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AN ANALYSIS OF GRAVITY DATA IN AREA 12, NEVADA TEST SITE

By Ronald R. Wahl

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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ILLUSTRATIONS

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ABSTRACT

The gravity data available from Healey and Miller (1963a) were augmented by new observations along three profiles through two new drill holes in Area 12; UE12t #1 and UE12p #1. The data were interpreted to allow evaluation of the geologic structure prior to the planning and excavation of two proposed tunnel complexes, U12t and U12p.

Density values for each of six rock units were determined to allow a two-dimensional analysis of the gravity data along the above-mentioned profiles. The surficial rocks of Quaternary and Tertiary age and the Tertiary volcanic rocks have a weighted average density of 1.86 gm/cc. The density of the caprock at Rainier and Aqueduct Mesas ranges from 2.17 gm/cc at UE12p #1 to 2.27 gm/cc at UE12t #1. The Gold Meadows stock and the associated Precambrian quartzite have an arithmetic average density of 2.60 gm/cc for all samples measured. The middle Paleozoic dolomite in Area 12 has an arithmetic average density of 2.75 gm/cc. The clastic rocks of Paleozoic age have an arithmetic average density of 2.60 gm/cc.

Interpretation of the residual gravity data indicates a maximum thickness of about 2,800 feet for all Tertiary volcanic rocks.

A normal fault striking N. 30° E. disrupts the pre-Cenozoic surface at UE12p #1 and 0.4 mile east of UE12t #1. The throw within rock of Paleozoic age is about 400-500 feet. Another normal fault that strikes about N. 20° E. is located about 1.5 miles east of UE12p #1. The throw of this fault is at least 1,100 feet in rocks of pre-Cenozoic age.

Elevation contours representing the pre-Cenozoic surface in Area 12 show a maximum relief of about 2,000 feet.

INTRODUCTION

In the summer of 1967 Defense Atomic Support Agency of the Department of Defense asked the U.S. Geological Survey to interpret the geologic structure in Area 12 and vicinity (fig. 1) of the Nevada Test Site, as an aid in the evaluation and planning of two tunnel complexes, U12p and U12t. The interpretation of the geologic structure presented in this report is based largely on the interpretation of geophysical data (primarily gravity observations) as the interpretation is constrained by existing geologic information. The geophysical interpretations were made along profiles close to two recently completed drill holes, UE12p #1 and UE12t #1. Elevations on the pre-Cenozoic surface from these profiles, plus other available data, were used to draw a map of elevation contours representing the pre-Cenozoic surface as it is now preserved in Area 12. Both the profiles and the contour map are provided to the reader as aids in the interpretation of the geologic structure.

The surface geology of Area 12 has been mapped by Gibbons and others (1963), Barnes, Houser and Poole (1963), Sargent and others (1966), and Rogers and Noble (in press). Subsurface data have been obtained from 11 drill holes that penetrate the pre-Cenozoic surface. These data include rock densities from core samples and elevations of the tops of the rock formations penetrated by the drill holes. Among these holes are UE12p #1 and UE12t #1.

Geophysical data consist primarily of more than 10,000 gravity observations made by the U.S. Geological Survey in and around the Nevada Test Site since 1958 (Healey and Miller, 1963a). Additional

