941 ft) at Mount Jefferson (fig. 1). Many mountain ranges have steep frontal scarps with more than 1800 m (6000 ft) of relief.

It is traditionally held that the rocks of the Tonopah sheet have undergone the following simplified geologic history (see Kleinhampl and Ziony, in press). During the late Precambrian and most of the Paleozoic, the entire region lay within the broad north-south-trending Cordilleran geosyncline along the western margin of the North American continent. The geosyncline was actually a westward-thickening prism of shelf deposits in which carbonate assemblage rocks graded successively westward and downslope into a coeval siliceous and volcanic assemblage formed in an oceanic island-arc system. The late Paleozoic Antler and succeeding early Mesozoic Sonoma orogenies telescoped the rocks, as seen in the juxtaposition of strata of the siliceous and volcanic assemblage from the west onto rocks of the carbonate assemblage in the region of the Monitor, Toquima, and Toiyabe Ranges. A relatively continuous period of Late Triassic and Early Jurassic sedimentation in the western half of the sheet was interrupted in the late Early Jurassic by the Nevadan orogeny that produced localized basins containing coarse clastic rocks (Dunlap Formation), southward-directed thrusting, high-angle faulting, and the emplacement of granitic plutons. The eastern half of the sheet was influenced by eastward-directed folding and thrusting associated with the Laramide Sevier orogeny. Large-scale folding and faulting continued throughout the region until the widespread and voluminous eruption of volcanic rocks during the Oligocene. Compound caldera complexes dot the entire region and are the source of enormous volumes of tuff spreading out for hundreds of kilometers. Calderas of different ages impinged, coalesced, and interacted with a Miocene system of transcurrent faults trending east-west to southeast-northwest, forming a jigsaw puzzle of Tertiary structures. Basin-and-range normal faults, striking north-south to northeast-southwest, became active in the late Miocene and continue to modify the present topography.

Sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to Quaternary crop out in the sheet. Cambrian to Permian sedimentary strata are common in the east, whereas upper Paleozoic and Mesozoic sedimentary strata interbedded with metavolcanic rocks occur in the west. The Paleozoic strata generally change progressively westward from a mainly carbonate (platform-facies) assemblage to a mixed carbonate-shale transitional (back-arc or slope facies) assemblage. Farther west, a volcanic-detrital assemblage with nearshore and slope facies elements is structurally interleaved with the platform-facies carbonate assemblage in the Paleozoic and Mesozoic sections along the western boundary of the sheet (Kleinhampl and Ziony, in press).

Jurassic to Tertiary plutonic and hypabyssal outcrops of small areal extent lie scattered throughout the western part of the sheet. Most of the plutons are Cretaceous, but at least one in the Toquima Range is Jurassic, and one hypabyssal granitic mass in the Toiyabe Range may be mid-Tertiary (Kleinhampl and Ziony, in press).

Very extensive and thick tuff sheets of silicic to intermediate composition are undoubtedly the characteristic rock of central Nevada. Composite sections locally reach thicknesses of 6000 m (20,000 ft) and are composed of multiple flows and cooling units ranging in age from early Oligocene to mid-Miocene. Andesitic to dacitic lava or

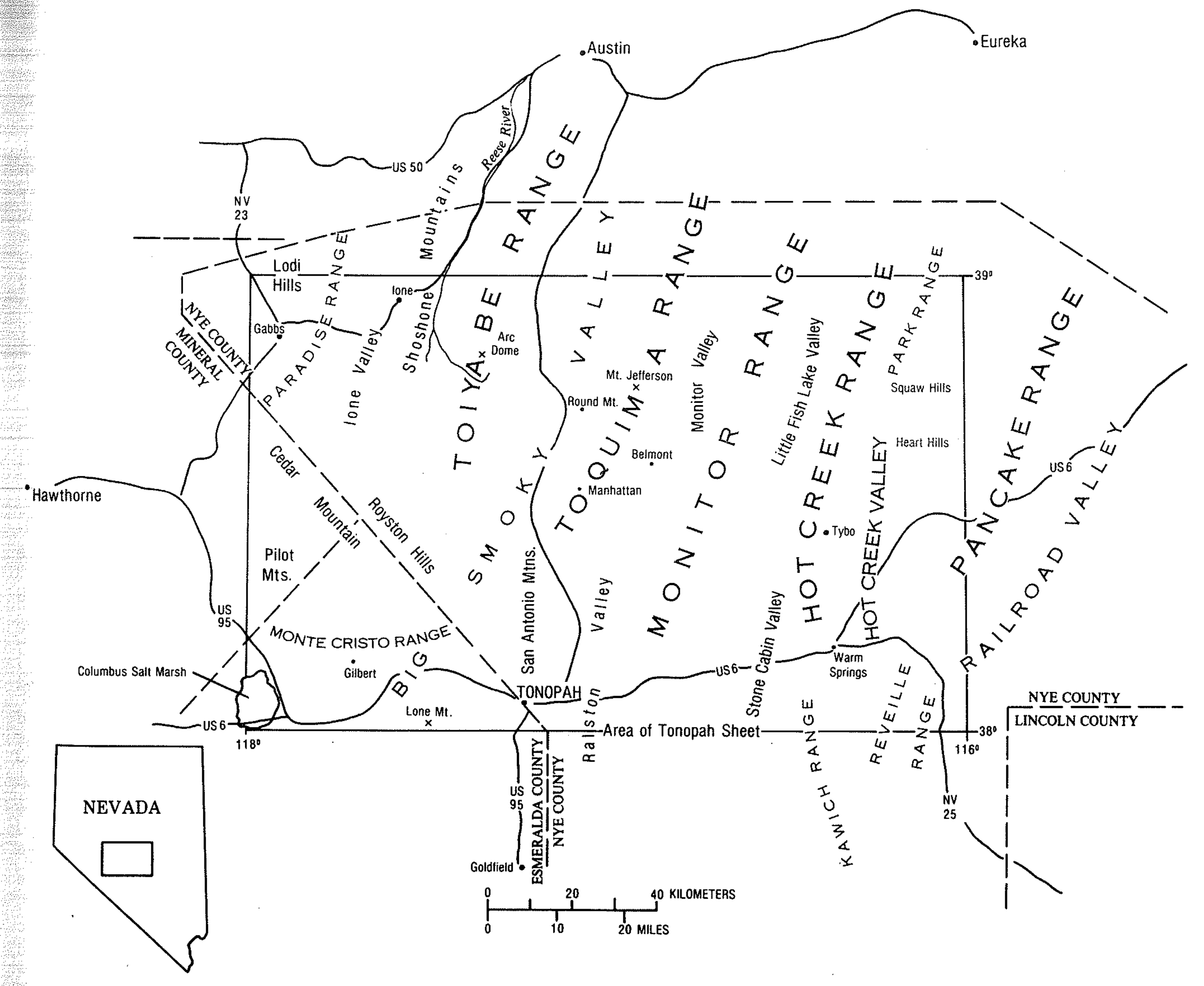


FIGURE 1. Location map showing the outline and location of the Tonopah sheet and the principal topographic features, towns, highways, and county boundaries within the quadrangle.

rhyolite clusters often are intercalated with the tuff near the base of the section (Kleinhampl and Ziony, in press).

Periods of deltaic and lacustrine continental sedimentation into relatively ephemeral and areally restricted basins during the early Cenozoic produced laterally discontinuous sedimentary units within the volcanic section. Holocene sediment, composed of fanglomerate, alluvium, lake beds, windblown sand, and silt, covers the intermontane valleys and overlies late Tertiary and Pleistocene basin-filling sediment that varies in thickness from 400 to 1900 m (1300 to 6000 ft).

The principal metallic and nonmetallic mineral products of the area have been gold, silver, lead, tungsten, molybdenum, mercury, and magnesite. Magnesite far exceeds the other products in volume of production. Minor production amounts or occurrences of antimony, zinc, fluorspar, barite, copper, arsenic, gemstones, uranium, vanadium, selenium, manganese, nickel, building stones, and glasses were also noted by Kleinhampl and Ziony (in press). The host rocks for these minerals are diverse in both age and type; they include Paleozoic and early Mesozoic sedimentary and volcanogenic strata; Jurassic, Cretaceous, and Tertiary plutonic rocks; Tertiary volcanic rocks; and Cretaceous(?) and Tertiary sedimentary rocks. Tertiary rocks at Tonopah and Tybo have yielded silver, and mercury has been produced from Tertiary rocks at the Union district (Kleinhampl and Ziony, in press). The bulk of the mined gold came from Tertiary volcanic rocks, although many gold occurrences are genetically or spatially related to Mesozoic intrusive rocks. Albers and Kleinhampl (1970, p. C1–C10) noted that frequently mineralization was spatially related to Tertiary volcanic centers. Fluorspar occurrences in the Tonopah sheet are generally associated with Tertiary volcanism. The magnesite at Gabbs is in a Triassic dolomite host rock but probably formed later, possibly in the Cretaceous. Much mountainous terrain remains largely unexplored. Potential mineral deposits beneath valley alluvium at minable depths are suggested by the gravity interpretation and indicate potential mineral production from the region.

