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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GRAVITY INTERPRETATION OF FRENCHMAN FLAT AND VICINITY, NEVADA TEST SITE

By

C. H. Miller and D. L. Healey

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INTRODUCTION

The objective of the report is to present and discuss the analysis of the gravity data for Frenchman Flat and vicinity, which is summarized as a complete Bouguer map, and to interpret the broad geologic features associated with the complete Bouguer anomalies.

The rectangular area covered by this report is defined by six 7-1/2-minute quadrangles (fig. 1), which are bounded by latitudes 36°37'30" N. and 36°52'30" N. and by longitudes 115°52'30" W. and 116°15'00" W., Nevada Test Site, Nye County, Nevada. The total area is about 300 square miles.

Application of these gravity data and interpretations are supplementary to geologic and hydrologic studies, and to the selection and evaluation of potential test media with respect to thickness and distribution of favorable alluvium and volcanic rock. The major anomalies defined by complete Bouguer analysis are usually caused by buried pre-Cenozoic rock, but as experience in Yucca Flat has shown, the analysis can also be used to make preliminary assessments of some major structural offsets of discontinuities within the Paleozoic rock.

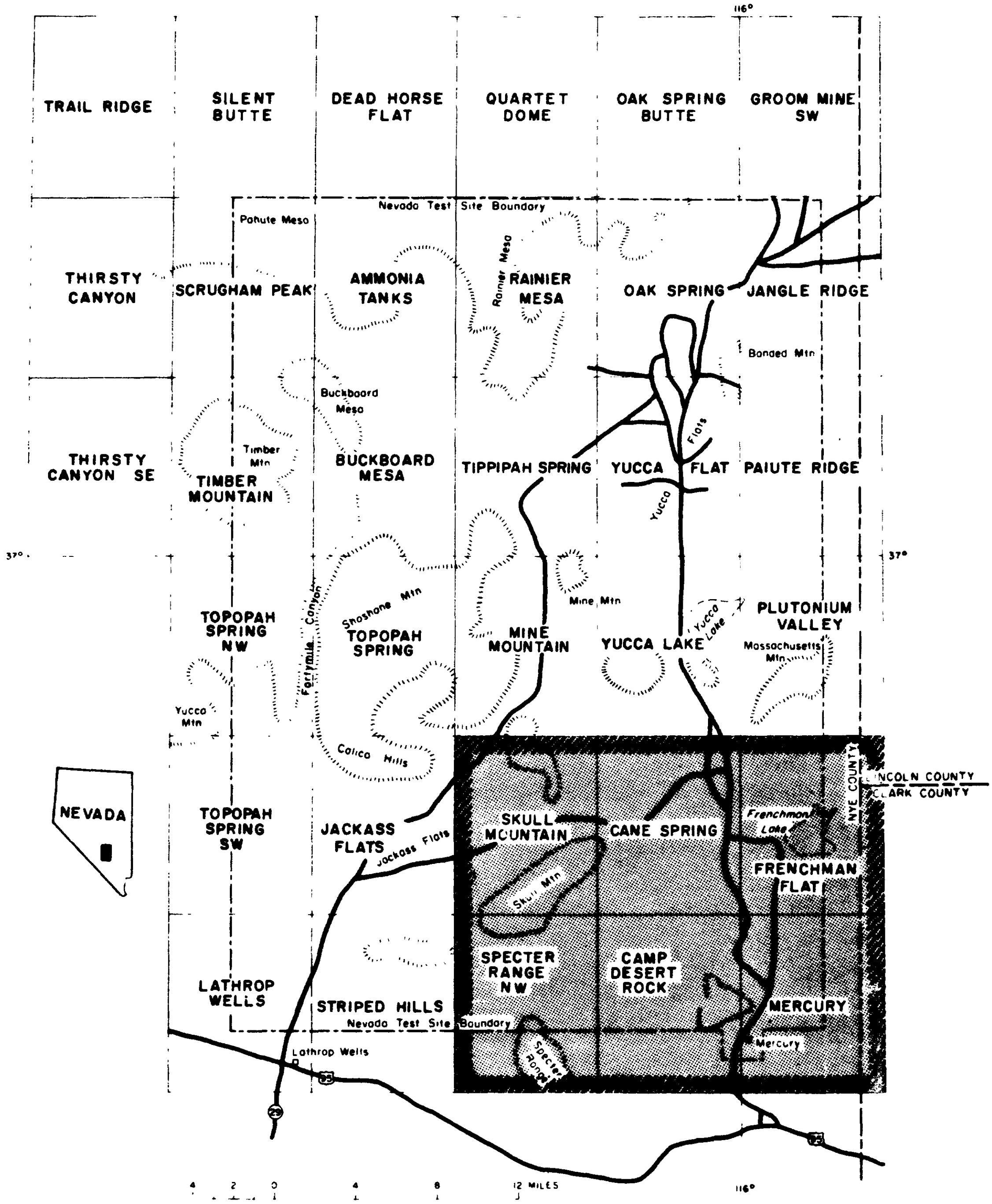

Figure 1.--Index map of Nevada Test Site showing quadrangles and area of report.

