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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A PRELIMINARY ANALYSIS OF GRAVITY AND AEROMAGNETIC SURVEYS OF THE TIMBER MOUNTAIN AREA, SOUTHERN NEVADA

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A Preliminary Analysis of Gravity and Aeromagnetic Surveys of the Timber Mountain Area, Southern Nevada

by

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Abstract

Recent (1977-1978) gravity and aeromagnetic surveys of the Timber Mountain region, southern Nevada, have revealed new details of subsurface structure and lithology. The data strongly suggest that deformation caused by volcanic events has been accomodated along straight-line faults combining in such a fashion as to give a curvilinear appearance to regional structure. Some of the curvilinear aspect may be caused by erosion and perhaps surface slumping following formation of the caldera. The magnetic data suggest that rock units in the central graben and along the southeast margin of Timber Mountain may have been altered, perhaps thermally, from their original state. The gravity data indicate that the south part of Timber Mountain is underlain by relatively dense rock possibly intrusive rock, like that which crops out along its southeast side. The gravity data also suggest that the Silent Canyon caldera may extend considerably south of its presently indicated southern limit and may underlie much of the area of Timber Mountain. The moat areas appear to be more rectangular or triangular than annular in shape. The southern part of Timber Mountain caldera is separated from the Yucca Mountain area to the south by a triangular horst. The structural relations of the rock units making up the horst are complex. Several linear terrain features in the southern part of the caldera area are closely alined with geophysical features, implying that the terrain features are fault-controlled.

Introduction

The Timber Mountain area of southern Nevada, located partly within the Nevada Test Site (Fig. 1), is underlain almost entirely by a caldera complex. Geologic mapping (Carr, 1977; Byers and others, 1976) and prior reconnaisance gravity and aeromagnetic surveys (Boynton and others, 1963; Boynton and Vargo, 1963; Healey and Miller, 1979; Carr, 1977) have provided substantial detailed information about the surface geology and more general information on the subsurface structure of the area. Additional detailed gravity and magnetic surveys were undertaken to refine the geophysical evidence of subsurface lithology and structure. This report is a preliminary analysis of these data and discusses the major geophysical anomalies and some of the problems of interpretation.

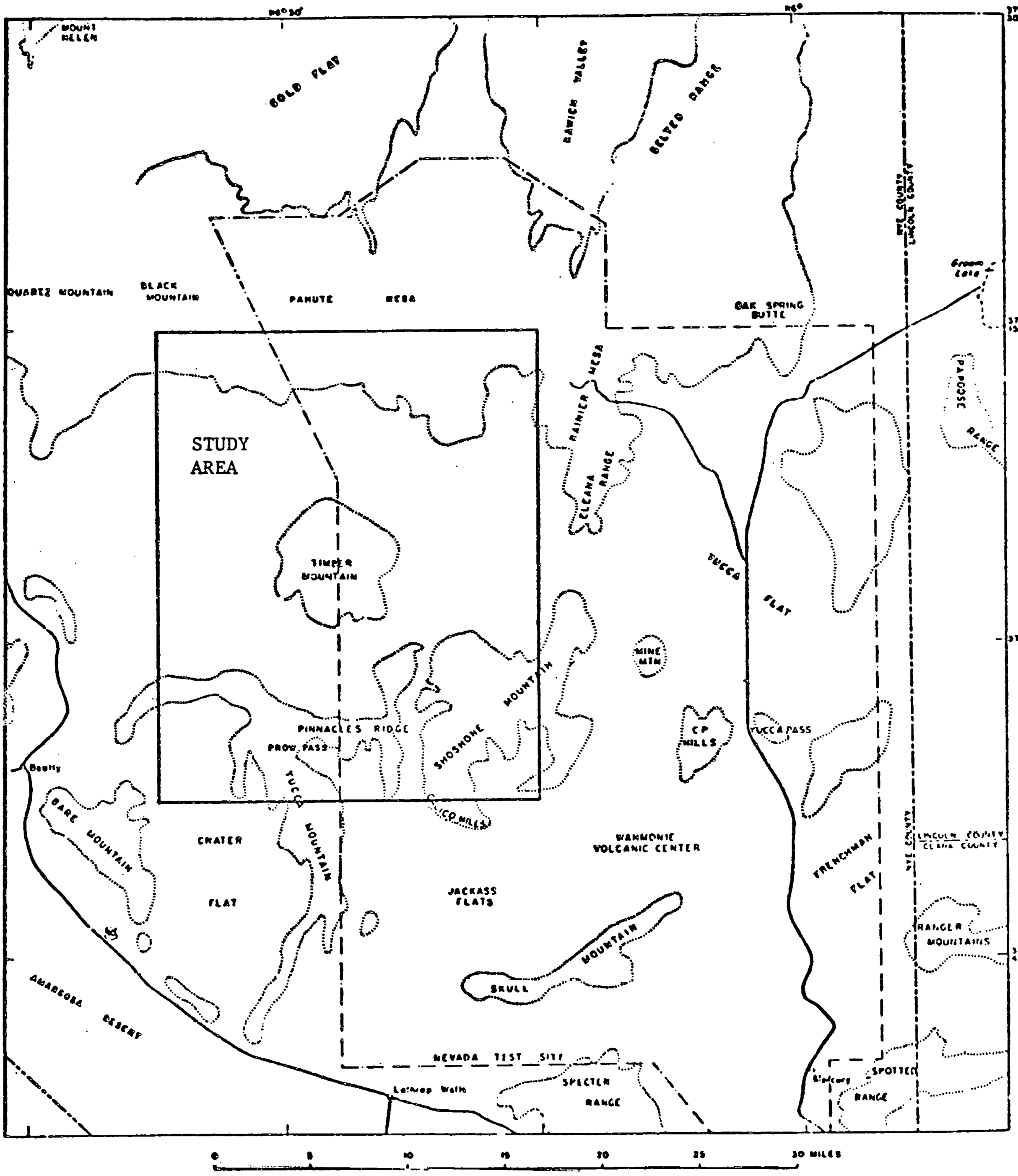

Figure 1. -- Location map of study area.

Surveys

The first aeromagnetic surveys of 1960 and 1961 (Boynton and others, 1963; Boynton and Vargo. 1963) cover the eastern two-thirds of the area: they were flown at 900-m (1/2-mile) spacing along east-west tracks at a constant barometric altitude of 2439 m (8000 ft). In general, the resultant maps show the major aeromagnetic anomalies of the survey area, but both the altitude and spacing make the data insufficient for other than general commentary on the anomaly sources and their significance (Carr, 1977, p. 32,33). Interpretation of these data is further constrained by ground to flight-level distances that vary by more than 800 m (2600 ft), a factor that is especially critical when the terrain is underlain by rocks of substantial and differing magnetic susceptibility. For these reasons the new aeromagnetic surveys were flown at a constant terrain clearance of 122 m (400 ft) and 400 m (1/4 mile) spacing; coverage was extended to include the western third of the area.

An earlier gravity survey comprising about 765 stations was used by Healey and Miller (1979) to investigate the regional structure underlying the area. A new survey was conducted in 1977 by Exploration Data Consultants (EDCON) of Denver, Colorado, under contract to the U.S. Geological Survey. The major objective of the new survey was to explore for the presence of competent plutons of reasonably large dimensions, perhaps in excess of a few kilometers in average diameter. About 180 of 317 new stations were concentrated in the immediate vicinity of Timber Mountain, where geologic mapping has revealed outcrop areas of porphyritic granite and intrusive rhyolite (Carr, 1977). The remaining stations were distributed in the surrounding area to improve the regional coverage. The gravity interpretation is based on the data of the report of Healey and Miller (1979), on subsequent measurements by D. L. Healey (written communication, 1979) for about 940 stations, and on the new data for a total of 2020 stations.

Data Reduction

Aeromagnetic readings were sampled at intervals along flight lines of about 30 m (100 feet) with an instrumental accuracy of ± 1 gamma. The data were corrected for IGRF 1975 (Barraclough and Fabiano, 1978) updated to the time of the field survey. These data were hand-contoured as detailed maps at scale 1:62,500 (U. S. Geological Survey, 1979). For purposes of this report, the data were continued upward to a uniform distance of about 250 m (820 ft) above the terrain in order to remove the effect of variations in flight altitude above terrain (Bhattacharyya and Chan, 1977).

The gravity data were reduced according to the Gravity Formula 1967 (International Union of Geodesy and Geophysics, 1967) and referred to the IGSN 1971 (International Union of Geodesy and Geophysics, 1971). Terrain corrections were made to a distance of 167 km (104 mi) using an experimental method by Donald Plouff (written communication, 1979).