REGIONAL GRAVITY

The Bouguer gravity field of the Tonopah sheet (Healey and others, 1981) ranges from a low of about −265 mGal (the lowest value in central Nevada) associated with the Monitor Valley at lat 38°45′ N. and long 116°45′ W. to a high of over −180 mGal related to several intrusive bodies along the western border of the sheet. The sheet is divided into two broad gravity regions that we call the Walker Lane and Lahontan regions because of their spatial association with the physiographic-tectonic subdivisions of those names. Lithological variations in the Paleozoic and Mesozoic rocks are not closely correlated with these gravity regions. The irregular border between the Walker Lane and Lahontan gravity regions is shown on plate 1. The −205 mGal gravity contour approximates this boundary with Bouguer anomalies related to similar rock structures generally 20 mGal less to the northeast; compare, for example, the southern Royston Hills with the southernmost part of the Toquima range (fig. 1).

The gravity boundary coincides with the north-northwest-trending Pancake Range lineament postulated by Ekren and others (1976). Kleinhampl and Ziony (in press) renamed it the Kawich-Toiyabe lineament (pl. 1) and described it as a zone of left-lateral shearing active during the Tertiary. A parallel lineament through Tybo (pl. 1) (Ekren and others, 1974b; 1976) is not clearly reflected in the gravity features of the area.

Both lineaments, and additional proposed lineaments to the northeast, undoubtedly reflect Cenozoic tectonism and regional stress. Apparently the Kawich-Toiyabe lineament also reflects a density boundary within the crustal rocks of the region; it may be the southwesternmost of several discontinuous left-lateral faults that form a broad shear zone between two local tectonic terranes.

Northeast of the Kawich-Toiyabe lineament, in the Lahontan region, Bouguer anomalies are seldom greater than −200 mGal. Ranges and valleys are elongate, narrow, and north-south trending. Range-front scarps are steep and the causal faults appear active, indicating current east-west extension. Elliptical gravity lows associated with the ranges and the abundance of Tertiary volcanic rocks strongly support the existence of numerous interrelated calderas in the vicinity.

Southwest of the lineament in the Walker Lane gravity region, gravity values are consistently greater than −190 mGal over pre-Cenozoic rocks. Ranges and valleys are arcuate, and there are some oroclinal flexures (Albers, 1967). Gravity features are also arcuate and the gravity highs are well correlated with plutonic outcrops (the "Tertiary to Jurassic intrusive rocks" of Healey and others, 1981). Relatively thin Cenozoic sedimentary and volcanic rocks undoubtedly cover rocks with a density of approximately 2.67 g/cm^3 that probably consist of Paleozoic and Mesozoic sedimentary strata and Mesozoic plutonic rocks.

A two-dimensional gravity model (A-A′-A″ on pl. 1; fig. 2) was constructed to investigate the near-surface density variations. The model assumes homogeneous density distributions within the specified modeling bodies. The assigned densities were determined from specific-gravity measurements of field samples and from drill-hole density logs (table 1; Healey, 1970). Surface contacts were taken from the simplified geologic base of the Bouguer gravity map of the Tonopah sheet (Healey and others, 1981). The observed gravity values were isostatically corrected (Jachens and Roberts, 1981) assuming Airy-type compensation with a sea-level crustal thickness of 25 km (15.5 mi); topographic density of 2.67 g/cm^3; and a lower-crust, upper-mantle density contrast of 0.4 g/cm^3. The western one-third of the modeled cross section lies within the Walker Lane gravity region, and the remaining two-thirds are in the Lahontan region (fig. 2).

This gravity model produced lower calculated gravity values in the Lahontan gravity region by extending the model bodies representing granitic plutons and tuff-filled calderas to depths as great as 3–4 km (2–3 mi). Only one model body, the 2.37 g/cm^3 body between 150 and 175 km in figure 2, has no supporting surface geologic evidence; this body was assigned its size, shape, and density a priori. An equally adequate match between observed and calculated gravity in this part of the profile could be achieved by substituting a body of greater extent and somewhat higher density but located at a greater depth. This model was arbitrarily constrained to elevations above 1 km (0.6 mi) below sea level.

An extensive system of tuff-filled calderas and near-surface intrusive bodies such as thick sills could be the sole cause of lower gravity values in this part of the Great Basin, provided Airy-type isostatic compensation occurs in this region. Other workers (Eaton and others, 1978; Kane and others, 1982; Oliver and others, 1982) have attributed the lower gravity values to crustal zones of lower density at depths of tens of kilometers.

LOCAL GRAVITY ANOMALIES

The rocks of central Nevada have undergone a long series of tectonic events that produced geologic structures characterized in a general way by either uniformly high- or low-density rocks. These structures can be associated with features in the gravity field less and less ambiguously the more recent a particular structure's age. Bands of low-amplitude gravity anomalies tens of kilometers wide are tentatively attributed to relatively dense Paleozoic and Mesozoic rocks found in thrust-and-fold belts juxtaposed with anomalously thick Cenozoic volcanic rocks filling topographic basins that formed after the development of the thrust-and-fold belts. Circular or elliptical gravity lows generally coincide with similarly shaped volcanic collapse zones in Cenozoic eruptive centers. These circular gravity anomalies are more distinctive than the banded anomalies and tend to disrupt and obscure them. East-west-trending strike-slip fault zones, also active during the Cenozoic, further displace the rocks and complicate the gravity interpretations. The most obvious local gravity anomaly features, ones that dominate all gravity field patterns related to the older structures, are clearly related to alluvium-filled basins produced by north-northeast-oriented high-angle normal faulting during the last 20 m.y.

This superposition of different-aged geologic structures makes the gravity anomaly map of the Tonopah sheet very complex. Because the anomalies correlated with the post-mid-Miocene tectonic structures are the most distinctive, the gravity features will be grouped and described according to present-day basins and ranges. The features are completely or partially described depending on whether they lie within the boundaries of the Tonopah sheet.

PARADISE RANGE

The north-south trending Paradise Range, lying mostly within the northwest corner of the Tonopah sheet (PR on pl. 1), has an associated broad gravity high. This gravity high undoubtedly reflects high-density rocks in a core of folded and faulted greenstone, carbonate, and clastic rocks that has been cut by plutonic rocks, predominantly granodiorite (Davis and others, 1979). (Note that the area directly east of the thrust fault on the map of Healey and others [1981] should be labelled "Mzvs," not "Czs.") Several such pre-Tertiary mountain cores and coincident Bouguer anomalies greater than −195 mGal occur within the Walker Lane gravity region. Within its core, the Paradise Range contains Permian and Triassic rocks in the upper plate of a thrust that has overridden an earlier thrust of Upper Triassic rocks over Jurassic rocks (Kleinhampl and Ziony, in press) and can therefore be considered part of a thrust-and-fold belt with an associated wide gravity high.

Remnants of Tertiary intermediate lava and rhyolitic welded tuff crop out around the exposed mountain core. On the east flank of the mountain, the tuff forms an east-dipping homocline (Kleinhampl and Ziony, in press) and the associated gravity values decline gradually to the east. The total magnitude of this gravity change implies that at least 2500 m (8000 ft) of basin fill underlies the surface of Ione Valley to the east if simple density distributions are assumed.

To the northwest, Bouguer anomalies as high as −175 mGal coincide with the relatively high density rocks of a large Jurassic to Tertiary intrusion. Magnetic studies suggest that this diorite pluton extends for several kilometers in the subsurface southwest of the outcrop (Davis and others, 1979). The gravity field, although not well constrained in this area, indicates a sharp bedrock dropoff along the faulted southwest border with Gabbs Valley, but extension of the pluton to the southeast is suggested by the −185-mGal gravity contour.