The gravity survey was done as a part of the Nevada Test Site Long Range Program of the U.S. Geological Survey for the U.S. Department of Energy (formerly U.S. Atomic Energy Commission). Data presented in this report were compiled in 1965 and have not been updated. U.S. Geological Survey personnel who contributed significantly to the gravity survey are: F. E. Currey, G. S. Erickson, J. F. Gibbs, J. Hendricks, D. C. Jackson, D. C. Muller, D. G. Murray, E. D. Seals, and R. C. Smith.

PHYSIOGRAPHY

The area of Frenchman Flat and surrounding mountains is typical of other parts of the Basin and Range province. North of the area, the mountains and valleys generally trend north-south. This contrasts with trends around Frenchman Flat which are north-south only in the north part and are west and northwest in the southern three-fourths of the area.

Geomorphologically, the area varies in age from young to mature. Intermittent streams in the eastern part are of the interior drainage type and drain to the playa of Frenchman Lake. Intermittent streams in the western and southern part, notably those in Rock and Mercury Valleys, drain southwest to the the dry Amargosa River.

GEOLOGY

The geology of the area is only briefly summarized here. In general, the rocks consist of thick deposits of faulted Precambrian and Paleozoic rocks commonly overlain by Tertiary volcanic rock and (or) Quaternary alluvium.

The broad distribution of the three major rock types--alluvium, volcanic rock, and pre-Cenozoic rocks--is pertinent to the interpretation presented in this report. Thick alluvial deposits are confined mainly to central Frenchman Flat and Rock Valley (Mercury Valley and Jackass Flats). Volcanic rocks, which are combined with alluvium in the ultimate interpretation of the pre-

Cenozoic surface, are highly variable in distribution and in physical nature. Outcropping pre-Cenozoic rocks are for the most part limited to the eastern and southern parts of the area. No outcrops of pre-Cenozoic bedrock are mapped in the Skull Mountain and Cane Spring quadrangles.

Pre-Cenozoic rocks are composed of limestone, dolomite, quartzite, argillite, and siltstone and are more than 37,000 ft thick (H. Barnes, USGS, written commun., 1962).

Tertiary rocks, which intrude and unconformably overlie the pre-Cenozoic rocks, include lavas, breccias, and tuffs overlain by rhyolitic tuffs with an aggregate thickness of more than 6,000 ft in the Skull Mountain quadrangle (Ekren and Sargent, 1965). Other rocks in minor amounts include basalt and sandstone, and granodiorite of intrusive origin.

Hydrothermally altered Tertiary lavas, breccias, and tuffs occur in the Skull Mountain and Cane Spring quadrangles. The principal alteration occurs in the older flows and breccias. The alteration usually has the effect of increasing the bulk density of the host rock but, in some situations, intense hydrothermal alteration may decrease bulk density (F. G. Poole, USGS, oral commun., 1964). The extent of alteration in the subsurface is unknown.

Quaternary alluvium overlies the Tertiary volcanic rocks in the main valleys but in some parts of the eastern area the alluvium is in contact with pre-Cenozoic rocks.

The many normal faults in the region around Frenchman Flat have caused the formation of south-trending horsts and grabens that are typical of the Great Basin province. The regional structure is similarly oriented in a southerly direction but in the area under consideration the structure strikes gradually westward as it is traced to the south.

Longwell (1960, p. 195-199) presents evidence that a buried shear zone with at least 25 miles of right lateral displacement extends through the Las Vegas and Indian Springs Valleys. The evidence includes the bending (interpreted as drag) of the mountain ranges, fold axes, thrust traces, and strikes of tilted beds near the valleys as well as the offset of strata on opposite sides of the valleys. Burchfiel (1960, p. 132-135) projects the trend of this Las Vegas Valley shear zone from the eastern border of the Camp Desert Rock quadrangle through Mercury Valley to the northwest of Camp Desert Rock, where it strikes west and cuts the Specter Range.