Gravimeters are generally accurate to within a tenth of a milligal. For these data, some of the inaccuracies arising from elevation control are as great as 0.3 mGal, although most of them are less; inaccuracies related to horizontal control are comparatively negligible. In considering the survey as a whole, the overriding inaccuracies are those due to the terrain correction and to the density factor in the Bouguer correction. In general, terrain corrections usually have a relative accuracy of ± 1 mGal except in areas of sharp local relief (within 1 km of the station). The density factor effect is a function of relative elevation and is minimal for areas of similar altitude (± 150 m). These inaccuracies enter into the interpretation in different ways and are discussed in more detail in the section on gravity interpretation.

Observable Anomalies and Physical Properties

The following discussion draws on reports by Bath (1968), Healey (1968), and Healey and Miller (1979) in which the authors report extensive measurements made on the volcanic rocks of the Timber Mountain area. Specific references are made, in the body of the report, to Bath's measurement of magnetic properties. There are three additional general observations by Bath that are worth noting here. The first is that remanent magnetization, the component of magnetization frozen into igneous rock at the time of its cooling, is the only producer of significant magnetic anomalies in the Timber Mountain region. Because the remanent magnetization is alined with whatever the direction of the Earth's field is at the time of rock cooling, it may be positive or negative. For the Timber Mountain area it is shown by measurement to be dominantly negative. Because of the young age of the rocks (middle to upper Miocene) the direction of magnetization, disregarding sign, is nearly the same as that of the present Earth's field. The second observation is that magnetization increases with the density of the volcanic rocks and is greatest in the lavas; the lavas are the major anomaly producers in the area except for two members of the Timber Mountain Tuff: the Rainier Mesa at the base and the Ammonia Tanks at the top. These tuffs are more densely welded than the average of the tuffs of the region. The third observation is that a combination of a minimum thickness and minimum magnetization is needed to produce anomalies of a given magnitude. The minimum amplitude of 200 gammas for the anomalies discussed here restricts the sources to thicknesses usually greater than 150 m (660 ft) and magnetizations usually greater than 1×10^{-3} emu.

There are two types of apparent anomalies that are not directly caused by magnetization. The first is a residual effect that can occur when a tract of nonmagnetic rocks is located between two tracts of magnetized rock that have anomalies of the same sign. A second type of apparent anomaly, the dipole effect, is caused by a nonvertical magnetization direction. In such cases a secondary anomaly appears along the fringe of the primary anomaly and is of opposite sign. With a highly inclined magnetization direction like that in the Timber Mountain region, the secondary anomaly is much less in amplitude than the primary anomaly. Much of the problem of identification of primary anomalies is avoided by restricting interpretation to major features.

Because of the inclination of the magnetization direction, outlines of magnetic anomalies are displaced somewhat south of the outline of the source. Displacements are small but observable for high inclinations like that of the Timber Mountain region, particularly for bodies elongated east-west.

Healey and Miller (1979) separate the densities of rocks in the Timber Mountain region into three primary groups, 2.67 g/cm^3 for pre-volcanic rock, 2.4 g/cm^3 for welded tuffs, and 2.2 g/cm^3 for nonwelded or lightly welded tuffs. On the basis of carbonate densities (calcite, 2.71 g/cm^3, dolomite 2.87 g/cm^3) however, Paleozoic sections with little porosity and substantial sections of limestone and dolomite may attain an effective density of 2.75 g/cm^3 or higher. Other density groups occur but with one exception, discussed in the following paragraph, they do not appear to be of sufficient mass to affect the gravity field within the precision measured here. Exposures of rock units with densities from 2.67 g/cm^3 to 2.75 g/cm^3 are limited to the perimeter of the Timber Mountain region and are only significant when making general estimates of the thicknesses of major igneous units. The density of

2.4 g/cm^3 is generally applicable in the immediate vicinity of Timber Mountain and, as will be shown, must be used in the Bouguer correction to derive an accurate insight into the density of the surface and subsurface rocks of that area. A density of 2.2 g/cm^3 is applicable to most of the volcanic rocks of Timber Mountain moat and beyond and must be used in the Bouguer correction for an accurate picture of rock distributions in that region. Recourse is made, therefore, to two different gravity maps to study the two regions of different principal densities.

Rhyolite lavas and intrusive units form an important exception to the groups discussed above. Rocks of this group may have a density ranging from 2.4 g/cm^3 to as much as 2.6 g/cm^3. Rhyolite lavas of sufficient volume cause notable anomalies when they are located within less dense tuff units. Intrusive rhyolites or their more coarsely crystalline equivalents may cause an observable anomaly even when emplaced with rock units like those of Timber Mountain, which have average densities of about 2.4 g/cm^3. As noted above, the lavas also tend to be moderately to strongly magnetized so that both gravity highs and magnetic highs or lows tend to be associated with their presence within the tuff units.

Aeromagnetics

Maps

The detailed aeromagnetic maps (U.S. Geological Survey, 1979) show an abundance of anomalies which, on an individual basis, are difficult to sort out and analyze. The most complete use of these detailed maps is achieved in conjunction with a coordinated geologic mapping program and extensive sampling of the underlying rock units for magnetic property measurements. It can be observed, however, that the anomalies tend to cluster in distinctive patterns which are outlined by well defined boundaries. The patterns are often associated with particular rock units, and the boundaries are a clue to underlying structure. In the upward continuation method, the patterns are simplified for easier recognition and interpretation without removing the evidence of boundaries. In addition, the magnetic anomalies over rock units whose thicknesses are only a fraction of the separation distance between the magnetic rock and the flight level (in this case simulated) tend to be damped out (Bath, 1968). Thus another important property of the upward-continued field is that it tends to "look deeper."

For ease of reference, the map of the upward-continued aeromagnetic field (Plate 1) is divided into nine sections identified by their relative geographic positions (e.g., NE designates northeast, C designates center). Two groups of anomaly patterns are distinguished on the map by superimposed boundaries. The first group comprises four more or less irregularly bound areas that have distinctive anomaly patterns of sufficient size to seem especially noteworthy. The largest of these, encompassing Timber Mountain, is further subdivided into three subordinate zones. The second group consists of linear zones that are oriented peripheral to Timber Mountain and enclose distinctive anomaly patterns. In the following discussion many of the anomalies are related to geologic units which are shown and described on the geologic map of the Timber Mountain area (Byers and others, 1976).

The drawing of boundaries on anomaly maps is to some extent subjective. There is one guideline however, that is definitive for both gravity and magnetics; it is that the contours are always more curved than the source outline. The corollary is that a linear anomaly pattern (like, for example, a linear gradient) always indicates a similar or more severe linearity in the source. For this reason, some boundaries are shown to extend beyond the limits of the linear gradients used to define the boundaries. In the case of anomaly patterns, it is clear that more than one type of source may be enclosed by the boundaries, except in cases where there is evidence of an association between a single anomaly and a geologic unit.

Timber Mountain

Timber Mountain, which takes up most of C as well as the northeast part of WC, is underlain almost wholly by the Ammonia Tanks Member of the Timber Mountain Tuff. The magnetic pattern of this area is distinguished from that of the immediate surrounding area by higher amplitudes and steeper gradients. Within the pattern the anomalies on the north are mostly positive and generally more pronounced in amplitude and orientation than those to the south. The north part of Timber Mountain is underlain primarily by the upper part of the Ammonia Tanks Member, which is identified by Bath (1968) as normally magnetized and anomaly producing. The correlation of magnetic highs with the outcrop areas of the upper part of the Ammonia Tanks is pronounced.

In the southern part of Timber Mountain the magnetic pattern is more complex; most of the anomalies are of lesser amplitude and more equidimensional in plan. In the part of the southern area that is shown on Plate 1 as continuous in magnetic pattern with the northern area, the positive anomalies correlate, as above, with the upper part of the Ammonia Tanks Member. Within this same pattern the magnetic expression over the lower part of the Ammonia Tanks, the dominant rock unit of the southern area, is either slightly negative or equivocal. If the anomaly-rock unit association of the northern zone and connecting southern zone is accepted as standard for Timber Mountain--an association strongly supported by the magnetic property measurements--then there is a central west-trending lobate zone and a southwest marginal zone where the magnetism appears reversed. In this central zone and southwest marginal zone the magnetic anomalies are positive over the lower part of the Ammonia Tanks and negative or null over the upper part of the Ammonia Tanks.

The central lobate zone of opposite magnetic association corresponds closely to the central, similarly trending graben of Timber Mountain

(Carr and Quinlivan, 1968). Central elongate grabens appear to be typical of resurgent domes (Smith and others, 1961). The magnetic data suggest that the rocks of the graben floor may have been heated and altered sufficiently, perhaps by magmatic fluids, to change their magnetic properties. The southeastern zone of opposite magnetic association is also a likely area for differential heating, as is shown by the presence of intrusive rock (Carr and Quinlivan, 1968). As will be pointed out below, the southeastern zone is also marked as an abnormal area by the gravity data.