MONTE CRISTO RANGE AND CEDAR MOUNTAIN

The Royston Hills, Monte Cristo Range, and Cedar Mountains (MC on pl. 1) form an uneven topographic arc that is convex toward the southeast. This arc is approximately concentric with the Silver Peak–Palmetto–Montezuma oroflex (Albers and Stewart, 1972, p. 42) but may be unrelated. J. H. Stewart (written commun., 1982) has suggested that the arcuate shape is at least partly caused by two nested calderas located in the Monte Cristo Range, the 10-km (6-mi)-diameter Gilbert caldera within the 21-km (13-mi)-diameter Monte Cristo caldera (pl. 1). Both calderas are circular and nearly concentric; the Gilbert caldera is slightly offset to the southeast.

Gravity model A-A′ (fig. 2) indicates that the two calderas in the Monte Cristo Range are shallow structures; a relatively thin veneer of tuff and alluvium presently fills a 1-km (0.6-mi) depression in denser subsurface rock. The large outcrop of Paleozoic rocks on the southwest flank of the range is the top of a relatively thick section that formed when the Monte Cristo thrust fault (Ferguson and Muller, 1949, p. 48–49), mapped within the Paleozoic sedimentary rocks, superposed two blocks of these relatively dense rocks. The thrust is not shown on the map of Healey and others (1981). The scattered Paleozoic outcrops near the mine camp of Gilbert are apparently not rooted, but they may represent rafted blocks within the surrounding Cenozoic tuff filling the Gilbert caldera (J. H. Stewart, written commun., 1982). The southward flexure in the −185 mGal gravity contour may be attributed to the tuff filling the Gilbert caldera in the northern half of the Monte Cristo Range.

The Royston Hills within Nye County (fig. 1) are composed chiefly of Tertiary welded tuff and basaltic andesite flows lying on Mesozoic metavolcanic and volcaniclastic rocks and chert (Kleinhampl and Ziony, in press). Farther south in the Royston Hills, quartz monzonite has intruded the pre-Tertiary rocks. High rock densities associated with this intrusion and related metamorphism are undoubtedly the cause of Bouguer anomalies locally greater than −185 mGal in the Royston Hills. In the northernmost Royston Hills, the Mesozoic rocks form a broad, west-plunging syncline that has a steep southern flank projecting westward into Cedar Mountain. Small diorite plutons here locally metamorphosed the rocks and sufficiently increased their density to cause Bouguer anomalies exceeding −185 mGal.

The dominant feature of the gravity field in this tri-county area is the large low containing anomalies of −220 mGal over Dry Lake between Cedar Mountain, the Pilot Mountains, and the Monte Cristo Range (fig. 1)—at least 2500 m (8000 ft) of low-density material such as alluvium and tuff are required to produce this feature. A Tertiary sedimentary basin beneath Dry Lake is a simple possible source of the gravity low; the locale of the gravity minimum is surrounded on the north by a semicircle of pre-Tertiary rock outcrops, including tilted and folded Mesozoic strata cut by Jurassic to Tertiary intrusive rocks. The calderas defined by arcuate patterns of faults and rock units in the Monte Cristo Range are geologically unconstrained by field data on their northern margin because of the paucity of outcrops. The northern extension of the gravity low may alternatively be due to the Monte Cristo

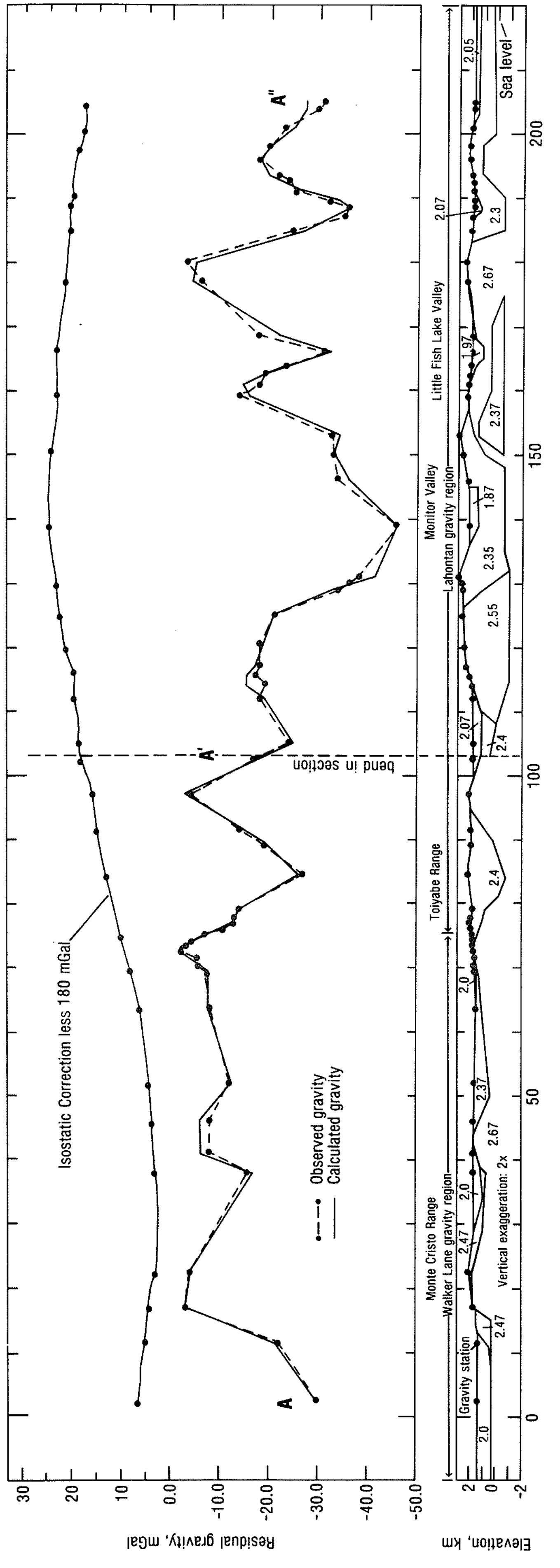


FIGURE 2. East-west gravity modeling profile A-A'-A'' (pl. 1). Body bulk densities indicated are in g/cm³ and assume homogeneity. Note the subsurface 2.37 g/cm³ body required on the eastern half. Observed values were isostatically corrected (Jachens and Roberts, 1981) assuming T_0 = 25 km, ϱ = 2.67 g/cm³, and σ_{Moho} = 0.4 g/cm³.

caldera merging into a greater caldera complex to its north, perhaps into a string of related calderas paralleling the western flank of Cedar Mountain and terminating on the south at Gilbert.

SAN ANTONIO MOUNTAINS

The San Antonio Mountains (SA on pl. 1) are chiefly composed of deformed and altered Oligocene and Miocene volcanic rocks overlain by the slightly to moderately deformed Fraction Tuff, younger tuff, and subhorizontal porphyritic dacite and capping basaltic andesite flows (Kleinhampl and Ziony, in press). Nolan (1935) concluded that the older volcanic rocks generally dip westward and are cut by a complex pattern of faults. Intrusion of an igneous cupola approximately 18 m.y. ago immediately beneath the present-day Tonopah mining district (Bonham and Garside, 1979) may have caused both the complex faulting and an alteration halo with mineral zonation. Another intrusive body, the Frazier's Well pluton of Bonham and Garside (1979), underlies both Black and Red Mountains (pl. 1); Bouguer anomalies greater than −195 mGal extend from the site of this pluton south to Tonopah. Intrusive bodies and related alteration and mineralization zones undoubtedly coincide with this entire gravity anomaly (also see Erwin, 1968, 1980).

The three small areas of Paleozoic outcrops in the San Antonio Mountains are enclosed by a −200 mGal contour and have associated anomaly values 5–15 mGal greater than those over the rest of the range. Relatively low gravity values at the north end of the range and near the Tonopah mining district support hypotheses of complex Tertiary volcanic centers in these two areas.

TOIYABE RANGE AND SHOSHONE MOUNTAINS

The southern one-third of the 160-km (100-mi)-long Toiyabe Range lies within the Tonopah quadrangle (fig. 1; TY on pl. 1). The range is more than 24 km (15 mi) wide here and merges with the Shoshone Mountains on the west. On the eastern side of the range, frontal faults of large throw coincide with a 15-mGal gravity change. The movement on these faults has tilted the range westward and formed an unbroken eastern crest higher than 3000 m (10,000 ft). Discontinuously exposed along this crest are Paleozoic sedimentary and metavolcanic strata that have been intruded by several granitic plutons and dikes. Bouguer anomaly values greater than −210 mGal coincide with the larger outcrops of these metamorphic and intrusive blocks.