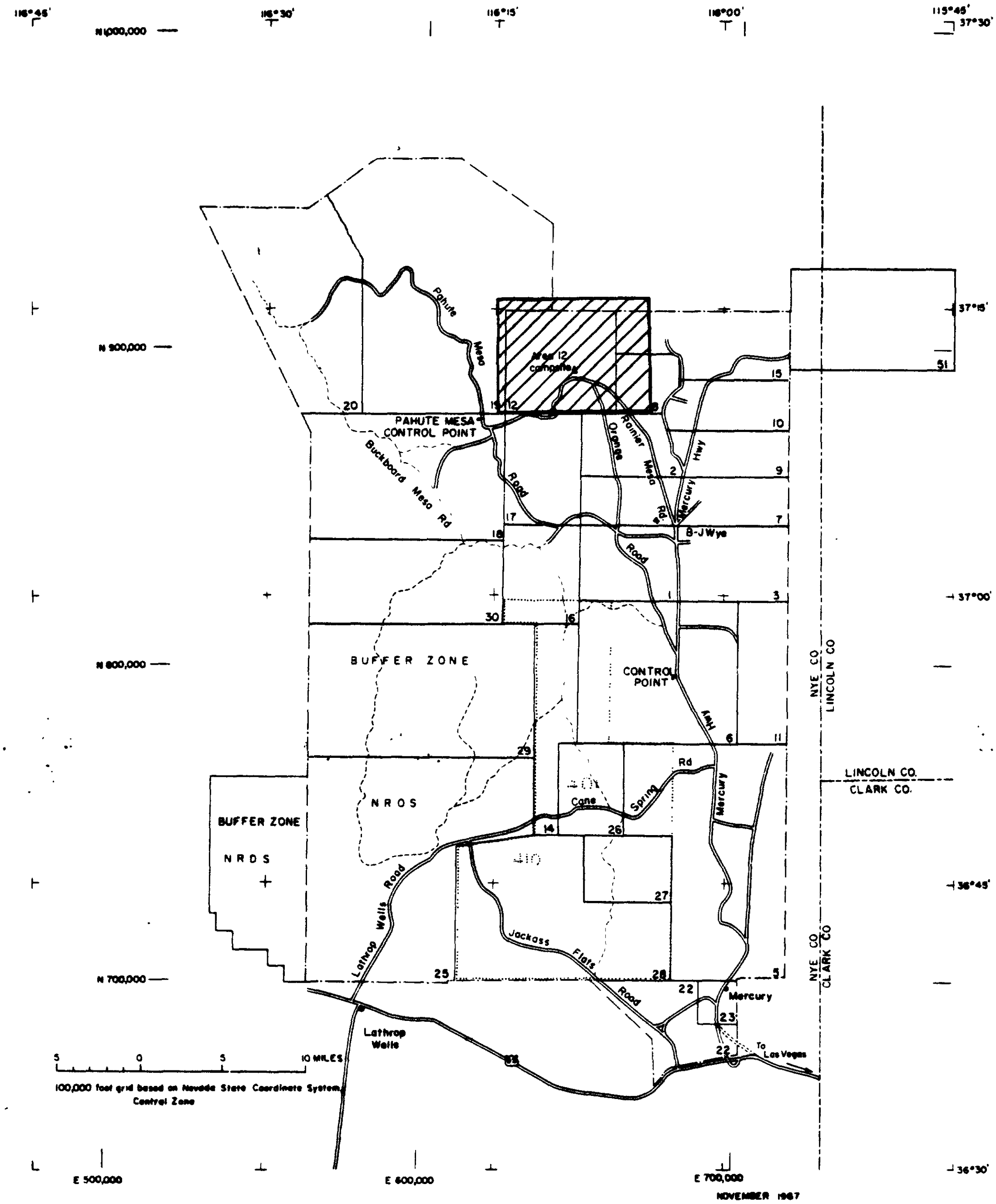

Figure 1.--Index map of the Nevada Test Site showing area of this report.

gravity observations were made along the interpretation profiles in the spring and summer of 1967. Aeromagnetic data are from Boynton, and others (1963).

GEOLOGY OF AREA 12

The geology of Area 12, the northwestern part of the Yucca Flat area, has been outlined by Barnes, Hinrichs, and others (1963). The following descriptions of lithology, structural features, and geologic history of Area 12 have been compiled primarily from that report.

Rock Units

The rocks of Area 12, as shown in figure 2, are grouped into six units for use in the two-dimensional analysis of the gravity data.

QTs: Quaternary and Tertiary surficial deposits

This unit is composed of unconsolidated to poorly consolidated alluvial and colluvial deposits. Landslides are found locally. The deposits form a veneer less than 100 feet thick along the interpretation profiles.

Tvw: Tertiary welded tuff caprock of Rainier and Aqueduct Mesas

This unit, largely the Timber Mountain Tuff, is composed of moderately to densely welded tuff with a maximum thickness of about 550 feet. Locally the Timber Mountain Tuff includes minor amounts of nonwelded bedded tuff, which, for this report, is not included in the unit Tvw.