F. G. Poole (USGS, oral commun., 1964) believes that the right-lateral displacement on the shear zone is taken up by a series of en echelon high-angle faults in the Specter Range. R. L. Christiansen (USGS, oral commun., 1964) thinks the right lateral displacement is taken up by flexure. R. H. Moench (USGS, oral commun., 1964) feels that the apparently offset structure and strata at opposite sides of the valleys under discussion in reality can be projected directly across the valleys and that the concept of a shear zone need not be introduced.

ROCK DENSITIES

The contrast in rock densities between the pre-Cenozoic rocks and the overlying volcanic rocks and (or) alluvium provides the basis for interpretation of the complete Bouguer anomalies indicated by the gravity data and for estimating the depth and configuration of the buried surface of pre-Cenozoic rock.

The densities of pre-Cenozoic rocks within the area range from about 2.48 to 2.84 gm/cc, and are comparable with the densities of pre-Cenozoic rocks from contiguous areas. The gross bulk densities of these folded and faulted rocks are considered to be generally constant.

The densities of Cenozoic rocks, however, are highly variable, depending upon the rock type and the state of alteration. The western part of the area is characterized by outcropping Cenozoic rocks that are frequently high-density altered or intrusive types. This is the area from which most of the samples of Cenozoic rock were taken. In the eastern and southern part of the area, most Cenozoic rocks have been stripped from the higher hills of pre-Cenozoic rock and the Cenozoic rocks in the intermontane basin are buried by alluvium. Few density samples of Cenozoic rocks and no density samples of alluvium have been taken from this locality; however, similar rock units have been sampled in nearby areas. The information on densities within the area is shown in table 1, which is a compilation mainly of surface samples that were collected in the course of geologic mapping. The table shows dry, saturated or natural-state bulk densities, as well as the geographic coordinates, and the rock types and age.

Densities of Pre-Cenozoic Rocks

Table 1 shows the densities of surface samples of pre-Cenozoic rock within the area. These bulk densities range from 2.48 to 2.84 gm/cc. Ten dry bulk and saturated bulk density samples average 2.64 and 2.68 gm/cc, respectively, and seven natural-state samples average 2.62 gm/cc.

Pre-Cenozoic rocks in Yucca Valley have a range of densities similar to those within the area of this report. These saturated and dry bulk density samples have densities that range from 2.49 gm/cc for quartzite to 2.85 gm/cc for dolomite, and average approximately 2.67 gm/cc (R. M. Hazlewood, USGS, written commun., 1963).

The densities of pre-Cenozoic dolomite have also been estimated from geophysical well logs taken from test well F (R. D. Carroll, USGS, written commun., 1963). Estimates of five intervals, covering a 265-ft interval,

Table 1.--Bulk densities--water saturated, dry, and natural state

[Analysts: D. R. Cunningham, John Moreland, and E. F. Monk]

Latitude	Longitude	Rock type and age group1/	Dry bulk density (g/cc)	Saturated bulk density (g/cc)2/	Natural state bulk density (g/cc)
36°49'	116°07'	DC - C	2.27	2.38	
36°49'	116°07'	DC - C	2.26	2.38	
36°49'	116°07'	DC - C	2.35	2.44	
36°46'	116°07'	TF - C	1.55		
36°46'	116°07'	SS - C	1.61		
36°46'	116°07'	FE - C	2.31		
36°46'	116°07'	SS - C	1.63		
36°46'	116°07'	PU - C	1.66		
36°46'	115°07'	TF - C	1.86		
36°46'	116°07'	SS - C	1.29		
36°46'	116°07'	SS - C	1.67		
36°46'	116°07'	FE - C	2.14		
36°46'	116°07'	FE - C	2.39		
36°46'	116°07'	FE - C	2.53		
36°46'	116°07'	FE - C	2.45		
36°46'	116°07'	TF - C	1.50		
36°46'	116°07'	TF - C	1.29		
36°46'	116°07'	TF - C	1.40		
36°46'	116°07'	TF - C	1.47		

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group[1/]	Dry bulk density (g/cc)	Saturated bulk density (g/cc)[2/]	Natural state bulk density (g/cc)
36°49'	116°07'	DC - C	2.32		
36°49'	116°07'	DC - C	2.26		
36°49'	116°07'	DC - C	2.36		
36°49'	116°07'	DC - C	2.24		
36°49'	116°07'	DC - C	2.42		
36°49'	116°07'	DC - C	2.46		
36°49'	116°07'	DC - C	2.39		
36°49'	116°07'	DC - C	2.09		
36°49'	116°07'	DC - C	2.43		
36°49'	116°07'	DC - C	2.46		
36°49'	116°07'	DC - C	2.49		
36°49'	116°07'	DC - C	2.55		
36°53'	116°15'	RY - C	2.37		
36°49'	116°07'	DC - C	2.25		
36°49'	116°07'	DC - C	1.94		
36°49'	116°07'	DC - C	2.32		
36°49'	116°07'	DC - C	2.39		
36°49'	116°07'	DC - C	2.29		
36°49'	116°07'	DC - C	2.17		
36°49'	116°07'	DC - C	2.29		