Pre-Cenozoic rocks are exposed along the western side of the Shoshone Mountains in a horst bounded on the east and west by en echelon normal faults active from the late Oligocene through the early Pleistocene (Bonham, 1970). Permian to Jurassic strata in this discontinuous belt of pre-Cenozoic outcrops form an east- to southeast-dipping homocline; Silberling (1959) interpreted these strata as forming the eastern upright limb of a large overturned anticline that plunges to the southeast (pl. 1). The crescent shape of the gravity high over the Shoshone Mountains supports this interpretation. The high anomalies in the eastern part of the Shoshone Mountains suggest that rocks with similar densities to those of the exposed Paleozoic and Mesozoic strata extend eastward beneath the surface.

The western two-thirds of the Toiyabe Range are exposures of Tertiary ash-flow tuff that gently dip toward the west. The Shoshone Mountains are also chiefly Tertiary volcanic rocks. Much of this area has associated Bouguer anomalies less than −210 mGal; these low gravity values indicate that more than 3 km (2 mi) of low-density volcanic rocks underlie this part of the mountain ranges (fig. 2). Nearly all outcrops are the gently warped Toiyabe Quartz Latite. The rocks form a broad, north-plunging syncline whose axis is approximately coincident with Indian Valley (Kleinhampl and Ziony, in press).

The great tuff thickness postulated by interpretation of the low gravity anomalies not only indicates nearby source areas but also makes accurate locations difficult both geologically and geophysically. The −220 mGal anomalies near Arc Dome and northwest of Peavine Creek may occur at the locations of calderas or source vents. G. F. Brem (written commun., 1982) has mapped a caldera at the mouth of Peavine Creek in an area of comparably low gravity anomalies. Overall, the vast expanse of tuff in the southern Toiyabe Range may fill a broad, segmented structural trough that trends northwest-southeast and contains or is adjacent to several calderas or volcanic vents.

TOQUIMA RANGE AND MONITOR VALLEY

Directly east across Big Smoky Valley from the Toiyabe Range lies the southern part of the 110-km (70-mi)-long Toquima Range (TQ on pl. 1). Normal faults (not all of which appear on the map of Healey and others [1981]) bound the Toquima Range to the east along the Monitor Valley, a basin associated with the lowest Bouguer anomalies in central Nevada. The range is segmented lengthwise into five discrete geologic blocks, each with associated gravity anomaly patterns. The largest area of pre-Tertiary outcrops in the range lies along the northern edge of the sheet where a series of imbricate thrust sheets emplaces intricately folded Ordovician chert and minor andesite lava on carbonate and transitional assemblage Cambrian to Devonian strata (Kay and Crawford, 1964; McKee, 1976). Relatively high Bouguer anomalies of −220 mGal coincide with this block of Paleozoic rocks.

To the south is the 3640-m (11,949-ft) Mount Jefferson, a discrete block of Tertiary ash-flow tuffs and minor tuffaceous sedimentary strata considered to coincide with its source vent, the Mount Jefferson caldera (Shawe, 1981a; Kleinhampl and Ziony, in press). Resurgence and westward tilting along basin-and-range faulting undoubtedly contributed to the great elevation of these rocks. The large gravity low in Monitor Valley indicates a great thickness of underlying low-density rocks (fig. 2) and lies directly opposite Mount Jefferson; the eastern part of the caldera complex may have been downdropped and covered with alluvium. A drill hole in northeastern Monitor Valley (no. 16 on pl. 1; fig. 3) penetrated 335 m (1100 ft) of alluvium and 954 m (3130 ft) of tuff (U.S. Geological Survey, 1969). This thick tuff and alluvium are either a locally great thickness of valley fill or as much as 3 km (2 mi) of intracaldera tuff beneath the valley alluvium (figs. 2, 3).

An antiform or elliptical dome of lower Paleozoic strata borders Mount Jefferson on the south. This dome has a core of Cretaceous plutons that crop out between Belmont and Round Mountain (Kleinhampl, 1967; Shawe, 1981a). Near Belmont (fig. 1), a drill hole (no. 1 on pl. 1) penetrated 207 m (680 ft) of granite (U.S. Geological Survey, 1969) with an average logged density of 2.60 g/cm³ (table 1, well UCE–1). The highest gravity anomalies associated with the antiform occur near its northwestern flank, close to Round Mountain.

The block of Tertiary volcanic rocks at Bald Mountain is considered to fill the Manhattan caldera, identified and

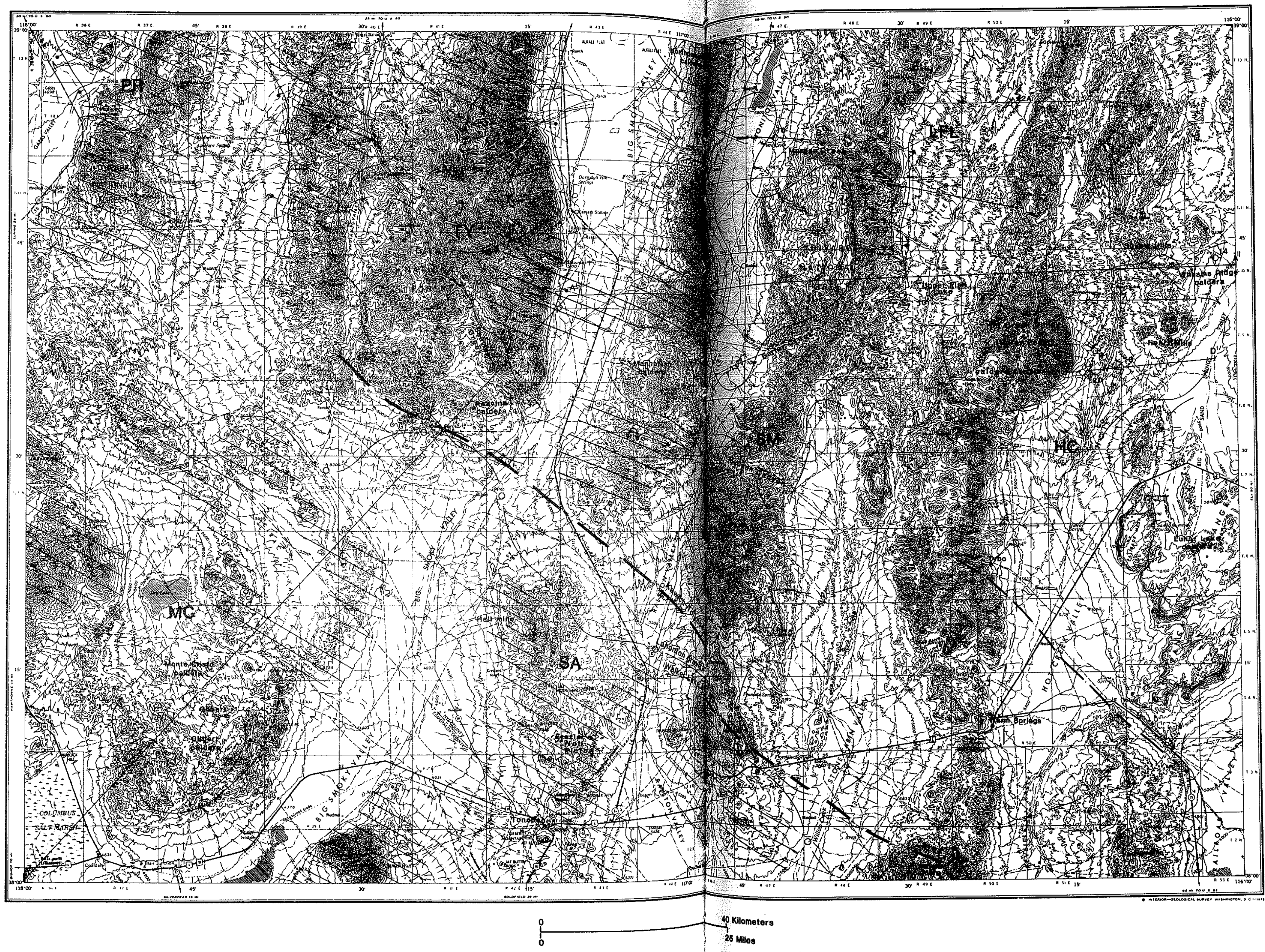
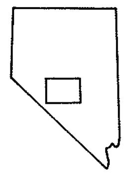


PLATE 1. Interpretative map of the Bouguer anomaly gravity field of Nevada—Tonopah sheet.