Tv: Tertiary volcanic rocks exclusive of welded tuff caprock, Tvw

This unit is composed of a thick sequence of volcanic rocks which underlie the mesa caprock (Tvw). These rocks include the Paintbrush and Indian Trail Formations and older units. The varied lithology is chiefly nonwelded bedded tuff and tuffaceous sediments, largely zeolitized in the lower part; it also includes lenses of welded tuff and rhyolite.

Mzqm: Mesozoic quartz monzonite with associated Precambrian quartzite

This unit is made up primarily of the quartz monzonite of the Gold Meadows stock with large inclusions of quartzite from the Wood Canyon Formation.

Pzc: Late Paleozoic clastic rocks, chiefly quartzite and argillite

This unit is largely the Devonian and Mississippian Eleana Formation, which includes minor amounts of conglomerate and limestone. However, small outcrops of limestone of Ordovician age (Pogonip Group) are included.

Pzd: Middle Paleozoic dolomite and dolomitic limestone

This unit includes the rocks shown as DSOl, Dda, Ddb, and Ddc on the geologic quadrangle map (Gibbons, and others, 1963); the age ranges from Ordovician to Devonian.

Major Structural Features

The major folds and faults in the area of figure 2 trend north-northeast. The more important structural features include:

1. The south-southwest plunging anticline formed by the late Paleozoic clastic rocks (Pzc) of Quartzite Ridge just east of Area 12.

2. To the west of Quartzite Ridge, a north-northeastward trending asymmetric syncline locally overturned to the southeast. The Eleana Range and other exposures of late Paleozoic clastic rocks east and northeast of the Area 12 camp (fig. 2) form part of the northwest limb of this syncline.

3. To the west of the Eleana Range is a reverse fault identified as probably part of the Mine Mountain thrust by Barnes, Hinrichs, and others (1963). This fault strikes N. 30° E. in the southern part of Area 12 but almost due north, north of Area 12 camp. Middle Paleozoic dolomite (Pzd) has been brought into contact with late Paleozoic clastic rocks by this fault.

4. To the west of the Mine Mountain reverse fault, and beneath the Tertiary volcanic rocks of Rainier and Aqueduct Mesas, an inferred north-eastward-trending reverse fault (fig. 2) is believed to bring Precambrian quartzite (later intruded by the quartz monzonite of the Gold Meadows stock, Mzqm) into contact with middle Paleozoic dolomite (Pzd). Harley Barnes (oral commun., 1967) believes that this buried fault is part of the root of the CP thrust fault. The presence of this fault in Area 12 is suggested primarily by drill-hole information presented by Gibbons and others (1963). The Hagestad drill hole, south of Gold Meadows stock (fig. 2), penetrated the pre-Cenozoic rock surface at an altitude of

5,589 feet and bottomed in a quartzite that was thought at the time to be the Precambrian Johnnie Formation, but is now thought to be part of the Wood Canyon Formation or the Stirling Quartzite. The Exploratory #1 drill hole (fig. 2) penetrated the pre-Cenozoic surface at an altitude of 3,670 feet, then a thin wedge of quartz monzonite, and bottomed in quartzite like that in the Hagestad drill hole.

The outcropping of Precambrian quartzite around the Gold Meadows stock fits the concept of a buried thrust fault because the quartzite dips westward into the stock and the altitude of the quartzite (Mzqm) surface is even higher than the surface of the middle Paleozoic dolomite (Pzd), which crops out southeast of Rainier Mesa. These dolomites also dip to the west and extend beneath the Tertiary volcanic rocks of Rainier and Aqueduct Mesas at least as far as drill holes U12e.06a, U12e.06b, U12b.07-2, UE12t #1, and UE12p #1 (fig. 2).

Geologic History

In Area 12, late Paleozoic rocks have been deformed into fairly broad northeast-trending asymmetric folds locally overturned toward the southeast. According to Harley Barnes (written commun., 1968), "Northeast-trending reverse faults in Area 12 are the roots of southeastward-directed thrust faults that developed during the folding of the Paleozoic rocks. As a result, Precambrian quartzite rests on middle Paleozoic dolomite that rests in turn on late Paleozoic clastic rocks. These thrust faults are believed to have developed at considerable depth and were themselves folded and cut by southeast-trending crossfaults."