Aeromagnetic patterns - irregular

In the northeast a dumbbell-shaped pattern of negative anomalies straddles the boundary between NC and NE. Although the anomalies correspond in part to the negatively magnetized Rainier Mesa Member of the Timber Mountain Tuff, they are substantially more intense than those observed elsewhere over the Rainier Mesa. Moreover, the pattern extends south of the Rainier Mesa outcrop area to a region underlain by members of the older formation, the Paintbrush Tuff and its associated rhyolite lavas. Some individual anomalies in the southern part of the pattern correspond closely to the lava outcrop areas. Bath (1968) identifies the lavas as negatively polarized and anomaly producing. It seems likely that this anomalous pattern identifies the extent of the subcrop area of these lavas and their associated tuffs.

A single but very intense negative magnetic anomaly is located astride the boundary between NE and EC. The outline of the northern half of the anomaly corresponds closely to an arcuate fault with concave side down. Much of the northern region of the anomaly is also underlain by the upper part of the Ammonia Tanks Member of the Timber Mountain Tuff which, as indicated above, is positively magnetized. The negatively magnetized Rainier Mesa Member of the Timber Mountain Tuff has the proper polarization to cause the anomaly but does not cause such a high amplitude elsewhere. The source rock for the anomaly is probably a lava with negative polarity. A gravity high (Plate 4), which also extends over the area of the anomaly, also indicates that the source is a thickened lava section. Possible candidates for the source are post-caldera rhyolite flows of Timber Mountain area and lava flows associated with the Paintbrush Tuff. The conformance of the anomaly to the mapped arcuate structure strongly suggests that the anomaly source and the structure are closely related.

A pattern of moderately intense, somewhat diffuse, anomalies occupies much of SE. This area is the location of Shoshone Mountain, which is underlain almost wholly by the rhyolite lava flows of that name. The central part of the pattern is dominated by magnetic highs presumably caused by the rhyolite lavas, which are known to be positively magnetized (G. D. Bath, oral communication, 1980). The same relationship is exhibited in the southeasternmost corner of SE, where a pronounced aeromagnetic high of 400 gammas coincides with a broad but isolated exposure of the lavas of the Shoshone Mountain type. Within the pattern over Shoshone Mountain, however, there are areas of prominent negative anomalies, which must originate in negatively polarized rocks below the rhyolite lavas. That the rhyolite lavas are thin in these areas is suggested by nearby windows which reveal exposures of older rock units. The source of the negative anomalies might be the underlying Rainier Mesa Member of the Timber Mountain Tuff, but the high amplitudes suggest the older, more magnetic lavas.

A cluster of westerly elongated magnetic lows, located just southwest of the center of NC correlates with pre-Ammonia Tanks rhyolite lavas and is presumably caused by them. The lavas are identified by Bath (1968) as negatively magnetized. There is an associated gravity high of about 10 mGal or more, which indicates that the lavas assuming they are 0.2 g/cm^3 more dense than the surrounding rocks, are more than 1200 meters (4000 ft) thick (Kane and Bromery, 1968, p. 418). To the northwest, just north of the east-central part of NW, a west-trending negative anomaly is centered over a much smaller area of outcrop of similar lavas. The anomaly is composed of two lobes, a western one trending slightly north of west and an eastern one trending slightly north of east. There is gravity high (Plate 4) centered over the exposed lavas, of equidimensional outline but much larger than the area of lavas, approaching in size the area of the composite magnetic low. If the gravity high is caused solely by the lavas, their thickness would be similar to that indicated for the lavas to the east. Under this assumption, the gravity anomaly indicates that the lavas to the west have an extensive subcrop area, perhaps as much as five times their exposed area.

Aeromagnetic patterns-linear

A prominent aspect of the aeromagnetics is an angularity or linearity that is exhibited in much of the region around Timber Mountain. By contrast, there is an apparent absence of angularity in the magnetic fields over Timber Mountain and over much of the northeast and southeast corners of the map. The angularity apparent in Plate 1 is even more pronounced on the more detailed aeromagnetic maps (U.S. Geological Survey, 1979). The linearities are generally expressed in one or more of three ways. The first type of expression is an alinement of anomalies, as typified by the linear negative anomaly that extends northwest from the northwest corner of NC to the north boundary of NW. The second is a more general grouping of anomalies, such as those on the southeast side of Timber Mountain extending from the northeast corner of SC into the southwest corner of EC. The third and perhaps most important expression of linearity is a boundary between broad zones of magnetic anomalies that contrast in a marked way. The contrast may be a sharp change in the sign, amplitude, general azimuth, or dominant shape of the anomalies; an extended gradient dividing two areas of differing appearance; or possibly some combination of these.

One of the most pronounced linearities is a north-trending feature along the west side of WC. It is a gradient that separates north-trending positive anomalies on the east from similarly trending negative anomalies on the west. The negative anomalies correlate with the Rainier Mesa Member of the Timber Mountain Tuff, which has the proper magnetization direction to cause the lows. The alined magnetic highs east of the gradient may be caused by moderately magnetic volcanic units or may be present as a residual high between two magnetic lows. There is a gravity high (Plate 4) or ridge which coincides with the alined magnetic lows. The anomalies lie along the west wall of the Timber Mountain west moat (Byers and others, 1976) and are evidence of the relative uplift of more dense and of negatively magnetized rock unit along the moat wall. Both the gravity (Plate 4) and magnetic evidence indicate that the subsurface feature causing them is straight between 37°00′ and 37°05′N., in contrast to the surface exposures, which indicate a sharp west-bending flexure at about 37°02.5′N., where Cat Canyon crosses the moat wall. The magnetic data indicates a change to a northwest trend at 37°05′ minutes, whereas the gravity anomaly appears to persist along a northerly strike to 37°07.5′N. There is, however, a second-order change in the gravity anomaly at 37°05′N., which may indicate a change in the anomaly source. Both types of anomalies are clearly discontinued at 37°07.5′N.

A gentle magnetic gradient extends N. 17° E. from the southwest corner of NW almost to its northern border. It separates positive anomalies of random trend on the northwest from negative anomalies of easterly trend on the southeast. The gradient does not have a clear counterpart in the gravity field (Plate 4), except that it follows the general trend of a major gravity gradient. It is in the general vicinity of the dashed (suggested) location of the northwest wall of the Timber Mountain moat.

The southwest end of the gradient of NW and the northern ends of the magnetic and gravity alinements of WC both converge in the area where the east end of the north wall of the Oasis Valley caldera segment impinges on the west wall of the Timber Mountain caldera. Perhaps the magnetic and gravity data are giving a clearer picture of the nature of the calderas′ walls at this junction. The gravity data suggest that the west wall of the Timber Mountain caldera must bend on either side of its junction with the wall of the Oasis Valley caldera segment. In essence, more dense rocks must be present at a more shallow depth in the west moat wall of WC.

The gradient trending south of east from the north side of NW into the northwest corner of NC is that given in the first example cited above. It appears to connect with another magnetic boundary that extends along a more southerly course to the east edge of the map. The gradient to the northwest bounds the southwest side of a like-trending magnetic low, which in turn lies slightly southwest of a faintly indicated gravity anomaly (Plate 4) (shown by flexures in the contours and a constriction in the gravity low in the northwest corner of NC). To the southeast the magnetic boundary separates distinctly different magnetic fields and has a clearly coincident gravity boundary.

The southeast-trending geophysical boundaries generally coincide with the northeast wall of the Timber Mountain moat, as shown on the geologic map of Byers and others (1976) and seem clearly to be caused by the underlying structural boundary. The major low in the gravity field indicates that the geophysical boundaries to the northwest cross the deepest part of the earlier Silent Canyon caldera. Possibly a thick section of younger tuffs that blankets this region is masking the evidence of the Timber Mountain caldera boundary in this locality. As will be discussed in the following paragraphs, the geophysical data suggest that the northwestern part of the caldera moat may be more complex than surface evidence indicates.

A broad linear zone, trending slightly north of east, extends from the south part of NW to the south-central part of NC, as indicated by parallel dashed lines. Anomalies within the zone are sharper and more random than those to the south or north. In a previous paragraph, the anomalies in the easternmost zone were identified on the basis of magnetic, gravity, and geologic evidence as being caused by pre-Ammonia Tanks rhyolite lavas. The westernmost magnetic closure within this linear zone coincides with both a local gravity high and a broad exposure of the rhyolite lavas of Fortymile Canyon. There is a local gravity high over the easternmost magnetic closure in the part of the zone in NW; there is no apparent gravity high over the circular negative closure in the north-central part of the zone in NW, although it should be noted that there are no gravity stations near the center of this magnetic low. In general, the evidence suggests that most of the anomalies are caused by rhyolite lavas.

The triangular region north of the parallel-sided zone is dominated by a central anomaly, which is discussed in a paragraph above. It was concluded that a rhyolite mass underlies much of the magnetic anomaly. The region to the south between the zone and Timber Mountain is underlain by a large, elongate magnetic anomaly which parallels the zone.

The combined evidence suggests that the triangular area northwest of Timber Mountain encloses an abundance of rhyolite lavas. There is evidence in both the gravity and magnetic fields (more definite in the magnetic fields) of north-of-east trends in the zone. The lavas both predate and postdate the Ammonia Tanks; the pre-Ammonia Tanks lava however, is not constrained to any of the north-of-east trends, but trends itself north of west, parallel to the magnetic boundary to the northeast.