EXPLANATION

Anticline

Plunging overturned anticline

Thrust and Fold belt remnant

Caldera boundary determined by both gravity interpretation and field mapping

Caldera boundary determined by gravity interpretation

High-angle fault reflected in the gravity field, bar and ball on downthrown side

Block of metamorphic and intrusive rocks in the subsurface

Left-Lateral shear zone or lineament

Gravity region boundary

Exploratory drill hole

B B'

Gravity modeling profile

SM

Letters designate area referred to in the text

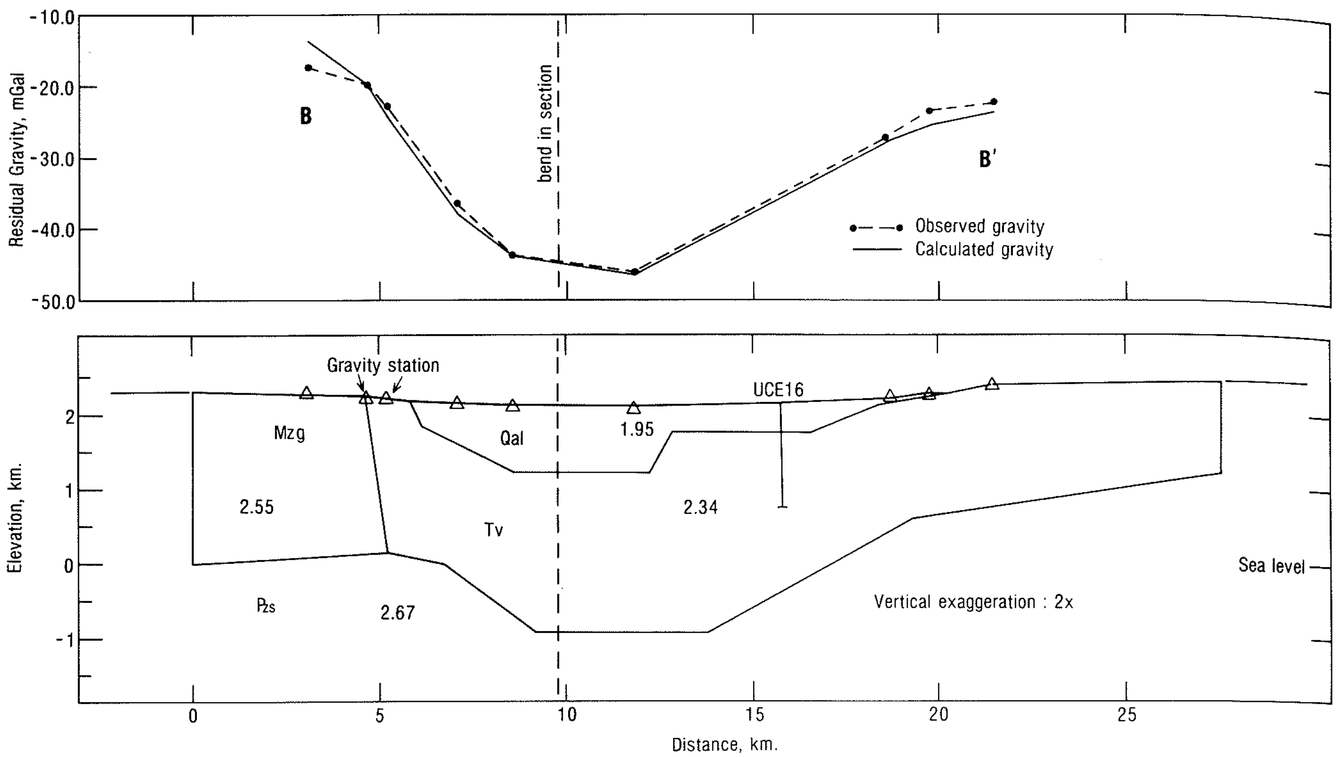


FIGURE 3. Two-dimensional gravity modeling profile B-B' across the Monitor Valley basin (pl. 1). Numbers on the cross section are the modeled bulk densities in g/cm³, assumed homogeneous throughout the body. Drill hole referenced in table 1. Pzs = Paleozoic sedimentary rocks, Tv = Tertiary volcanic rocks, Qal = Quaternary alluvium, Mzg = Mesozoic intrusive rocks. Observed values were isostatically corrected (Jachens and Roberts, 1981) assuming T_0 = 25 km, ρ = 2.67 g/cm³, and σ_{Moho} = 0.4 g/cm³.

named by Shawe (1981a, 1981b). An elongate gravity low coincides with the caldera, and gravity is very useful in predicting the location of caldera walls at this location. Gravity interpretation indicates that more than 2 km (1 mi) of tuff may fill the Manhattan caldera.

The southernmost block of the Toquima Range contains the complexly deformed and isoclinally folded Paleozoic rocks (Ferguson, 1924) of the Manhattan mining district (fig. 1) and the associated pluton. The main block is a faulted anticlinorium in which fold axes trend northwest-southeast parallel to the main faults. Many of the folds are overturned toward the northeast (pl. 1). Porphyritic greenstone and associated serpentinite, as well as the Triassic Candelaria Formation, crop out along the western edge of the block (Poole and Wardlaw, 1978; Kleinhampl and Ziony, in press). A gravity high coincides with the anticlinorium and reaches values of −200 mGal. As was the case in the blocks of the granitic rocks near Belmont and the volcanic rocks at Bald Mountain, the highest gravity values lie along the western border of the range. Apparently, thicker sections of denser Paleozoic strata and metamorphosed rocks underlie this down-tilted side of the range south of Mount Jefferson.

SOUTHERN MONITOR RANGE

The Monitor Range widens abruptly at the southern end of the Monitor Valley; south of this point (SM on pl. 1), the great thickness of Tertiary tuff, the complex faulting, and the numerous rhyolitic intrusive bodies suggest the proximity of Tertiary calderas (Kleinhampl and Ziony, in press). Large isolated blocks of Paleozoic strata and Cretaceous(?) granitic rocks southwest of Big Ten Peak (pl. 1) have been interpreted as landslide masses off caldera walls; the areally small gravity high there indicates either a local block of denser rock continuous with the outcrops and beneath a surface veneer of tuff or increased rock densities due to metamorphism or sulfide mineralization (F. J. Kleinhampl, written commun., 1982). The pair of elliptical gravity lows and uninterrupted surficial tuff to the northeast of these Paleozoic outcrops are strong evidence for the presence of one or more calderas or perhaps one caldera with a resurgent dome or peripheral intrusion along its northern margin (pl. 1).

South of these twin gravity lows the anomaly values continuously increase to a maximum of −190 mGal over the Paleozoic rocks exposed near the southern edge of the sheet. One exception is the elliptical low north of U.S. Highway 6 along the east margin of the Monitor Range. A buried caldera or vent filled with low-density rocks is a strong possibility, as the gravity anomaly is not well correlated with either topographic or surficial geologic structures.

The southern Monitor Range is cut by numerous northwest-southeast striking normal faults (not shown on the map of Healey and others [1981]) that may be components of a linear zone termed the "Kawich-Toiyabe lineament" by Kleinhampl and Ziony (in press). The lineament is indicated on plate 1 and roughly parallels the −205 mGal gravity contour as it passes through the southern Monitor Range.

LITTLE FISH LAKE VALLEY AND CENTRAL MONITOR RANGE

The geology of Little Fish Lake Valley (LFL on pl. 1) has been described by Ekren and others (1974a); their conclusions are summarized here. Their interpretation was aided by 15 drill holes in the vicinity (pl. 1; U.S. Geological Survey, 1969), many of which had gamma-gamma density log measurements as well as fairly complete suites of core-sample specific-gravity determinations. These data provide excellent density control on the subsurface materials and are summarized in table 1. The table shows that alluvium in this part of central Nevada averages 2.1 g/cm³ in density, while the Tertiary volcanic rocks average 2.3 g/cm³.

The drill holes in Little Fish Lake Valley (pl. 1) penetrated an alluvial thickness of 850 m (2800 ft) in the center of the valley (fig. 4), 810 m (2660 ft) beneath the seasonal lake at the southern end, and 450 m (1500 ft) at the northeastern end (U.S. Geological Survey, 1969). Average alluvial densities range between 1.94 and 2.08 g/cm³ in these areas (table 1). The southern drill hole near Upper Fish Lake did not penetrate tuff but bottomed in massive dolomite with a density of 2.84 g/cm³. The central hole bottomed in tuff, which is estimated from gravity modeling to have 610 m (2000 ft) in total thickness (fig. 4); a relatively shallow basin with 1460 m (4800 ft) of tuff and alluvial fill is the source of the 20-mGal gravity low associated with the valley. Combined displacement of at least 1800 m (5900 ft) along several faults on the west margin of the valley places Paleozoic rocks at the surface west of the faults. Ekren and others (1974a, p. 114) concluded that the southern half of the valley overlies a former topographic high that was never covered by tuff or that was stripped before the present basin formed in late Miocene or early Pliocene time. The Little Fish Lake area clearly has much thinner tuff sections than those found near Monitor Valley (figs. 2, 3, 4).