In Jurassic or Cretaceous time, the Gold Meadows stock intruded the Precambrian quartzite, possibly along the CP thrust. The widespread deep erosion that followed removed much of the upper plates of the thrust faults and left only the roots of these thrusts exposed as high-angle reverse faults.

According to Harley Barnes (written commun., 1968), the Tertiary period was marked by extreme volcanic activity, faulting, and intermittent erosion. The eroded surface of the pre-Cenozoic rocks was buried beneath thick deposits of volcanic rocks and cut by northeast and northwest-trending faults. More than once during the period the flows and pyroclastic deposits of the Rainier Mesa area were deeply dissected by erosion. Late in the Tertiary period, the rocks were cut by a north-trending set of high-angle faults.

Density of the Rock Units

1. QTs: The surficial deposits are close to the Tertiary volcanic rocks (Tv) in density and are grouped with them for interpretive purposes.

2. Tvw: The welded tuff caprock has a higher density than the Tertiary volcanic rocks (Tv). The density of the caprock as determined from core samples is 2.17 gm/cc in UE12p #1 and 2.27 gm/cc in UE12t #1 (Walter Danilchik, written commun., 1967).

3. Tv: The Tertiary volcanic rocks have densities that range from 1.50 to 2.40 gm/cc as obtained from the cores of UE12p #1 and UE12t #1. The weighted average density from each of these cores is 1.86 gm/cc.

4. Mzqm: The density values for the quartz monzonite of the Gold Meadows stock range from 2.45 to 2.74 gm/cc with an average value of 2.62 gm/cc (Healey and Miller, 1963a). Density values that range from 2.65 to 2.68 gm/cc were computed from the mineral composition and the average density values for each mineral. The stock appears to be much fractured in the vicinity of U12s; and alteration of the quartz monzonite along these fractures would have a tendency to lower the density of this body.

Few density values are available for the Precambrian quartzite in this area. The available values range from 2.51 to 2.63 gm/cc. The arithmetic average of these values, 2.60 gm/cc, is used in this report for this unit.

5. Pzc: Density values of this rock unit, based on four samples of argillite and siltstone, range from 2.58 to 2.65 gm/cc (Carr and others, 1967). Carr and others (1967) also cite one sample with a density of 2.30 gm/cc. Healey and Miller (1963a), however, assumed a value of 2.62 gm/cc on the basis of density data available at that time. The arithmetic average of all samples evaluated give a value of 2.60 gm/cc.

6. Pzd: Published density logs and other physical property data from Carr and others (1967) and unpublished density logs and other physical property data indicate a wide variation in density for the middle Paleozoic dolomite. Density log values range from 2.69 to 2.85 gm/cc. Computation of the density from the physical property data gives values that range from 2.72 to 2.82 gm/cc.

Density values for core samples from holes in the area vary widely. Core samples from U12b.07-2 give values that range from 2.54 to 2.76 gm/cc with a weighted value of 2.71 gm/cc. Core samples from UE12t #1, which penetrated 40 feet into the dolomite, give a weighted average value of 2.79 gm/cc. Three samples from UE12p #1, which penetrated the upper 20 feet of the dolomite, give an average value of 2.71 gm/cc.

The density chosen for this interpretation is 2.75 gm/cc, which is very close to the average of all the data for this unit (Pzd).

GEOPHYSICAL DATA

The gravity data obtained in Area 12 have been reduced by methods described by Heiskanen and Vening-Meinesz (1958) to complete Bouguer gravity values. Simple Bouguer gravity values were obtained using an elevation factor of 0.06 mgal/ft. Terrain corrections were applied through Hammer zone "L" (Hammer, 1939). These complete Bouguer values were contoured at a 2-mgal interval on a map at a scale of 1:24,000. Along with the generalized geology of the area these contours are shown on figure 2.

The aeromagnetic map of Boynton and others (1963) was subjected to a very preliminary interpretation by G. D. Bath (oral commun., 1967). His interpretation helped to locate the eastern edge of the Gold Meadows stock.