A parallel-sided zone of sharp anomalies trending northeast, referred to as an example above, is located along the southeast margin of Timber Mountain. The anomalies coincide with the general outcrop area of post-Ammonia Tanks mafic lavas, which are approximately equivalent in age with the Fortymile Canyon rhyolite lavas. The post-Ammonia Tanks mafic lavas are identified as positively magnetized by Bath (1968). Variations in the amplitudes of the highs are probably a reflection of variations in thickness. Some of the lows flanking the highs appeared to be caused by the dipole effect. There is a faint expression of a low-amplitude gravity high over much of the surface extent of the lavas. The lavas also occur to the south and west of Timber Mountain but do not seem to have any prominent gravity or magnetic anomalies associated with them. The evidence suggests that the bulk of these lavas occurs in the zone southeast of Timber Mountain; the geometry of the zone suggests some type of conformable structural control on their emplacement. There is a similar association between the magnetic high that trends northwest from the northwest corner of EC across the northeast corner of C, and the trachybasalt of Buckboard Mesa. It is the youngest volcanic unit in the area and is positively magnetized (Bath, 1968).

Just southeast of the zone described above, and sharing a common boundary, is a second zone that has similar width and direction but is typified mostly by negative anomalies and a low gradient. Beyond the southeast boundary of this latter zone the magnetic field exhibits more sharply defined anomalies, which are variably positive or negative. There is also a suggestion of elongation of anomalies along the trend of the zone, especially in its central part. There is no clear counterpart anomaly in the gravity field, although the gravity (Plate 4) trend of the central part of a major low follows the trend of the zone. The evidence seems to point to the southeast boundary of the zone as the southeast wall of the Timber Mountain caldera. If so, the wall appears to have developed across a thick sequence of low density volcanic rocks (shown by the gravity low) that underlie for the most part, the lavas of Shoshone Mountain. In this sense it resembles the northwest part of the northeast boundary of Timber Mountain caldera discussed above. In any case, the suggested boundary occurs in the general vicinity of that suggested by the geologic evidence.

Triangular zone

A triangular zone, narrowing and elongate to the northwest is indicated along the southwest edge of the Timber Mountain caldera. The southwest boundary of the zone divides anomalies on the south, which have northerly trends, from those within the zone, which have a dominant southeast trend. The location of the northeast boundary is more arbitrary than that to the south; it is located in part by gradient trends in the southwest moat area of Timber Mountain. The triangular magnetic zone corresponds closely with a similar zone of gravity highs; its boundaries are partly guided by the gravity field expression. Whatever the precise boundaries, there is abundant geologic and gravity evidence to support definition of the zone as a distinctive feature of the regional geologic structure. The northeast boundary of the zone clearly defines the southwest wall of the southwest moat area of Timber Mountain. The geologic data identify the triangular data as containing the Claim Canyon caldera segment, which brings the units of the Paintbrush Tuff and associated rock lavas up into a structural high, relative to Timber Mountain caldera.

The largest anomaly within the triangular area is a boomerang-shaped low occupying much of the southeast part. The western leg of the low is much more intense than the leg to the east. The gravity field is of moderate intensity over the western leg; the anomalies correlate with the rhyolite lavas of the Paintbrush Tuff, which are negatively magnetized (Bath, 1968). The lavas are the likely source of both the magnetic and gravity expressions. The more moderate magnetic low to the east is associated with a gravity low and is underlain by the lavas of Fortymile Canyon, which are also negatively magnetized. The magnetic low is probably caused by the lavas, but the gravity low suggests that the lavas may be underlain by a section of lower density tuffs. The magnetic lows within the zone farther to the west are associated with the lower part of the Paintbrush Tuff and may likewise be caused by the lavas associated with this tuff.

A magnetic high is present in the west-central part of SC, just to the north of the boomerang-shaped low. Its position, shape, and amplitude suggests that it may be a dipole fringe anomaly to the low on the south. Another magnetic high is present just to the west in the northeast part of SW. It seems too large for a dipole effect; it correlates with a low in the gravity field. There is no indication of a probable source in the geology of the area; the underlying tuff of Chocolate Mountain has negative polarity (G. D. Bath, oral communication, 1980), so it cannot be the source of the magnetic anomaly.

A cluster of magnetic lows is centered at about 36°55N. and 116°22.5′W. It correlates with an area underlain by the rhyolite lavas of Fortymile Canyon and has an associated gravity high. The magnetic anomaly pattern resembles that over the rhyolite lavas associated with the Paintbrush Tuff, as described before for the northeast part of NC. The cause of the anomalies might be the lavas of Fortymile Canyon. The northwest boundary of the cluster of magnetic lows is linear and coincides with the southeast margin of the parallel-sided magnetic zone described above. There is a secondary flexure in the gravity expression (Plate 4) that would correspond approximately to the same margin. A topographic feature, Pah Canyon, also occurs along the trend of the margin and appears to mark a boundary in the placement of the volcanic rocks. Both the magnetic and gravity anomalies north of the margin would be reasonable extensions of the magnetic anomaly cluster and gravity high to the south, if their source had been downdropped and deflected northeast. These conditions would be satisfied, at least in part, if the southeast margin of the magnetic zone is, as suggested above, caused by the southeast wall of the moat of Timber Mountain.

The southeast half of the southwest margin of the triangular magnetic and gravity zone described above correlates with Yucca Wash and the sharply delineated northeast margin of Yucca Mountain. Much of Paintbrush Canyon is aligned along a major northeast-trending fault, which crosses the caldera wall into the Timber Mountain southern moat and marks the western limits of the prominent outcrop area of the basalt of Dome Mountain. The line of this fault is along an alinement of magnetic anomalies, forms a boundary between major clusters of magnetic anomalies described above, and appears as a boundary in the gravity expression. There seems little doubt that the topographic features referred to in this paragraph and the one above are controlled by underlying structure. In each case the geophysical data suggest vertical offsets on the order of many hundreds of meters (a few thousand feet). Fortymile Canyon follows a gravity high (Plate 4) from $36^{o}52.5'$ to about $37^{o}00'$N., but the relationship is obscured by the problem of a correct density factor for the Bouguer correction. This subject is discussed further in the section on gravity.

Gravity

General

Plates 2, 3, 4, and 5 are gravity maps of the Timber Mountain area using different parameters in the data reduction. Although most of the discussion will center on Plates 4 and 5, it is useful to discuss each of the maps in turn to illustrate certain features and interpretations of the gravity field.

Plate 2 is a standard Bouguer map corrected for terrain using a density factor of 2.67. The reduction datum is sea level. The high negative values are typical of high-altitude continental terrain and are attributed to isostasy.

There are certain features worth noting for comparison with the maps that follow. Most of the northern half of the map is occupied by an angular gravity low bound by fairly steep gradients to the east, west, and south. There appears to be a step or shelf in the southern part of the low with a change in level of about 15 mGal positive to the south. An irregular south-trending gradient, positive to the east, follows the east boundary of the map; its values are successively higher southward. The highest values on the map are in the southwest corner (-146 mGal) and the southeast corner (-152 mGal), where bedrock of Paleozoic age is exposed. The steep gradients bordering these highs mark the outermost edge of the structural depression associated with the volcanics.

In the central part of the map the gradients are easterly. The very center of the map, the location of Timber Mountain, is nearly featureless except for minor anomalies. In WC however, a central north-trending trough is paralleled to the west by a north-trending ridge. Like the gradients in the center, the values increase southward along these features. The gravity can also be seen to increase southeasterly from the northwest corner of EC.

Gravity increases to the southwest across a southeast-trending gradient that extends from the west part of the north boundary of SW almost to the east boundary of SC. This feature becomes more clear on successive maps. A gravity ridge, becoming more negative to the north, trends along most of the boundary between SC and SE and then turns northeasterly as it passes into EC; its trend breaks rather sharply as it passes into EC. This feature corresponds rather closely with a topographic low (shown on the modified topographic map of Plate 6), except for a widening of the gravity anomaly along the south part of the boundary between SC and SE. The topographic map is based only on the elevations of the gravity stations in order to emphasize inaccuracies that may arise from an inaccurate density factor in the Bouguer correction. The inverse correlation of gravity and topography in plates 2 and 6 is strong evidence that the chosen density factor 2.67 g/cm^3 is too high.

As noted above, the Bouguer gravity field of the Timber Mountain area is negative because of isostatic compensation for the elevated terrain. Gravity values for individual or comparable features have been seen to increase southward, whereas the topography generally rises northward (Healey and Miller, 1979). In order to allow a more direct comparison of features across the map, the method of Mabey (1966) has been used to remove the regional effect of isostasy.