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group[1]	Dry bulk density (g/cc)	Saturated bulk density (g/cc)[2]	Natural state bulk density (g/cc)
36°49'	116°07'	DC - C	2.11		
36°49'	116°07'	DC - C	2.28		
36°49'	116°07'	DC - C	2.24		
36°49'	116°07'	DC - C	2.15		
36°49'	116°07'	DC - C	2.26		
36°49'	116°07'	DC - C	2.23		
36°49'	116°07'	DC - C	2.30		
36°49'	116°07'	DC - C	2.25		
36°49'	116°07'	DC - C	2.31		
36°49'	116°07'	DC - C	2.26		
36°49'	116°07'	DC - C	2.36		
36°49'	116°07'	DC - C	2.29		
36°49'	116°07'	DC - C	2.31		
36°49'	116°07'	DC - C	2.22		
36°53'	116°14'	RD - C	2.56		
36°49'	116°07'	DC - C	2.35		
36°49'	116°07'	DC - C	2.33		
36°49'	116°07'	DC - C	2.28		
36°49'	116°07'	DC - C	2.49		
36°49'	116°07'	DC - C	2.24		

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group 1/	Dry bulk density (g/cc)	Saturated bulk density (g/cc) 2/	Natural state bulk density (g/cc)
36°49'	116°07'	DC - C	2.30		
36°49'	116°07'	DC - C	2.28		
36°45'	116°00'	RY - C	2.34		
36°45'	116°00'	AN - C	2.71		
36°45'	116°00'	RD - C	2.09		
36°45'	116°00'	RD - C	2.63		
36°45'	116°00'	RD - C	2.28		
36°45'	116°00'	RD - C	2.22		
36°45'	116°00'	RD - C	1.79		
36°45'	116°00'	AN - C	2.67		
36°45'	116°00'	RD - C	2.34		
36°45'	116°00'	RD - C	2.45		
36°45'	116°00'	RD - C	2.55		
36°45'	116°00'	RD - C	2.51		
36°45'	116°00'	RD - C	2.57		
36°45'	116°00'	RD - C	2.41		
36°45'	116°00'	RD - C	2.47		
36°45'	116°00'	RD - C	2.55		
36°37'	116°03'	LS - p-C	2.67	2.68	
36°37'	116°03'	LS - p-C	2.84	2.84	

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group[1]	Dry bulk density (g/cc)	Saturated bulk density (g/cc)[2]	Natural state bulk density (g/cc)
36°48'	115°53'	LS - p-C	2.71	2.71	
36°48'	115°53'	SH - p-C	2.59	2.63	
36°48'	115°53'	LS - p-C	2.60	2.68	
36°48'	115°53'	LS - p-C	2.65	2.67	
36°37'	116°02'	DO - p-C	2.66	2.68	
36°49'	116°07'	RD - C			2.28
36°49'	116°07'	RD - C			2.31
36°49'	116°07'	RD - C			2.28
36°49'	116°07'	RD - C			2.33
36°49'	116°07'	RD - C			2.35
36°49'	116°07'	RD - C			2.32
36°49'	116°07'	RD - C			2.38
36°49'	116°07'	PO - C			2.11
36°49'	116°07'	PO - C			1.99
36°49'	116°07'	PO - C			2.18
36°49'	116°07'	PO - C			2.18
36°49'	116°07'	PO - C			2.05
36°49'	116°07'	PO - C			2.31
36°49'	116°07'	PO - C			2.17
36°49'	116°07'	PO - C			2.19

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group[1]	Dry bulk density (g/cc)	Saturated bulk density (g/cc)[2]	Natural state bulk density (g/cc)
36°49'	116°07'	PO - C			2.23
36°49'	116°07'	PO - C			2.38
36°49'	116°07'	PO - C			2.43
36°49'	116°07'	RD - C			2.13
36°49'	116°07'	RD - C			2.10
36°49'	116°07'	RD - C			2.45
36°49'	116°07'	RD - C			2.40
36°49'	116°07'	RD - C			2.27
36°49'	116°07'	RD - C			2.30
36°49'	116°07'	RD - C			2.32
36°49'	116°07'	RD - C			2.28
36°37'	116°03'	SH - p-C	2.48	2.58	
36°45'	116°07'	DO - p-C			2.48
36°45'	116°07'	TF - C			2.45
36°45'	116°07'	TF - C			2.32
36°45'	116°07'	TF - C			2.42
36°45'	116°07'	TF - C			2.24
36°45'	116°07'	LS - p-C			2.50
36°45'	116°07'	DO - p-C			2.78
36°37'	116°02'	DO - p-C	2.48	2.57	2.54