Bouguer Gravity Map

Bouguer gravity decreases generally across the area from southeast to northwest. In the vicinity of gravity station 4-28 in the southeastern part of figure 2, the gravity gradient is close to 0 mgal/mile. At the eastern edge of the mesas, gravity decreases across a gradient of 37 mgal/mile. On top of Aqueduct Mesa the gravity gradient becomes -21 mgal/mile to the northwest. One mile southeast of station 5-137 gravity starts to increase to the northwest across a gradient of 20 mgal/mile, and then west of station 5-137 gravity decreases across a gradient of 25 mgal/mile.

The high average value of the gravity gradient over the mesas and over the area to the northwest has two probable causes: (1) the effect of the large volume of low-density volcanic rocks which underlie the mesas; and (2) the close proximity of Rainier and Aqueduct Mesas to the Silent Canyon caldera which, in turn, probably produces a very large gravity low (D. L. Healey, oral commun., 1967).

Three of the four closed gravity highs are associated with pre-Cenozoic rock outcrops. One of these highs is associated with the Gold Meadows stock, another with the outcrop of Pzd 1.5 miles west-southwest of the Area 12 camp, and a third with Quartzite Ridge, whose center is about 1 mile south of station 4-38. The fourth closed gravity high is centered less than 0.1 mile southeast of UE12p #1, but it has no apparent surface geologic association.

A long northeast-trending gravity high open to the southwest is associated with the Eleana Range and extends northeast toward Quartzite Ridge.

The only closed gravity low in the area is northwest of Gold Meadows stock and is centered 1.2 miles west-northwest of station 5-137. It is associated with a small mesa of Tertiary volcanic rocks preserved from erosion by welded tuff caprock.

Interpretation of Geophysical Data along Profiles A-A', B-B', and C-C'

A two-dimensional interpretive technique was used in studying the gravity data to determine pre-Cenozoic surface along profiles A-A', B-B', and C-C' (fig. 2). This technique uses a mechanical integrator as first developed by Gamburzeff (1929) and modified by D. L. Peterson, Geophysicist, U.S. Geological Survey (oral commun., 1965). The basic assumption, as in all two-dimensional interpretive methods, is the indefinite extent of the rock units involved in a direction normal to the profile. The density contrasts, with Pz c as a reference, are shown in figures 3a, 3b, and 3c.

In choosing the models for interpretation several additional assumptions were made:

1. That the thickness and density of the welded tuff caprock are known so that its gravity anomaly can be computed and removed from each observed data curve. The thickness data were provided by Walter Danilchik (written commun., 1967) from a study of drill-hole cores and logs.

2. That the rock units Pz c and Mz qm can be grouped together for interpretive purposes because the average density of each is close to 2.60 gm/cc.

3. That the eastern edge of the Gold Meadows stock has the approximate configuration shown on figures 3a, 3b, 3c and 4 (G. D. Bath, written commun., 1967 and Boynton and others, 1963).

4. That a block of dolomite, Pzd, of the approximate configuration shown on figures 3a, 3b, and 3c is also present under Aqueduct Mesa as well as under Rainier Mesa (Gibbons and others, 1963). The assumption is probably justified because:

a. Both drill holes, UE12p #1 and UE12t #1, penetrated dolomite beneath the Tertiary volcanic rocks (Tv) of Aqueduct Mesa. These drill holes are in the northward projection of the upper plate of the Mine Mountain thrust which, in this area, is composed of middle Paleozoic dolomite (Pzd) that is exposed west of the Eleana Range and dips westward under Rainier Mesa.

b. South of Area 12 the eastern contact of the dolomite (Pzd) with the clastic rocks (Pzc) is a thrust fault that changes to a high-angle reverse fault in its northern exposures (Gibbons and others, 1963). This fault is thought to be part of the Mine Mountain thrust (Barnes and others, 1963).

c. The western boundary of the Paleozoic dolomite (Pzd) is probably formed by the Gold Meadows stock and its associated Precambrian quartzite (Mzqn). The Precambrian quartzite is believed to be thrust onto the dolomite (Pzd) (Gibbons and others, 1963). Barnes (oral commun., 1967) suggests that this fault is the CP thrust fault and that the faulting occurred before the quartzite and dolomite were intruded by the Gold Meadows stock.

d. The configuration of the pre-Cenozoic surface, as determined from the interpretation of the gravity data along profiles A-A', B-B', and C-C' using a single density contrast between the Cenozoic and pre-Cenozoic rocks, is unrealistic.