At least some of the Paleozoic rocks exposed as thrust plates in the central part of the Monitor Range are postulated by Lowell (1965) and Kleinhampl and Ziony (in press) to be the easternmost occurrence of eugeosynclinal rocks forming a trace, approximately 70 km (45 mi) wide, of the early Mesozoic Golconda thrust (Stewart, 1980, p. 59). Large eastward movement of the upper Paleozoic rocks in the Monitor Range is required to explain the great lithological differences between these and correlative rocks in the Hot Creek Range directly to the east; however, the string of outcrops that presently marks the postulated edge of the Golconda thrust make up less than 10% of exposed Paleozoic bedrock in the Monitor Range. The long, narrow gravity high that coincides with all the outcrops of Paleozoic strata along the entire eastern edge of the central Monitor Range indicates that Paleozoic rocks are continuous beneath the surface along this range margin as far

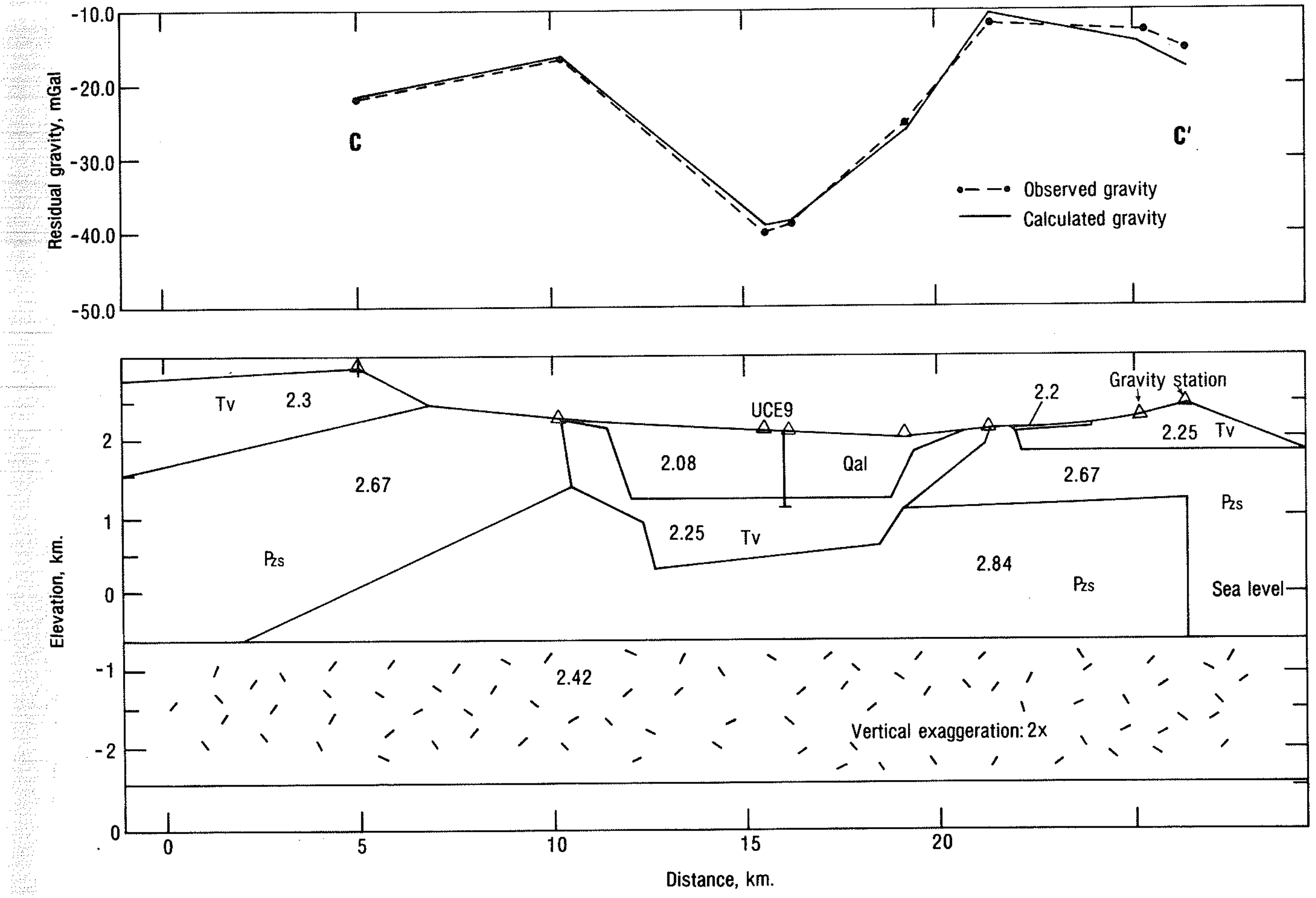


FIGURE 4. Two-dimensional gravity modeling profile C-C' across Little Fish Lake Valley (pl. 1). Pzs = Paleozoic sedimentary rocks, Tv = Tertiary volcanic rocks, Qal = Quaternary alluvium, Mzg = Mesozoic intrusive rocks. Observed values were isostatically corrected (Jachens and Roberts, 1981) assuming T_0 = 25 km, ρ = 2.67 g/cm³, and σ_{Moho} = 0.4 g/cm³.

south as lat 38°30′ N. This Paleozoic section, approximately 500 m (1600 ft) thick, is an example of a thrust-and-fold belt correlating with an elongate north-south-trending gravity high.

The gravity anomaly values drop off rapidly just west of the outcrops of Paleozoic rocks except south of Barley Creek, where westward-dipping Paleozoic rocks apparently extend across the entire range in the subsurface. The relatively low gravity values north of Barley Creek suggest that the Tertiary volcanic rocks extend from the surface to significant depths. The area between Barley and Morgan Creeks may be a caldera segment related to the proposed Mount Jefferson caldera structures in the Toquima Range and Monitor Valley to the west; the −235 mGal anomalies at the crest of the Monitor Range are directly adjacent to the pronounced gravity low over the Monitor Valley.

undoubtedly related to the Williams Ridge caldera and Hot Creek Valley caldera complex (Ekren and others, 1973a; Stewart, 1980, fig. 50), inferred to extend east-northeast from Morey Peak (pl. 1) across Hot Creek and Big Sand Spring Valleys and south to include much of the area of the southern Pancake Range and Hot Creek Valley. Drill holes directly east of Morey Peak (pl. 1; U.S. Geological Survey, 1969) penetrated more than 640 m (2000 ft) of alluvium underlain by at least 900 m (3000 ft) of Tertiary tuff, tuffaceous sedimentary strata, and rhyolite lava. This section of volcanic rocks is much thicker than in areas immediately to the north or south and is broken by an irregular, dense network of normal faults of small displacement (Ekren and others, 1973a). At least 2500 m (8000 ft) of tuff and alluvium are estimated to underlie the minimum gravity anomaly in Hot Creek Valley (fig. 5).