Table 1.--Bulk densities--water saturated, dry, and natural state--continued

Latitude	Longitude	Rock type and age group1/	Dry bulk density (g/cc)	Saturated bulk density (g/cc)2/	Natural state bulk density (g/cc)
36°37'	116°02'	DO - p-C			2.63
36°37'	116°02'	DO - p-C			2.67
36°46'	116°01'	DO - p-C	2.71	2.75	2.73
36°45'	116°07'	SS - C			2.41
36°45'	116°07'	CN- C			2.27

1/ Abbreviations for rock types: DC - dacite, TF - tuff, SS - sandstone, FE - felsite, PV - pumice, RY - rhyolite, RD - rhyodacite, AN - andesite, LS - limestone, SH - shale, DO - dolomite, PO - porphyry, CN - conglomerate. Age is indicated by: p-C - pre-Cenozoic, C - Cenozoic.

2/ Water method.

range from 2.44 to 2.70 gm/cc; the average density of the dolomite is 2.55 gm/cc.

Densities of Cenozoic Volcanic Rocks and Alluvium

Some densities of surface samples of Cenozoic volcanic rock within the area are shown in table 1. These bulk density samples ragne from 1.55 gm/cc for tuff to 2.71 gm/cc for andesite. Seventy-seven dry bulk and saturated bulk density samples average 2.22 gm/cc. Thirty-one natural-state density samples average 2.27 gm/cc.

The densities and other physical properties of some Cenozoic volcanic rocks have been studied in detail at Area 401, Wahmonie Flat, Nevada (J. R. Ege and R. B. Johnson, USGS, written commun., 1962). Samples of Cenozoic rocks were taken from five test holes and a pilot underground air storage access shaft and pressure chambers. One hundred and sixty-five dry bulk samples of Cenozoic rock range in density from 1.35 to 2.55 gm/cc and average 2.27 gm/cc.

In situ densities were determined from geophysical logs from test well F for Cenozoic rocks as well as for pre-Cenozoic rocks. These estimated densities range from 1.90 to 2.59 gm/cc and average 2.24 gm/cc.

North of the area, in Yucca Flat, the densities of nonwelded tuff and alluvium average about 1.94 gm/cc. However, the partly welded and densely welded tuffs have slightly higher densities and increase the average density of the Cenozoic section. The Yucca Flat area was interpreted using a combined density of 2.0 gm/cc for the Cenozoic section, that is, grouped Tertiary rocks and Quaternary alluvium (R. M. Hazlewood, USGS, written commun., 1963).

GRAVITY SURVEY

Field Work

Worden Educator type gravimeters were used to make the gravity observations. Seven different meters were used at various times throughout the survey. Instrument constants ranged from 0.0820 to 0.5391 mGal per scale division. The constant of each meter was roughly checked by repeat readings between accurately established base stations. Repeat readings at previously occupied stations also were used as a check.

All gravity observations were made on bench marks, at photogrammetric spot elevations that are listed on recent topographic maps, or on surveyed points. Bench marks having horizontal and vertical control were established by the U.S. Coast and Geodetic Survey, the U.S. Geological Survey, and the U.S. Army Corps of Engineers. Many observational locations were established by the gravity crew by plane table surveying. In addition, some observation locations were established by transit crews of Holmes and Narver, Inc.

The elevations of the bench marks are generally accurate to within one-tenth of a foot vertically. The transit surveying is considered accurate to within a foot and the plane table surveying to within 3 ft vertically. The horizontal accuracy of the plotted transit and plane table surveying is considered accurate to within 100 and 250 ft, respectively. Photogrammetric spot elevations (unchecked) are generally considered accurate to within $\pm 1/4$ the 20-ft contour interval, or 5 ft vertically [1]. A 5-ft vertical error in the elevation of a gravity station would result in a Bouguer anomaly error of 0.3 mGal, which is well within the limits of allowable error for most interpretations.

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[1] Standards for the treatment of map features: Topographic Instructions of the U.S. Geological Survey, book 3, chapter 3A1-3A9.