For example, in figure 3a, the dashed line represents the pre-Cenozoic surface utilizing the assumption of paragraph d (above) and the attitude of the pre-Cenozoic surface from UE12t #1. Elevation differences ranging from 600 to 1,800 feet along high-angle faults close to UE12t #1 are necessary to explain the residual gravity anomaly along profile A-A'.

The next step in the interpretive procedure, after assumption of the basic configuration of the model, was the computation and removal of the effect of Pzd and Tvw from the observed Bouguer gravity values.

Next, regional gravity values, computed by a method of moving averages, were applied to the data corrected for the effect of Pzd and Tvw along profiles A-A' and B-B' to produce the residual anomaly curves shown in figures 3a and 3b. The regional gradient for profile C-C' was computed from the residual gravity value on profile B-B' at the point of intersection with profile C-C' (fig. 2).

The final determination of the pre-Cenozoic surface required, at most, two computations at each computation point. First, the effect of the Tertiary volcanic rocks was computed. Then, if necessary, the effect of Pzd was recomputed. With just a few trial-and-error adjustments at each computation point, the pre-Cenozoic surface for each profile was determined (figs. 3a, 3b, and 3c). The density contrasts, with Pzc as a reference, are shown in figures 3a, 3b and 3c.

Profile A-A'

This profile trends N. 64° W. (fig. 2) from an outcrop of Pz east of gravity station 4-28 across Aqueduct Mesa and Gold Meadows stock through gravity station 5-137. From gravity station 4-28 to a point 1.4 miles east of UE12t #1 Bouguer gravity values are fairly constant. But from 1.4 miles east of UE12t #1 to 0.8 mile west of the drill-hole site gravity decreases across a gradient of 9.3 mgal/mile--from about -156 mgal to about -182 mgal. Gravity then increases to the northwest across a gradient of 7.4 mgal/mile to about -17 mgal. The maximum residual anomaly along A-A' is -16.4 mgal (fig. 3a).

The interpretation shows that the pre-Cenozoic surface dips gently to the east from the outcrop of the surface 1,600 feet east of station 5-137 to about the vicinity of UE12t #1. A maximum thickness of 2,200 feet for the Tertiary volcanic rocks is measured in the vicinity of UE12t #1 (Tv plus Tvw). A normal fault that may or may not extend to the surface cuts the pre-Cenozoic surface 1,200 feet east of UE12t #1. The apparent throw within pre-Cenozoic rocks is about 500 feet. This amount of displacement of the pre-Cenozoic surface is necessary to obtain a computed residual gravity curve that fits the observed curve. However, this fault may be the fault with a displacement of 75-100 feet (Barnes, oral commun., 1967) that cuts the caprock (Tvw) 0.07 mile southeast of UE12t #1 on A-A'. Farther east the pre-Cenozoic surface dips very gently to the west until it crops out about 1.7 miles east of UE12t #1.

Profile B-B'

This profile (fig. 2) trends N. 75° E. starting about 1.6 miles west of station 5-137, crosses profile A-A' at station 5-137, then diagonally crosses Aqueduct Mesa and Burnt Mountain to a point 0.2 mile east of station 4-38. From station 4-38, for about 1.2 miles westward, gravity decreases from about -163 mgal to -174 mgal. In the next 4,000 feet, gravity decreases from -174 mgal to -176 mgal, and beyond this point to 0.7 mile west of UE12p #1, gravity ranges to -179 mgal with variations of ±1.5 mgal in the vicinity of UE12p #1. Gravity then decreases to its minimum value at a point 1.2 miles east of station 5-137. In the next 1,000 feet to the west the gravity increases to -178 mgal. At station 5-137 gravity has increased to -174 mgal. The maximum residual anomaly along B-B' is -16.5 mgal.

The interpretation shows that, except for one notable depression, the pre-Cenozoic surface dips gently to the east for about 2.5 miles, from its western outcrop 0.6 mile east of station 5-137 to about 0.1 mile east of UE12p #1. The 2,800-foot maximum thickness of Tertiary volcanic rocks along B-B' is found in this depression in the pre-Cenozoic surface. The depression in the pre-Cenozoic rocks might be a graben or a valley.