Plate 3 and all the following gravity maps have been reduced for isostasy. On Plate 3, it may be noted that all of the regional features pointed out on Plate 2 have been preserved. Although the values on the map are all still negative, they now reach values between -16 and -20 mgal in the southeast and southwest corners of the map. The amplitudes of the minima centered in the northwest corner of NC and southeast corner of NW are now comparable in value, whereas on Plate 2 a 15-mGal difference is observed. The values along the irregular gradient that extends along almost all of the east boundary of the map no longer show the increase from north to south. The southward-increasing gradient trending easterly across the north boundaries of WC and C is strongly diminished, as are the gradients along the south-trending gravity features of WC; the westernmost one along the west boundary of WC now shows closure. The gravity field over Timber Mountain (section C and the western third of WC) is now much less irregular; a broad high is revealed over its southern half.

The inversely related gravity-topography feature trending north along the boundary between SC and SE is still apparent on Plate 3. Other evidence of an inverse relation can be seen by comparing gravity and topography over the north and central parts of Timber Mountain. In particular, a southward deflection of the gravity contours centered along 116°27.5'W. corresponds closely to the broad north highland of Timber Mountain (Plate 6). Conversely, an easterly elongated gravity high crossing the boundary between WC and C corresponds with the topographic lowland separating the northern and southern parts of Timber Mountain. A similar inverse relation can be observed in the northeast corner of SW. As pointed out above, the inverse gravity-topographic relation is direct evidence that a density of 2.67 g per cm^3 is too high for a proper Bouguer correction.

Bouguer gravity of region around Timber Mountain

Specific gravity data (Healey and Miller, 1979) show a density of 2.4 g/cm^3 for the rock units of Timber Mountain and 2.2 g/cm^3 for outlying volcanic units. Plate 4 is a gravity map reduced for 2.2 g/cm^3. Except for a few regions noted below, the major gravity anomalies observed on Plate 3 are still preserved, although slight changes in trends and relative values can be seen. This indicates that the elevation changes for these areas are small enough and gradual enough that a change in the Bouguer density factor produces relatively minor changes in the Bouguer correction. In general, the pattern of gravity anomalies seems more simple and coherent than that of Plate 3, evidence that the density of 2.2 g/cm^3 is more applicable than 2.67 g per cm^3. Prominent changes can be seen over Timber Mountain, where a pronounced gravity high is present; over a zone extending from the northwest corner of SW to the central part of SC, where two broad highs are alined southeasterly; and over the boundary between SC and SE, where the pronounced north-trending linear high of Plate 3 is decomposed into a broad high on the south and a small northeast-trending linear high on the north. The broad low to the east, which underlies much of the western part of Shoshone Mountain, is diminished but still clearly evident.

The broad gravity high over Timber Mountain (Plate 4) corresponds generally to the topographic high, indicating that the Bouguer density factor is too low. It establishes, together with the correlation of a gravity low with topographic peaks for Plate 3, that an appropriate density for Timber Mountain proper is between 2.2 and 2.67 g/cm^3. The direct correspondence of topography and gravity is more emphasized for the southern highlands of Timber Mountain than for the highland on the north, suggesting that the density of the surface rocks in the south is higher. A small highland area in the south part of Timber Mountain centered on 116°30'W., does not have a corresponding gravity anomaly, suggesting that 2.2 g/cm^3 may be close to the density of the rock units making up the highland.

The positive correlation of topographic highs and gravity highs in SW and SC show, as in the Timber Mountain area, that the rocks making up the topographic highs are more dense than 2.2 g per cm^3. It can be observed, however, that the northward bulge of the topographic high in SW does not have a corresponding gravity feature, and so the rock mass underlying the bulge probably has a density of about 2.2 g/cm^3. The result of the correction is to bring out the strongly linear gravity gradient, positive to the south, which extends from the northwest corner of SW to the north-central part of SC.

The foregoing analysis suggests that aside from Timber Mountain and the triangular area of gravity highs to the southwest (Plate 4), the appropriate map for analyzing the relationships between geology and gravity is one reduced with a Bouguer density factor of 2.2 g/cm^3. Timber Mountain, however, is the region of primary interest, so the Bouguer gravity map reduced with a density factor of 2.4 g/cm^3 (Plate 5) is the most appropriate one to use in analyzing the subsurface structure and lithology in that area.

As indicated in an earlier paragraph, the outer boundary between the volcanically induced depression and the surrounding host rock of Paleozoic age is indicated by steep gravity gradients at the southeast and southwest corners of the map (Plate 2). It is not possible to give the precise lateral location of the boundary or to comment on its nature without considerable additional analysis, but it should be within several kilometers (a few miles) of the steepest part of the gradient. The irregularity of the gradient trace in the southeast corner is at least partly caused by terrain correction inaccuracy and superimposed anomalies. The eastern boundary of this gradient lies a few miles east of the edge of the mapped area. The boundary is not indicated to the north, west, or south and must lie outside the mapped area.

A prominent gravity low (Plate 5) extends southwest from the northwest corner of NC to south of the south boundary of NW. The low is bound to the northwest by a broad southwest-trending gradient, which is somewhat distorted by superimposed anomalies. The edge of the source is probably near the northwestern part of the gradient. The east edge of the anomaly is not clearly indicated, but it may be along the steepened gradient that trends southward in NE approximately along 116°20′W. Many smaller anomalies appear to be superimposed on the low, and these probably reflect dense lavas and dense older rocks in structures associated with the formation of the northern moat of Timber Mountain. If this is the case, then the original low encompasses almost all of NW and NC, and the center of the low abuts directly on the high over the north side of Timber Mountain. A gradient along the axis of the low in the central part of WC increases southward, and one along the axis of the low over the common corner of NC, NE, C, and EC increases southeastward. If these are taken to be the remnants of gradients associated with the original low, then Timber Mountain overlies a considerable part of the area which that may have been occupied by the southern extent of the gravity low. The general area of the low has been identified on geologic grounds, supported by ample drill-hole data, as the location of the Silent Canyon caldera, most of which is located north of the northern rim of the Timber Mountain caldera (Orkild and others, 1968). The interpretation given here would place the east and northwest boundaries in a similar position but would locate the position of the south boundary an additional 6 to 10 miles to the south, that is, near 37°00′N. Timber Mountain would be contained almost entirely within the Silent Canyon caldera if it is defined in this way.

If the preceding analyses are correct, it suggests that the Silent Canyon caldera is enclosed within a broader and presumably older volcanic depression which is indicated to east, southeast, and southwest by gradients described previously. The postulated older depression would continue to the south to include the area of Yucca Mountain, which extends southward from the southern part of SC. A possible candidate for the older depression is the Sleeping Butte caldera (Byers and others, 1976), whose only known mapped geologic boundary is located just west of the northwest part of the map.

There is a great degree of similarity between the Bouguer gravity map reduced at 2.4 g/cm^3 (Plate 5) and that reduced at 2.2 g per cm^3 (Plate 4). The main difference is an overall lowering of the Bouguer values by about 15 mgal on the 2.4 g/cm^3 map. This change is not a significant factor in the analysis, since the gravity interpretation deals primarily with relative gravity changes. The most marked difference is the re-emergence of the strong linear trend along the boundary between SC and SE that was noted before on the map reduced at 2.67 g/cm^3 and attributed to an erroneously high Bouguer density factor. The appearance of the anomaly on Plate 5 suggests that a density of 2.4 g per cm^3 is also too high for this region.

Terrain correction effects

Before proceeding with analysis in the Timber Mountain area, it is necessary to review the possible effects of the experimental terrain corrections used in the data reduction. It is generally recognized that the most accurate method of calculating inner zone terrain corrections in areas of rugged topography is the manual one (Kane, 1962). The following comments are based on a comparison of corrections for 317 stations done manually with those done by the experimental method.

For the majority of the terrain corrections, the difference between the two methods is within 1 mGal, which indicates a general geometric accuracy of about the same value. The density factor for an area with well-determined densities should be accurate within 5 percent, so the inaccuracy due to this source is negligible. For the most part then, the inaccuracy is about half that of the contour interval and should not have a noticeable effect on the anomalies as displayed here. In particular, the terrain corrections for Timber Mountain fall within this category of accuracy, as shown by a comparison of the two types of corrections for critical stations. Similar inspection for stations in the Shoshone Mountain area, however, showed that there are discrepancies between the two methods ranging between -3 mGal and +2 mGal for individual stations. Moreover, the errors are distributed so as to create a false anomaly of as much as 5 mgal. From inspection the sharp northwestward bulge in the contours centered at 36°57.5′N. and 116°17.5′W. is caused mostly by terrain correction inaccuracy of the experimental method. The cause of this inaccuracy appears to be very steep topographic slopes in the immediate vicinity of the stations (they were measured on individual peaks), which could not be adequately accounted for in the present version of the experimental computer method.