Approximately 950 gravity observations were made in the area of this report and the average density of gravity stations is about 2.7 stations per square mile. Individual gravity observations were made on a single loop from a convenient base station. Generally a station that was occupied during a previous loop was reoccupied as an accuracy check.

Reduction of Data

Standard methods were used throughout this survey to reduce all gravity observations. Details of reduction procedures may be found in geophysics textbooks, such as Nettleton (1940), Heiland (1946), Jakosky (1950), and Dobrin (1952).

All gravity observations were reduced to a common datum through a network of base stations. Each base was established by a minimum of three repeat readings relative to an adjacent base. The base network is tied to a master station established by Woollard (1958, p. 520-535) at McCarran Field in Las Vegas, Nev. This master station is part of a nationwide network, and had a value of 979,604.7 mGal until adjusted in 1963 (Woollard and Rose, 1963). Because the relative difference between stations is more important to exploratory work than the absolute value, the gravity survey has not been adjusted to this new value. The error in absolute value due to this adjustment is approximately 0.2 mGal.

A combined free-air and Bouguer elevation factor of 0.06 mGal/ft, which corresponds to a density of 2.67 gm/cc (Nettleton, 1940, p. 55) was used to reduce all data to a sea-level datum. Terrain corrections were computed through Zone L (Hammer, 1939, p. 184-194), a radial distance of 9 mi, and applied to all stations. The computed terrain effect varies from less than 0.40 mGal at Frenchman Flat to a maximum of about 13.3 mGal at Skull Mountain.

The standard correction for latitude was made using the table computed by Nettleton (1940, p. 137-143) from the 1930 International formula.

DEPTH CONTROL

Depth control within the area consists of drill holes, seismic refraction studies, electrical resistivity studies, and the known geology.

Drill Holes

Drill-hole control in the area consists of several holes; only one of the holes penetrates pre-Cenozoic bedrock. Drill holes that do not penetrate pre-Cenozoic rocks range in depth from a few tens of feet to 2,668 ft (UE5c). The holes predominantly are located at Frenchman Flat; all of the holes, except UE5c and possibly hole 5A, at Frenchman Flat are bottomed in alluvium. The deeper drill holes that do not penetrate pre-Cenozoic rock give a negative control that is a minimum limit of depth for the buried surface of pre-Cenozoic rock.

Drill hole F penetrates 3,137 ft of volcanic rock and encounters Paleozoic dolomite at an elevation of 1,006 ft. The hole penetrates Wahmonie and Salyer Formations, Mara Wash tuff, and Pavits Spring rocks, which have an average density of 2.24 gm/cc. The estimated density of dolomite averages 2.55 gm/cc.

Electrical Resistivity

Electrical resistivity surveys in the area have been confined to the 401 Area and Frenchman Flat. The resistivity measurements at the 401 Area were made to provide bulk physical characteristics and depth extent of a dacite porphyry. One of the electrical profiles showed no apparent change from 1,050 ft to 1,800 ft and it was reasonably assumed that the rock type in this interval is homogeneous and water saturated. It was also suggested that the rock type may be a bedded tuff, although it is not possible to define the rock types on a basis of the measured resistivity.

The resistivity surveys made at Frenchman Flat were mainly concerned with shallow measurements in alluvium. However, some resistivity measurements were made using the Schlumberger electrode configuration (J. H. Scott and R. A. Black, USGS, written commun., 1962).

Valid resistivity measurements were obtained to depths of as much as 3,000 ft. Because the electrical resistivity of Tertiary welded tuff and pre-Cenozoic limestone and dolomite is much higher than alluvium, a change in resistivity is expected at the contact of these electrically dissimilar lithologies. The measured resistivity is relatively constant at approximately 21 ohm-meters from 140 ft to 1,000 ft at most stations and about 3,000 ft at one station (pl. 1). Therefore, it was tentatively concluded that the tuff and pre-Cenozoic rock are more than 3,000 ft at the one station and more than 1,000 ft deep at the other stations.

Aeromagnetic Data

Aeromagnetic surveys were flown at the Nevada Test Site during 1961 and the data for most of the area of this report have been published (Boynton and Vargo, 1963). Although these data have not been geologically interpreted, the map provides general trends of volcanic and intrusive rocks.

The main magnetic anomaly of the Boynton and Vargo map is centered at the Wahmonie mining area. Locally, this anomaly is somewhat elongated northeast-southwest and is paralleled by an anomaly along the southeast flank of Skull Mountain. However, at a larger scale the main anomaly has a northwest trend.