About 400 feet west of UE12p #1 a normal fault cuts the pre-Cenozoic surface (fig. 3b). The apparent throw is about 400 feet. This fault is believed to be the same one that is seen in profile A-A'.

From the vicinity of UE12p #1 northeastward to a point 1.2 miles west of station 4-38, the pre-Cenozoic surface dips gently to the west. But, 1.2 miles west of station 4-38 the pre-Cenozoic surface is displaced by a normal fault. The apparent throw cannot be measured but is at least 1,100 feet. Just west of the fault the Tertiary volcanic rocks are about 1,400 feet thick.

Profile C-C'

This profile trends N. 20° W. (fig. 2) from a point about 600 feet south of station 4-213, crosses Aqueduct Mesa close to the U12p adit, intersects profile B-B' just east of UE12p #1, and ends about 1.3 miles northwest of UE12p #1. Gravity decreases rather uniformly to the northwest from -158 mgal 0.6 mile north of station 4-213 to -189 mgal at the end of the profile 1.3 miles north of UE12p #1. There are no residual gravity minima associated with this profile (fig. 3c).

The interpretation (fig. 3c) shows that the pre-Cenozoic surface dips gently northwestward from a point about half a mile northwest of station 4-213 to the vicinity of UE12p #1. The same normal fault shown just west of UE12p #1 in figure 3b extends to this profile also. The apparent throw is about 400 feet. The pre-Cenozoic surface continues to dip gently to the northwest beyond the fault. The maximum thickness of the Tertiary volcanic rocks along C-C' is about 1,900 feet.

MAP OF ELEVATION CONTOURS ON THE PRE-CENOZOIC SURFACE

The map showing elevation contours representing the pre-Cenozoic surface (fig. 4, in pocket) was compiled from information contained in NTS-45, Part B, figure B-7 (Healey and Miller, 1963b); geologic quadrangle maps of Rainier Mesa and Oak Spring (Gibbons and others, 1963 and Barnes, Houser, and Poole, 1963); NTS-40 (Healey and Miller, 1963a) and the points of elevation from figures 3a, 3b, and 3c including UE12t #1 and UE12p #1. The elevation contours south of Gold Meadows and the southeastern part of the map are from Healey and Miller (1963b). The elevation contours in the areas of pre-Cenozoic outcrops are from Gibbons and others (1963) and Barnes, Houser, and Poole (1963). Additional elevation points on the pre-Cenozoic surface are from drill holes Exploratory #1; Hagestad; Effinger #1, #2, and #3; U12b.07-2; U12e.06A; U12e.06B, and U12r.

The area including the Gold Meadows stock has been subjected to a three-dimensional analysis by Healey and Miller (1963a). The two-dimensional computed elevation points on the pre-Cenozoic surface along profiles A-A' and B-B' are close to the elevation data (including the horizontal position of the data points) obtained by Healey and Miller (1963a).

All computed elevation points presented in figures 3a, 3b, and 3c are felt to be accurate to within ±10 percent of the total thickness of the Tertiary volcanic rocks. The greatest error (perhaps more than 10 percent) is associated with the C-C' profile north of UE12p #1.

The process of connecting the elevation points on the profiles and integrating these contours with previously drawn contours is somewhat arbitrary, but certain trends show up if the practice of choosing the simplest configuration possible is followed.

The isomilligal contours (fig. 2) trend generally northeast-southwest and are roughly parallel to the trend of the topography, particularly along the eastern edge of Rainier and Aqueduct Mesas. The trend of the elevation contours on the pre-Cenozoic surface (fig. 4) also is roughly parallel to the isomilligal contours. This may explain the parallelism between the gravity contours and the surface topographic contours. Also, the trend of topographic features on the pre-Cenozoic surface is north to northeast, parallel to the trend of the structural features in this area.