Bouguer gravity of Timber Mountain and the triangular zone

The most important changes from Plate 4 to Plate 5 for the purposes of this report are those over Timber Mountain. The gravity high (Plate 4) which correlates with the peak area of north Timber Mountain, is not present in Plate 5. There is a slight southward deflection of the contours in the local peak area, which suggests that the density of the surface rocks is locally less than 2.4 g/cm^3. Otherwise, 2.4 g/cm^3 seems to be an appropriate density for the Bouguer correction in the north. In the south a gravity high still correlates with the topography. The peak on the gravity high to the west would probably be eliminated by a density factor of 2.5 or 2.55 g/cm^3, but a broad, low-amplitude high would remain. The peak to the east is broader and is present even on the map reduced at 2.67 g/cm^3. The conclusion is that a mass more dense than 2.4 g/cm^3 (the average density of the rocks of Timber Mountain) must underlie the east peak and probably the west peak. It seems especially noteworthy that the mapped porphyritic microgranite crops out along the east edge of the eastern gravity high. Carr (1977) notes that the measured specific gravity of the microgranite is 2.4 g/cm^3 and attributes this low value to microporosity. If the microgranite is the cause of the gravity high, its density must increase in the subsurface in order for it to cause an anomaly. The lateral extent of the proposed subsurface body is not clearly indicated, but it is probably a few square kilometers (a couple square miles) if it only underlies the eastern region and perhaps twice that if it underlies the western area as well.

There is about a 10-mGal difference between the gravity field over the south moat and that over Timber Mountain. This anomaly would correspond to a minimum thickness ranging from about 750 m (about 2500 ft) to about 1200 m (about 4000 ft), for a density contrast range of 0.3 to 0.2 g/cm^3. A gravity difference of about 20 mGal exists between the exposed rocks of Paleozoic age in the southernmost part of SE and Timber Mountain. If the relative low over Timber Mountain is caused entirely by altered Timber Mountain Tuff with an average density of 2.5 g/cm^3, then the gravity difference suggests that the altered tuff extends to a depth of from 1500 m-2500 m (about 5000-8000 ft); this model assumes that a rock of about the same density as the rock of Paleozoic age forms the base on which the tuff rests. The model also indicates that a significant thickness of rock of low density (presumably an older tuff) cannot exist below the Timber Mountain Tuff unless the Timber Mountain Tuff is thinned by an appropriate amount or unless an equal thickness of rock of the same density underlies the rocks of Paleozoic age to the southeast.

If an intrusion of average granite composition (2.60 g/cm^3) is present beneath Timber Mountain, then it must penetrate the pile of Timber Mountain indicated in the previous paragraph, because its low density relative to rocks of Paleozoic age would cause an additional negative anomaly. The combined intrusion-volcanic pile could range from about 5 km (16,000 ft) in thickness if almost completely an intrusive mass, to about 2.5 km (8000 ft), if almost completely a moderately altered tuff (assuming the host rock of Paleozoic age has an average density of about 2.7 g/cm^3).

The gravity anomaly over Timber Mountain has an angular outline caused by relatively steep linear gradients (shown by dashed lines) which exist on all sides. The steep gradients mark the approximate location of the major density contrast between the domed Timber Mountain Tuff and the surrounding moat rocks. The linearity and position of the gradients offer two additional insights on the shape of the mass causing the Timber Mountain gravity high. The linearity of the gradients show that the resurgence of the dome has been accommodated along straight line segments, which must be linear faults. Thus the gravity evidence attests, like the aeromagnetic evidence, that the deformation accompanying the volcanic events in the Timber Mountain region has generally taken place along a linear fault system. The dominant directions are north, northeast, and west of northwest.

The location of the gradients outside of the half-amplitude trace of the anomaly shows that more than half the anomalous mass must lie centerward from the gradients. For a single-density source this mass distribution would require that the walls of the mass dip inward. A two-density structure such as that given by a high density igneous mass penetrating a lower density volcanic pile, would be an alternate model.

The triangular area of high gravity south of the south moat of Timber Mountain has about the same gravity level as Timber Mountain. Similarly, the gravity values over the south moat of Timber Mountain are about the same level as those in the broad low that lies to the south of the triangular area of high gravity. The gravity high in the west part of the triangular area coincides with a broad exposure of the Crater Flat Tuff and intercalated lava flows; a more local high occurs near a smaller exposure of the same volcanic unit along the boundary between SW and SC just south of 36°55′N. This volcanic unit is associated with the Sleeping Butte caldera, the oldest volcanic structure known in the complex. The eastern gravity high in the triangular area, which reaches approximately the same level as the one to the west, is underlain by units of the younger Paintbrush Tuff that are associated with the Claim Canyon caldera; another caldera, the Silent Canyon, was formed between the times of formation of the Claim Canyon and the Sleeping Butte calderas. Presumably, considerable thicknesses of younger low-density volcanic rocks associated with these calderas should cause a much lower gravity field in the area of the eastern high.

The significance of the comparability of the gravity over areas underlain by substantially different geologic units is not clearly understood. The angular nature of the triangular area indicates that its source is horst-like, probably with a steeper boundary on the north than on the southeast. The gravity level over the western part could be explained if the underlying volcanic units are relatively dense like those of Timber Mountain, or if a triangular wedge of the Paleozoic basement has been lifted up relative to the areas to the north and south. In either case the volcanic units of the Claim Canyon and Silent Canyon calderas must be either very thin or altered into rocks as dense as those of Timber Mountain. A possibility, perhaps unlikely, is that both groups of volcanic rocks are remnants of their associated caldera domes. The general appearance of the gravity low to the south of the triangular zone suggests that it is caused by volcanic tuffs of low density, probably 2.2 g/cm^3. If this density is correct the thickness would be more than 1500 m (more than 5000 ft) relative to the Paleozoic rocks but probably not more than 2500 m (about 8000 ft). The volcanic units could be those of either the Claim Canyon caldera (Paintbrush Tuff) or the Silent Canyon caldera. The close association of the gravity high in the western part of the triangular zone with the known rocks of the Sleeping Butte caldera suggests that these units are not the cause of the gravity low unless these rocks in the area of the gravity high were part of the dome of the caldera.

Summary and Discussion

The new aeromagnetic survey and the additional new gravity stations in the Timber Mountain area have brought to light several new aspects of the subsurface geology of the region. First and most clearly demonstrated is that the structural accommodation to the volcanic forces in the region has taken place along a system of linear faults. The clearest evidence is the gravity and magnetic data for the region surrounding Timber Mountain and the gravity data for Timber Mountain itself. The aeromagnetic data has, in addition, shown that the magnetism of the rocks of the central graben and of the southeastern margin of Timber Mountain is different from that of the remainder of the area. A likely explanation is that the magnetic properties have been altered by a heating event probably caused by intrusive activity along the southeast margin and by hydrothermal alteration in the central graben. An alternate explanation for the central graben is that the rock units of that area have been dropped closer to and heated by an igneous source. The source would have to be close enough to raise the temperature of the rock above the Curie point.

The most important conclusion for the purposes of this report is that the intrusive rock mapped along the southeast margin probably extends in the shallow (less than 2000 ft ?) subsurface a couple of miles to the west and possibly underlies much of the southern part of Timber Mountain. The evidence strongly suggests that the rock units underlying the southern part of Timber Mountain are denser than those to the north. The nature of the density change--that is, whether it is intrusive rock or a densification of volcanic rock units--cannot be unequivocally determined. Further geophysical work, probably geoelectrical surveys and ultimately drilling, would be needed to fully resolve this question.

There is suggestive evidence of caldera outlines somewhat different from those revealed by surface geologic evidence. The most strongly indicated and most significant of these outlines represents a substantial southward extension of the Silent Canyon caldera. The results indicate that the northern part of the Timber Mountain caldera now overlies the southernmost part of the older caldera. Otherwise it is difficult to explain the north- and northwest-dipping gravity gradients in the moats on the west and northeast sides, respectively, of Timber Mountain.

The west and south boundaries of the Timber Mountain moat are clearly indicated by the aeromagnetic and gravity data. The northwest and southeast sides are indicated in the magnetic data; the lack of correlative gravity expression suggests that these boundaries cross areas underlain by substantial thicknesses of older, low-density volcanic units, which prevent the development of horizontal density contrasts at shallow depth. The eastern moat area is least clearly indicated. Gravity and magnetic evidence is obscured by the anomalies caused by mafic volcanics at the east edge of Timber Mountain. The eastern moat area may be a triangular zone with its eastern apex blunted against what may be the wall of an older caldera.

The gravity and aeromagnetic anomalies in the triangular area southwest of Timber Mountain are the most clearly defined and probably the least understood. The geology-gravity correlations suggest that the volcanic units of the Sleeping Butte caldera shown in the triangular area are confined at that level to an uplifted horst and that they do not extend uninterruptedly southward as interpreted from the surface geology (Byers and others, 1976, cross section A-A′).