Seismic Refraction and Experimental Reflection

Seismic refraction and some experimental reflection work was done at Frenchman Flat by J. C. Roller (USGS, oral commun., 1960). The experimental reflection work consisted of several seismic lines on the playa proper. The results were inconclusive.

Seismic refraction records were obtained from six shot points. Plate 1 (in pocket) shows three velocity layers with depths to the layer of intermediate burial, V_2, and to that of deepest burial, the V_3 layer. The velocities range from about 3,700 ft/s for the upper V_1 layer to about 14,000 ft/s for the V_3 layer. Depths to the upper surface of the V_2 and V_3 layers range from a minimum of about 400 ft to a maximum of 2,600 ft.

The seismic depths of the V_3 layers at the west side of Frenchman Flat are in general agreement with the depths to pre-Cenozoic rocks computed from the gravity anomaly. At the dry lake and north, however, the seismic depths to the V_3 layer are much less than the gravity interpreted depths to pre-Cenozoic rock. It is, therefore, suggested that the velocity of the V_3 layer may be associated with the volcanic rock beneath Frenchman Lake.

DISCUSSION OF COMPLETE BOUGUER GRAVITY MAP

Plate 2 shows the complete Bouguer map of the area under consideration. Corrections for drift, elevation, terrain, and latitude have been applied. The resulting data have been plotted and contoured at an interval of 1 mGal. All numbers are negative and the low areas are hachured.

The regional gradient decreases to the north at a rate of about 1 mGal per mile. This gradient has not been removed from the complete Bouguer anomaly map.

The magnitude of a gravity value is maximum (less negative) on or near the thick sections of pre-Cenozoic rocks. These high values are considered to define the regional gradient. Minimum (more negative) gravity values occur on or near the Cenozoic rocks and alluvium. These low anomalies are proportional to the thickness of low density Cenozoic rocks and alluvium that overlie the pre-Cenozoic rocks.

Gravity Highs

A dominant gravity high extends from the southwest corner of the map (pl. 2) to the east-central border, and is moderately concave towards the northwest. This high is caused by extensive pre-Cenozoic terrane of the Specter Range, Mercury Range, and Ranger Mountains. The magnitude of the high ranges from more than -115 mGal (the highest in the area) to about -135 mGal. The gravity gradient decreases in the direction of concavity at a rate as much as 10 mGal/mi. South of the arcuate feature the gradient is relatively uniform over the abundant outcrops of pre-Cenozoic rock.

The arcuate feature is a demarcation line for outcrops of pre-Cenozoic rocks; none of these rocks crop out north of the demarcation line and within the area. However, there are two general highs north of the demarcation line that are not necessarily caused by pre-Cenozoic rocks. One of the highs coincides with the ridges of the Hampel Hill-Mount Salyer area, the other coincides with the topographic low and hydrothermally altered and mineralized Wahmonie area west of Area 401.

Hampel Hill-Mount Salyer

The Hampel Hill-Mount Salyer anomalous high curves northward and northeastward for a distance of 12 mi from a point 3 mi southeast of Hampel Hill to a gravimetric divide between the Frenchman Flat and C P Basin low anomalies. Gravity values along the crest of the anomaly decrease northeastward from about -131 mGal at the Hampel Hill area to about -150 mGal near the northern part of the map. The anomaly coincides in part with the Cenozoic outcrops of the Hampel Hill-Mount Salyer area but is not particularly affected by the thickest section of outcrops, nor highest areas of relief.

Wahmonie Mining Area

The gravity high associated with the Wahmonie mining area is bounded by lows at Skull Mountain on the south and at the Kiwi Mesa-Lookout Peak area on the north. This high anomaly is irregular in outline and is somewhat elongated southwest to northeast. Gravimetric relief ranges from about 7 to 10 mGal. The northern part of the high is elongated across the hydrothermally altered area (Ekren and Sargent, 1965) and generally extends across the mining area and the granodiorite stocks to a xenolith of pre-Cenozoic rock.

Gravity Lows

Frenchman Flat

The Frenchman Flat gravity low anomaly is the most prominent in the area (pl. 2). The gravimetric relief ranges from about -130 mGal at the Ranger Mountains to about -179 mGal at the center of the anomaly--a gravimetric relief of about 40 mGal in less than 7 mi. The anomaly is generally ellipsoidal in plan but is elongated to the southwest towards Rock Valley. It is bounded on the south and east by the high gravity over pre-Cenozoic rocks in the southern map area, and on the west and northwest by the Hampel Hill-Mount Salyer high anomaly. The lowest part of the Frenchman Flat anomaly is displaced about 3 mi directly north of the playa.