Abrupt changes in elevation probably indicate faulting with a north-to-northeast trend. Profile A-A' extends across Gold Meadows stock by way of a divide between two trough-like depressions in the pre-Cenozoic surface, one plunging to the southwest and the other plunging to the north. These depressions might reflect erosion along fault zones associated with the intrusion of the Gold Meadows stock or graben-like structures on the pre-Cenozoic surface. South of the supplementary-contoured area (Survey Butte) the altitude of the outcrops of dolomite (Pzd) and clastic rocks (Pzc) is about 6,000 feet, and no abrupt changes in altitude occur either east or west of these outcrops. The large outcrop of clastic rock (Pzc) east of Survey Butte also has an altitude about 6,000 feet. The altitude also decreases to the south and east in a fairly uniform manner. However, north of the outcrop of Pzd and Pzc (fig. 2), and west of the large outcrop of Pzc, the change in altitude is much more abrupt. The fault shown on figure 3b, 1.2 miles west of station 4-38 may extend 2 miles south of its intersection with profile B-B'. Harley Barnes (oral commun.,1967) finds some evidence to infer the extension of this fault northeastward onto the Oak Spring Butte quadrangle (Rogers and Noble, in prep.).

In the supplementary-contoured area there is more than 1,400 feet of relief on the pre-Cenozoic surface. East of UE12p #1 and UE12t #1 there are depressions in the pre-Cenozoic surface with altitudes of less than 4,500 feet, and less than 4,000 feet, respectively. West of UE12p #1 is a point on the pre-Cenozoic surface with an altitude of more than 5,400 feet.

The depressions east of the drill holes are thought to have been caused by motion along a normal fault (or faults). Except for the depression in the pre-Cenozoic surface on profile B-B' (fig. 3b) east of the Gold Meadows stock, the pre-Cenozoic surface is interpreted to have a gently changing slope. The only places of exception to this on all three profiles are found immediately east of the drill holes, UE12p #1 and UE12t #1. Walter Danilchik (oral commun., 1968), on reexamination of the core from UE12p #1, has found evidence of faulting near the bottom of the core. Previous examinations of this core have indicated that a large section in the Tertiary volcanic rocks is missing.

There are three possible interpretations of this faulting: (1) that the faults east of UE12p #1 and UE12t #1 (figs. 3a, 3b, and 3c) and the fault whose surface trace is shown east of UE12t #1 in figure 4 are independent; (2) that these three faults are in reality the same fault; and (3) that the faults east of UE12p #1 and UE12t #1 that disrupt the pre-Cenozoic surface are the same fault, but the fault with the surface trace (fig. 2) is independent of this fault or faults.

The third interpretation is felt to be the most probable one. If a line is constructed at a constant altitude in the fault plane on profiles B-B' and C-C' and this line is then extended to intersect profile A-A', the point of intersection of this line with A-A' is very close to the position in space of the point in the fault plane crossing A-A' having the same altitude as the line. Also as the fault with the surface trace southeast of UE12t #1 trends north, the fault on the pre-Cenozoic surface trends northeast, and the fault on the pre-Cenozoic surface has no apparent surface trace. No displacement can be seen in the welded tuff caprock (Tvw) any place on Aqueduct Mesa (figs. 2 and 4) which this latter fault must cross. The throw of this fault is about 500 feet, east of UE12t #1 and about 400 feet, east of UE12p #1.

RECOMMENDATIONS

In an area such as this, more drill-hole data would be valuable. Not only would more drill holes provide additional depth and density information, but also they would constrain future interpretation of the already available data to more closely parallel the actual geologic situation.

A specific location for a suggested drill hole would be on the B-B' profile about 0.9 miles west of UE12p #1. This drill hole would explore the conspicuous topographic high on the pre-Cenozoic surface at that point (fig. 4). This point on the pre-Cenozoic surface has an altitude of more than 5,400 feet. The portal of U12p has an altitude of about 5,600 feet; therefore, an inclined tunnel driven westward from U12p might hit the quartzite west of the CP thrust. The maximum thickness of the volcanic rocks (Tv plus Tvw) above the quartzite is about 1,400 feet. If the buried quartzite-dolomite contact is actually farther west than shown on B-B' (fig. 3b) the maximum thickness of the volcanic rocks is even less.

This hole need not be cored, but simply drilled through to the pre-Cenozoic surface. The hole recommended would provide information that would refine the interpretation presented in this paper.

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