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PLATE 1

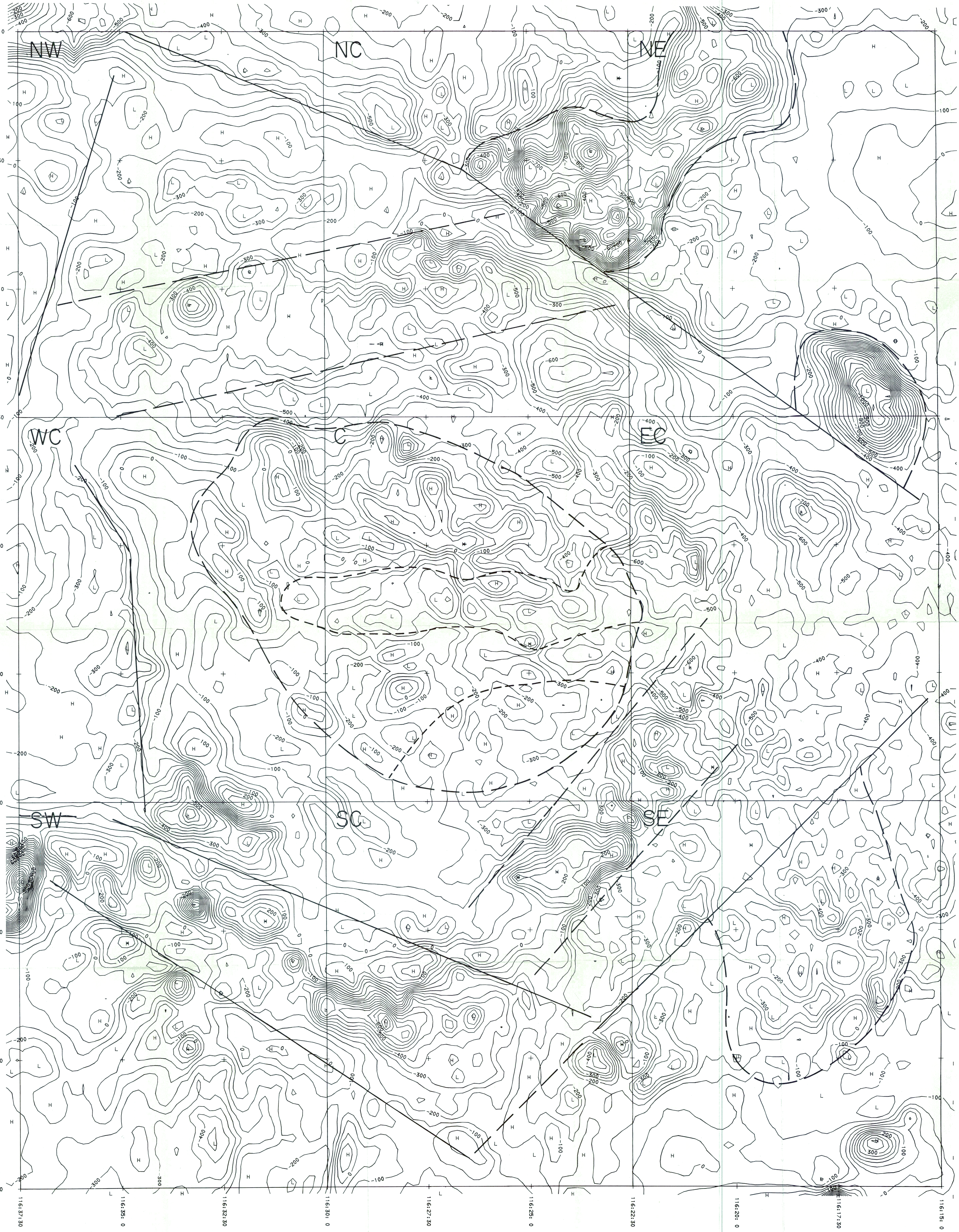

PLATE 1 - AEROMAGNETIC MAP OF THE TIMBER MOUNTAIN REGION

SCALE 1:48,000

EXPLANATION

Calculated with a constant terrain clearance of about 250 m (800 feet). Flight lines are oriented east-west at about 400 m (1/4 mile) spacing. Superimposed lines indicate boundaries of areas of distinctive magnetic pattern (discussed in text); dashed where irregular or less certain. Contour interval is 50 gammas; H = high, L = low.

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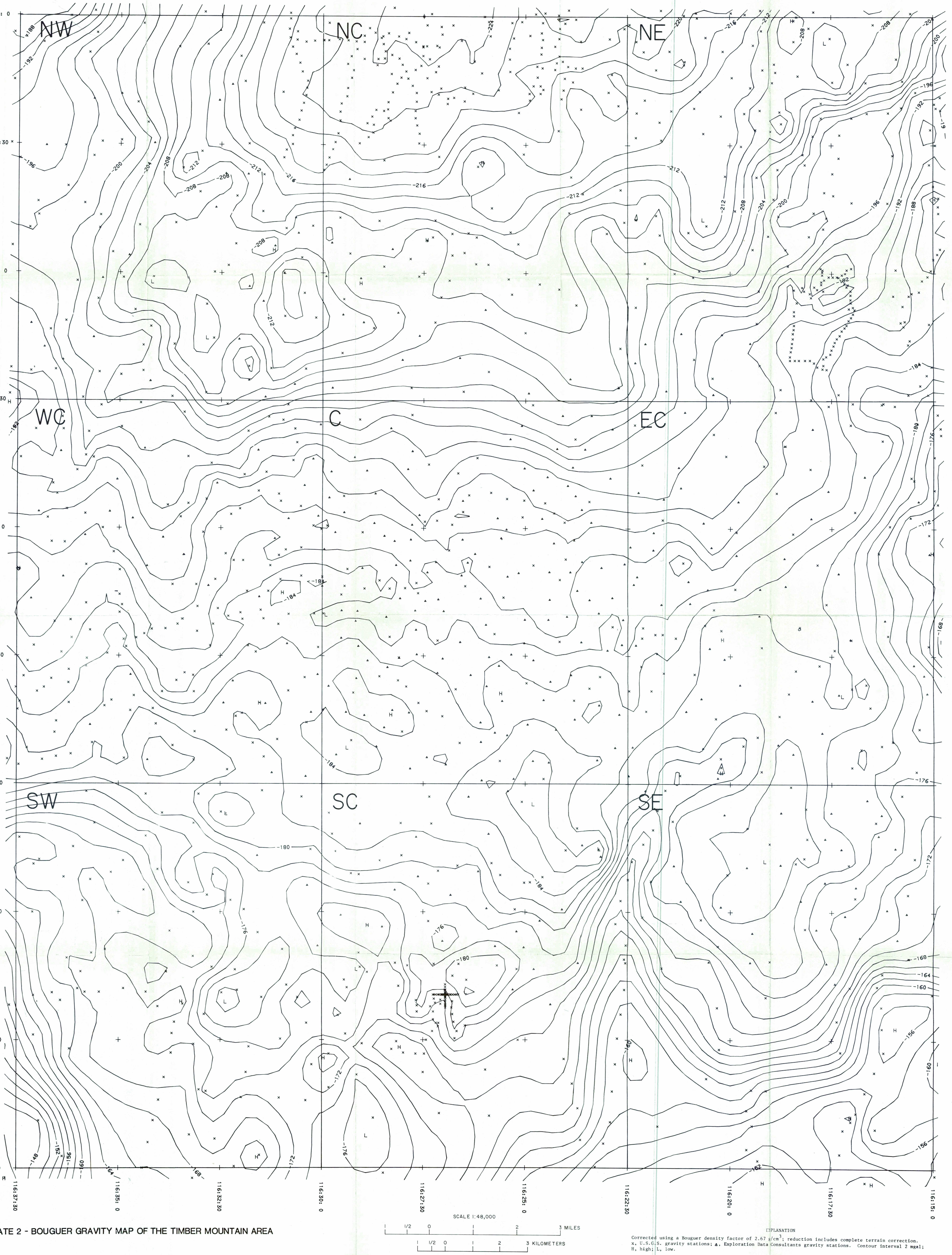
PLATE 2



SCALE 1:48,000

1 1/2 0 1 2 3 MILES

1 1/2 0 1 2 3 KILOMETERS

PLATE 2 - BOUGUER GRAVITY MAP OF THE TIMBER MOUNTAIN AREA

EXPLANATION

Corrected using a Bouguer density factor of 2.67 g/cm^3; reduction includes complete terrain correction. x, U.S.G.S. gravity stations; ▲, Exploration Data Consultants gravity stations. Contour interval 2 mgal; H, high; L, low.