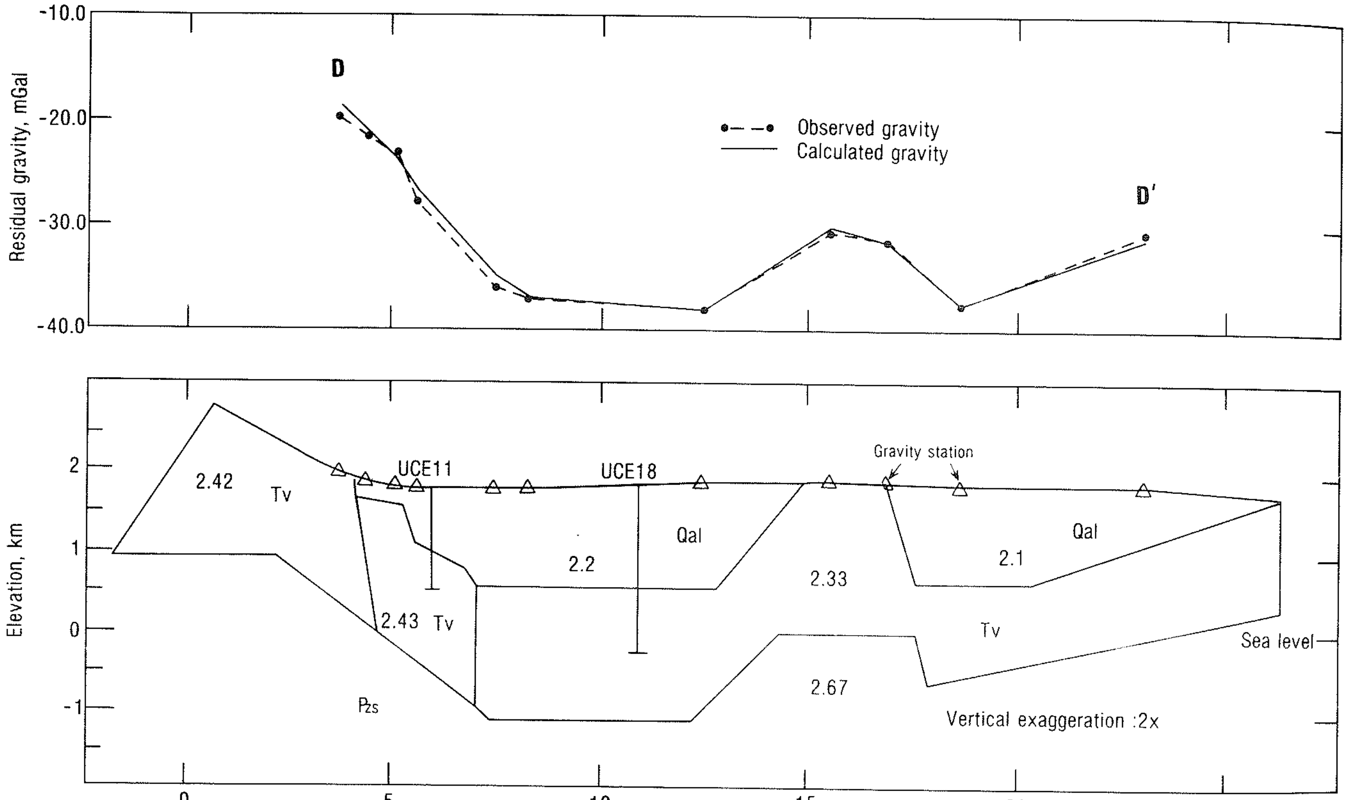


FIGURE 5. Two-dimensional gravity modeling profile D-D′ across the northern Hot Creek Valley (pl. 1). Pzs = Paleozoic sedimentary rocks, Tv = Tertiary volcanic rocks, Qal = Quaternary alluvium, Mzg = Mesozoic intrusive rocks. Observed values were isostatically corrected (Jachens and Roberts, 1981) assuming T_0 = 25 km, ϱ = 2.67 g/cm³, and σ_{Moho} = 0.4 g/cm³.

HOT CREEK VALLEY AND SURROUNDING RANGES

Two long, narrow gravity anomaly features extend across nearly the entire Tonopah sheet along its eastern border. A gravity low coincides with the alluvium-filled Hot Creek Valley (HC on pl. 1), and a gravity high immediately adjacent to the low on the west coincides with the Hot Creek Range. The other ranges surrounding Hot Creek Valley—the Kawich, Reveille, and Pancake Ranges; the Heart and Squaw Hills; and the Park Range (fig. 1)—are marked by discontinuous gravity trends with local, irregular high and low contour closures.

The gravity low associated with Hot Creek Valley dominates this portion of the gravity map. This anomaly is

The Hot Creek Range is similar to the central Monitor Range in that both have a narrow gravity high associated with a discontinuous fringe of Paleozoic rocks along the eastern range margin. The remainder of each of those west-tilted range blocks is composed mostly of Tertiary volcanic rocks. The central Hot Creek Range is similar to the Mount Jefferson part of the Toquima Range in that it is marked by a belt of relatively low gravity values coinciding with a major caldera remnant. In the Hot Creek Range this caldera remnant is the Morey Peak massif, a resurgent part of the Hot Creek Valley caldera complex (Ekren and others, 1973a). Just northwest of Morey Peak, a series of klippen, remnants of a major thrust from the west, stack Devonian and Mississippian clastic rocks on Silurian and Devonian

carbonate rocks; south of Morey Peak the Paleozoic rocks form the western limb of a broad, north-south-trending anticline with an axis in Hot Creek Valley; and near Warm Springs (pl. 1), more thrust plates involve Paleozoic strata (Kleinhampl and Ziony, in press). The discontinuous outcrops of Paleozoic rocks in the Hot Creek Range thus represent telescoped rocks of a thrust-and-fold belt that may form a thick stack of relatively dense Paleozoic rocks partly covered by surface tuff. This thrust-and-fold belt coincides with a narrow, north-south-trending gravity high.

The Kawich Range, farther south, forms a topographic and structural continuation of the Hot Creek Range, but it is composed nearly entirely of Tertiary tuff. A large, irregular body of porphyritic quartz latite (Cornwall, 1972), thought to represent the resurgent core of a caldera, is located on the edge of the quadrangle. The low gravity anomaly of −215 mGal permits this interpretation of a caldera structure.

The Reveille Range (fig. 1) is composed mainly of Tertiary and Quaternary volcanic rocks; a core of Paleozoic rocks crops out near the mining camp of Reveille. Kleinhampl and Ziony (in press) suggested that a small part of the Paleozoic rocks is allochthonous and represents the easternmost remnant of an eastward-directed thrust sheet. Tertiary andesite and tuff capped by olivine basalt flows (Ekren and others, 1973b) overlap the Paleozoic section. The source of the 24–27-m.y.-old Monotony Tuff (Marvin and others, 1970) is a caldera partly exposed along the eastern edge of the range; the caldera is disrupted by a series of curvilinear, left-lateral strike-slip faults trending north-south to northwest-southeast. En echelon normal faults cutting Holocene deposits along the east front of the range in Railroad Valley (Ekren and others, 1973b) suggest that the Reveille Range has been recently tilted to the west. Gravity anomalies indicate that the western edge of the caldera producing the Monotony Tuff nearly coincides with the eastern frontal scarp and is immediately adjacent to a substantial section of Paleozoic rocks on the west.

The southern Pancake Range, immediately to the north, is underlain by several nested or coalescing Tertiary calderas (Ekren and others, 1974b, figs. 2, 3). The most recent caldera is the approximately 25-m.y.-old Lunar Lake caldera; this structure roughly coincides with the irregular −220 mGal gravity contour closure. This entire eruptive complex has been extensively modified by basin-and-range faulting. The superposed fault structures and eruptive constructs undoubtedly combine to produce the low-amplitude and very irregular gravity pattern over the Pancake Range.

Farther north, the Squaw and Heart Hills (pl. 1) are physiographically and geologically more a part of the Hot Creek Range than a part of the Pancake Range. Ekren and others (1973a) mapped a breccia unit bisecting the Squaw Hills and suggested that the southern hills lie within the Hot Creek Valley caldera complex while the northern hills do not; the north-south gravity gradient near the Squaw Hills can easily be interpreted as caused by a caldera boundary. Farther north, autochthonous(?) Mississippian rocks and smaller patches of older rocks in exotic slide blocks appear to form a small horst (Kleinhampl and Ziony, in press). The horst may have originated from a combination of caldera subsidence, lateral shearing, and basin-and-range normal faulting. An isolated block of relatively thick Paleozoic rocks with steep contacts is indicated by the small −210 mGal gravity anomaly closure over the northern hills.

The Park Range closes the circle around Hot Creek Valley. The range is a northeast-southwest-trending, east-dipping homoclinal block of Tertiary volcanic rocks that was faulted up along its western edge (Kleinhampl and Ziony, in press). Andesite Ridge forms a smaller similar block to the east. The gravity field is very smooth over this area, indicating the absence of dense Paleozoic rocks near the surface and the possible site of an eruptive center.

Each area of related basins and ranges that has been discussed in this report has a unique combination of geologic structures that produces a distinctive gravity pattern. The individual contributing structures, however, if broadly defined, are common to the entire area of the Tonopah sheet. These features are generalized on plate 1 and include the thrust-and-fold belts, the metamorphic-intrusive mountain blocks, the calderas and source vents, the east-west left-lateral shear zones, and the basins and ranges bounded by high-angle faults. None are completely defined as isolated phenomena; a clear understanding of their interactions remains an even greater challenge to geology and geophysics.

REFERENCES

Albers, J. P. (1967) Belt of sigmoidal bending and right lateral faulting in the western Great Basin: Geological Society of America Bulletin, v. 78, no. 2, p. 143–156.

Albers, J. P., and Kleinhampl, F. J. (1970) Spatial relation of mineral deposits to Tertiary volcanic centers in Nevada: U.S. Geological Survey Professional Paper 700–C, p. C1–C10.