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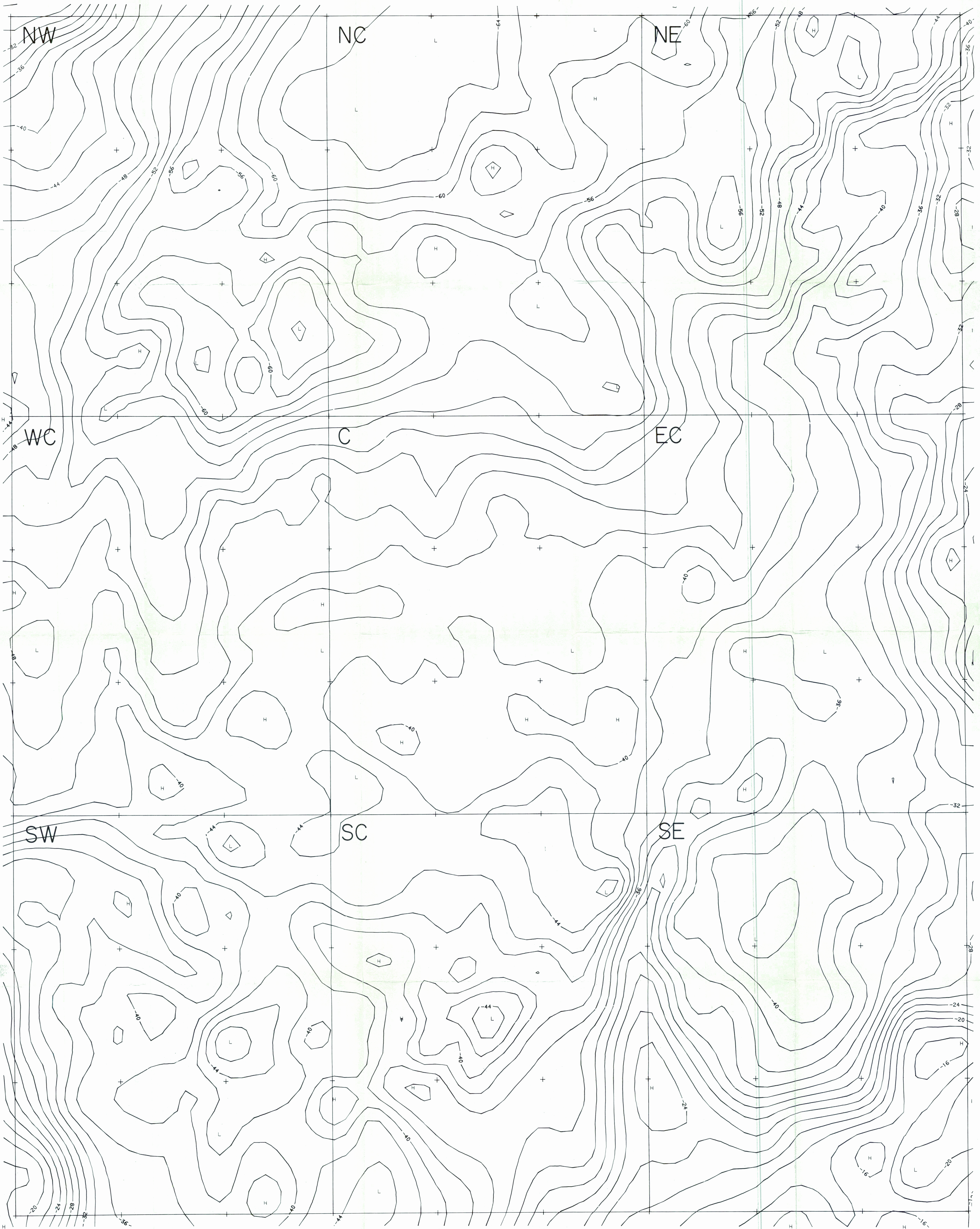
PLATE 3



SCALE 1:48,000
1 1/2 0 1 2 3 MILES
1 1/2 0 1 2 3 KILOMETERS

PLATE 3 - BOUGUER GRAVITY MAP OF THE TIMBER MOUNTAIN AREA

EXPLANATION

Reduced for a density factor of 2.67 g/cm^3 and corrected for isostasy-topography effect.
Contour interval 2 mgal; H, high; L, low.

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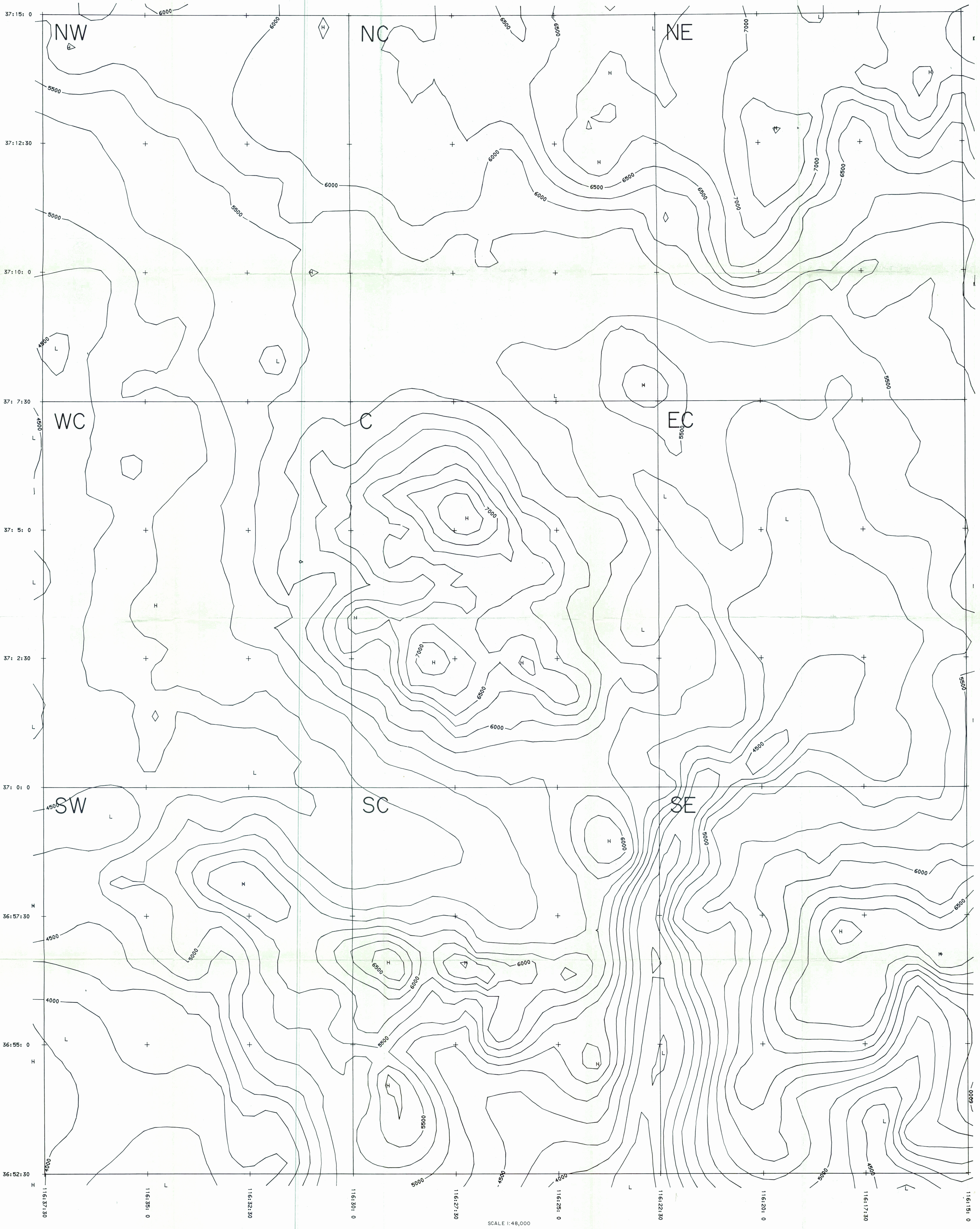
PLATE 6



SCALE 1:48,000

1 1/2 0 1 2 3 MILES

1 1/2 0 1 2 3 KILOMETERS

PLATE 6 - GRAVITY STATION ELEVATION CONTOUR MAP OF THE TIMBER MOUNTAIN AREA

EXPLANATION

Based only on elevations of the gravity stations shown on Plate 2. Contour interval 250 feet (~75 m); H, high; L, low.

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PLATE 5

SCALE 1:48,000
1 1/2 0 1 2 3 MILES
1 1/2 0 1 2 3 KILOMETERS

PLATE 5 - BOUGUER GRAVITY MAP OF THE TIMBER MOUNTAIN AREA

EXPLANATION

Reduced for a density of 2.4 g/cm^3, the average density of the volcanic units of Timber Mountain, and corrected for isostasy-topography effect. Superimposed lines show subsurface boundaries of Timber Mountain indicated by linear gravity gradients; dashed where less certain. Contour interval 2 mgal; H, high; L, low.

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PLATE 4

PLATE 4 - BOUGUER GRAVITY MAP OF THE TIMBER MOUNTAIN AREA

SCALE 1:48,000

1 1/2 0 1 2 3 MILES

1 1/2 0 1 2 3 KILOMETERS

EXPLANATION

Reduced for a density of 2.2 g/cm^3, the average density of volcanic rock units other than those of Timber Mountain, and corrected for isostasy-topography effect. Contour interval 2 mgal; H, high; L, low.