Albers, J. P., and Stewart, J. H. (1972) Geology and mineral deposits of Esmeralda County, Nevada: Nevada Bureau of Mines and Geology Bulletin 78, 80 p., 2 pls.

Bonham, H. F. (1970) Geologic map and sections of a part of the Shoshone Mountains, Lander and Nye Counties, Nevada: Nevada Bureau of Mines and Geology Map 38, scale 1:62,500.

Bonham, H. F., and Garside, L. J. (1979) Geology of the Tonopah, Lone Mountain, Klondike, and northern Mud Lake quadrangles, Nevada: Nevada Bureau of Mines and Geology Bulletin 92, 142 p., 2 pls.

Cornwall, H. R. (1972) Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77.

Davis, W. E., Kleinhampl, F. J., and Ziony, J. I. (1979) Aeromagnetic and generalized geologic map of the Paradise Range area, Nevada: U.S. Geological Survey Map GP–926, scale 1:125,000.

Eaton, G. P., Wahl, R. R., Prostka, H. J., Mabey, D. R., and Kleinkopf, M. D. (1978) Regional gravity and tectonic patterns—their relations to late Cenozoic epeirogeny and lateral spreading in the western Cordillera, *in* Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51–92.

Ekren, E. B., Anderson, R. E., Rogers, C. L., and Noble, D. C. (1971) Geology of northern Nellis Air Force Base Bombing and Gunnery Range, Nye County, Nevada: U.S. Geological Survey Professional Paper 651, 91 p.

Ekren, E. B., Bath, G. D., Dixon, G. L., Healey, D. L., and Quinlivan, W. D. (1974a) Tertiary history of Little Fish Lake Valley, Nye County, Nevada, and implications as to the origin of the Great Basin: U.S. Geological Survey Journal of Research, v. 2, p. 105–118.

Ekren, E. B., Bucknam, R. C., Carr, W. J., Dixon, G. L., and Quinlivan, W. D. (1976) East-trending structural lineaments in central Nevada: U.S. Geological Survey Professional Paper 986, 16 p.

Ekren, E. B., Hinrichs, E. N., Quinlivan, W. D., and Hoover, D. L. (1973a) Geologic map of the Moores Station quadrangle, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Map I–756, scale 1:48,000.

Ekren, E. B., Quinlivan, W. D., Snyder, R. P., and Kleinhampl, F. J. (1974b) Stratigraphy, structure, and geologic history of the Lunar Lake caldera of northern Nye County, Nevada: U.S. Geological Survey Journal of Research, v. 2, p. 599–608.

Ekren, E. B., Rogers, C. L., and Dixon, G. L. (1973b) Geologic and Bouguer gravity map of the Reveille quadrangle, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Map T-806, scale 1:48,000.

Erwin, J. W. (1968) Gravity map of the Tonopah, Baxter Spring, Lone Mountain, and San Antonio Ranch quadrangles, Nevada: Nevada Bureau of Mines and Geology Map 36.

_____ (1980) Seismic refraction studies, Tonopah area: Nevada Bureau of Mines and Geology Report 35, 9 p.

Ferguson, H. G. (1924) Geology and ore deposits of the Manhattan district, Nevada: U.S. Geological Survey Bulletin 723.

Ferguson, H. G., and Cathcart, S. H. (1954) Geology of the Round Mountain quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-40, scale 1:125,000.

Ferguson, H. G., and Muller, S. W. (1949) Structural geology of the Hawthorne and Tonopah quadrangles, Nevada: U.S. Geological Survey Professional Paper 216.

Healey, D. L. (1970) Calculated in situ bulk densities from subsurface gravity observations and density logs, Nevada Test Site and Hot Creek Valley, Nye County, Nevada: U.S. Geological Survey Professional Paper 700B, p. B52–B62.

Healey, D. L., Snyder, D. B., and Wahl, R. R. (1981) Bouguer gravity map of Nevada, Tonopah sheet: Nevada Bureau of Mines and Geology Map 73, scale 1:250,000.

Healey, D. L., Wahl, R. R., and Currey, F. E. (1980) Complete Bouguer gravity map of the Tonopah 1° x 2° quadrangle, Nevada: U.S. Geological Survey Open-file Report 80-611, 91 p., 1 pl.

International Association of Geodesy (1971) Geodesy reference system 1967: International Association of Geodesy Special Publication No. 3, 116 p.

Jachens, R. C., and Roberts, C. W. (1981) Documentation of a FORTRAN program, 'isocomp,' for computing isostatic residual gravity: U.S. Geological Survey Open-file Report 81-574, 26 p.

Kane, M. F., Hildebrand, T. G., Simpson, R. W., Jr., Godson, R. H., and Bracken, R. E. (1982) Crust and mantle structure of the conterminous United States from wavelength-filtered gravity data (expanded abstract): Society of Exploration Geophysicists Technical Program, 1982 Annual Meeting, Dallas, Texas, p. 232–234.

Kay, Marshall, and Crawford, J. P. (1964) Paleozoic facies from the miogeosynclinal belt in thrust slices, central Nevada: Geological Society of America Bulletin, v. 75, no. 5, p. 425–454.

Kleinhampl, F. J. (1967) Geologic re-evaluation of several metalliferous mining districts, Nye County, Nevada (abs.): Mining Engineering, v. 19, no. 8.

Kleinhampl, F. J., and Ziony, J. I. (1967) Preliminary geologic map of northern Nye County, Nevada: U.S. Geological Survey Open-file Map, scale 1:200,000.

_____ (in press) Geology and mineral deposits of northern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin.

Locke, Augustus, Billingsley, P. R., and Mayo, E. B. (1940) Sierra Nevada tectonic patterns: Geological Society of America Bulletin, v. 51, p. 513–540.

Lowell, J. D. (1965) Lower and Middle Ordovician stratigraphy in the Hot Creek and Monitor Ranges, central Nevada: Geological Society of America Bulletin, v. 76, no. 2, p. 259–266.

Marvin, R. F., Byers, F. M., Jr., Mehnert, H. H., Orkild, P. P., and Stern, T. W. (1970) Radiometric ages and stratigraphic sequence of volcanic and plutonic rocks, southern Nye and western Lincoln Counties, Nevada: Geological Society of America Bulletin, v. 81, p. 2657–2676.

McKee, E. H. (1976) Geology of the northern part of the Toquima Range, Lander, Eureka, and Nye Counties, Nevada: U.S. Geological Survey Professional Paper 931, 49 p.

Morelli, C., ed. (1974) The international gravity standardization net 1971: International Association of Geodesy Special Publication No. 4, 194 p.

Nolan, T. B. (1935) The underground geology of the Tonopah mining district, Nevada: Nevada Bureau of Mines and Geology Bulletin 23 [v. 29, no. 5].

Oliver, H. W., Saltus, R. W., Mabey, D. R., and Hildenbrand, T. G. (1982) Comparison of Bouguer anomaly and isostatic residual-gravity maps of the southwestern Cordillera (expanded abstract): Society of Exploration Geophysicists Technical Program, 1982 Annual Meeting, Dallas, Texas, p. 306–308.

Plouff, Donald (1977) Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-file Report 77-535, 45 p.

Poole, F. G., and Wardlaw, B. R. (1978) Candelaria (Triassic) and Diablo (Permian) Formations in southern Toquima Range, central Nevada, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, Los Angeles, California, 573 p.

Saltus, R. W., Snyder, D. B., and Karish, C. R. (1981) Principal facts, accuracies, sources, base station descriptions, and plots for 1380 gravity stations in the Tonopah 1° x 2° quadrangle, Nevada: Springfield, Virginia, National Technical Information Service NTIS-PB81-219-081, 85 p.

Shawe, D. R. (1981a) Geologic map of the Round Mountain quadrangle, Nye County, Nevada: U.S. Geological Survey Open-file Report 81-515, scale 1:24,000.

_____ (1981b) Geologic map of the Manhattan quadrangle, Nye County, Nevada: U.S. Geological Open-file Report 81-516, scale 1:24,000.

Silberling, N. J. (1959) Pre-Tertiary stratigraphy and Upper Triassic paleontology of the Union district, Shoshone Mountains, Nevada: U.S. Geological Survey Professional Paper 322, 67 p.

Speed, R. C., and McKee, E. H. (1976) Age and origin of the Darrough felsite, southern Toiyabe Range, Nevada: U.S. Geological Survey Journal of Research, v. 41, no. 1, p. 75–81.

Stewart, J. H. (1980) Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

U.S. Geological Survey (1969) Report of exploration progress, central Nevada; period January 1, 1968, to April 1, 1969: U.S. Geological Survey Report USGS-474-18, 34 p.