C P Basin

The southern end of the C P Basin low is delineated by gravity data between the Black Ridge area and the hills northeast of Mount Salyer. That part of the anomaly shown is bifurcated, with the major elongation extending southwestward into the area of Cane Spring Wash. This elongation is a complimentary low on the northwest side of the Hampel Hill-Mount Salyer high. The other elongation is less apparent and extends to the Black Ridge area.

Skull Mountain-Jackass Flats

A sharp, narrow gravity low is associated with Skull Mountain. This low is variable in width and is more than 7 mi long. It trends northeast and is very nearly aligned with the southwestern trend of the major elongation of C P Basin, although not necessarily structurally related. The Skull Mountain low is the southeastern complement of the Wahmonie high.

A broad, nondescript gravity low at the northwest part of the map is associated with Jackass Flats. This low anomaly merges with the Skull Mountain low. These lows are somewhat separated by the southwest extension of the Wahmonie gravity high.

Mercury and Northwest Mercury Basin

The northern parts of the two gravity lows are delineated by gravity data at the southern part of the map area. One low is associated with the main part of Mercury Valley; the other low is associated with the same valley but at the northwest end.

The basins interpreted from the gravity lows are called Mercury and northwest Mercury basins, respectively. Mercury basin low has an absolute magnitude of about -135 mGal. The nearby Mercury Ridge produces a gravity high of -120 mGal, a gravimetric relief of some 15 mGal in less than 2 mi. The northern half of the Mercury low has a half-length of about 3 mi and a width of about 3 mi. It is elongated to the south-southwest and merges with the northwest Mercury low on the northwest.

The northwest Mercury basin low has an amplitude that is similar to that of the Mercury basin low--15 mGal. The low is irregular in plan and is about 5 mi long in the northwest direction and 5 mi wide in the northeast direction.

GEOLOGIC INTERPRETATION OF GRAVITY DATA

Discussion

The gravity method assumes that the crust of the Earth is homogeneous and of constant density for short distances and that the observed gravity will likewise be constant. Any deviation in observational data from this assumption is termed an anomaly. The magnitude and character of the observed anomaly is controlled by the density contrast and distribution of the mass that causes the anomaly.

There is no unique interpretation of gravity anomaly. The interpretation is made by applying a finite density and by assuming a configuration for the anomalous mass that produces a reasonable geologic situation. The assumed configuration is then adjusted by computation to fit the observed gravity. The adjustment is controlled by independent data such as other geophysical surveys and drill holes.

Geologic interpretation of the gravity data in the Nevada Test Site area is based on the knowledge that the pre-Cenozoic rocks are the prime factor controlling the complete Bouguer values (regional gradient). These relatively dense rocks are so thick and extensive that any gravity station not established on or near them will have an anomalously low value due to the lower density of the intervening volcanic rocks and alluvium. The magnitude and character of the anomaly is proportional to the thickness and densities of these Tertiary and Quaternary rocks.

The two-dimensional graticule analysis and three-dimensional Talwani-Ewing methods (1960, p. 203-225) were used in the interpretation of the gravity data.

Figure 2 shows a hypothetical two-dimensional graticule analysis. In the ideal case, this method is applied to an anomalous body of limited width and of a length that is at least two times greater than the width. The magnitude of the regional gradient is considered to be controlled by the dense pre-Cenozoic rocks. In the two-dimensional method, a straight line connecting two gravity values on pre-Cenozoic rock is used as the assumed regional gradient. The straight line functions as a short chord on a broadly undulating regional gradient. The curved line connects points of measured complete Bouguer values--observed gravity. Superimposed on the curve are points of theoretical gravity values--computed gravity. The area between the observed gravity curve and the assumed regional gradient, is the residual gravity anomaly and is proportional to the thickness and distribution of the low density Tertiary rock and Quaternary alluvium that overlies the pre-Cenozoic rock. The difference in density (density contrast) between the Cenozoic and pre-Cenozoic rocks is then applied in the computation of a configuration of the buried surface of pre-Cenozoic rock that fits the observed gravity curve.

Density Contrasts

The range in densities of known pre-Cenozoic rocks of the area is from approximately 2.48 gm/cc for shale to 2.84 gm/cc for limestone--a span of 0.36 gm/cc. As indicated, the carbonate rocks are generally more dense than the noncarbonate rocks. The gross ratio in quantity of these rocks and their interrelated distribution in the area is unknown. However, a gravimeter would sense the gross or average density of pre-Cenozoic rock at a distance (buried and at depth).

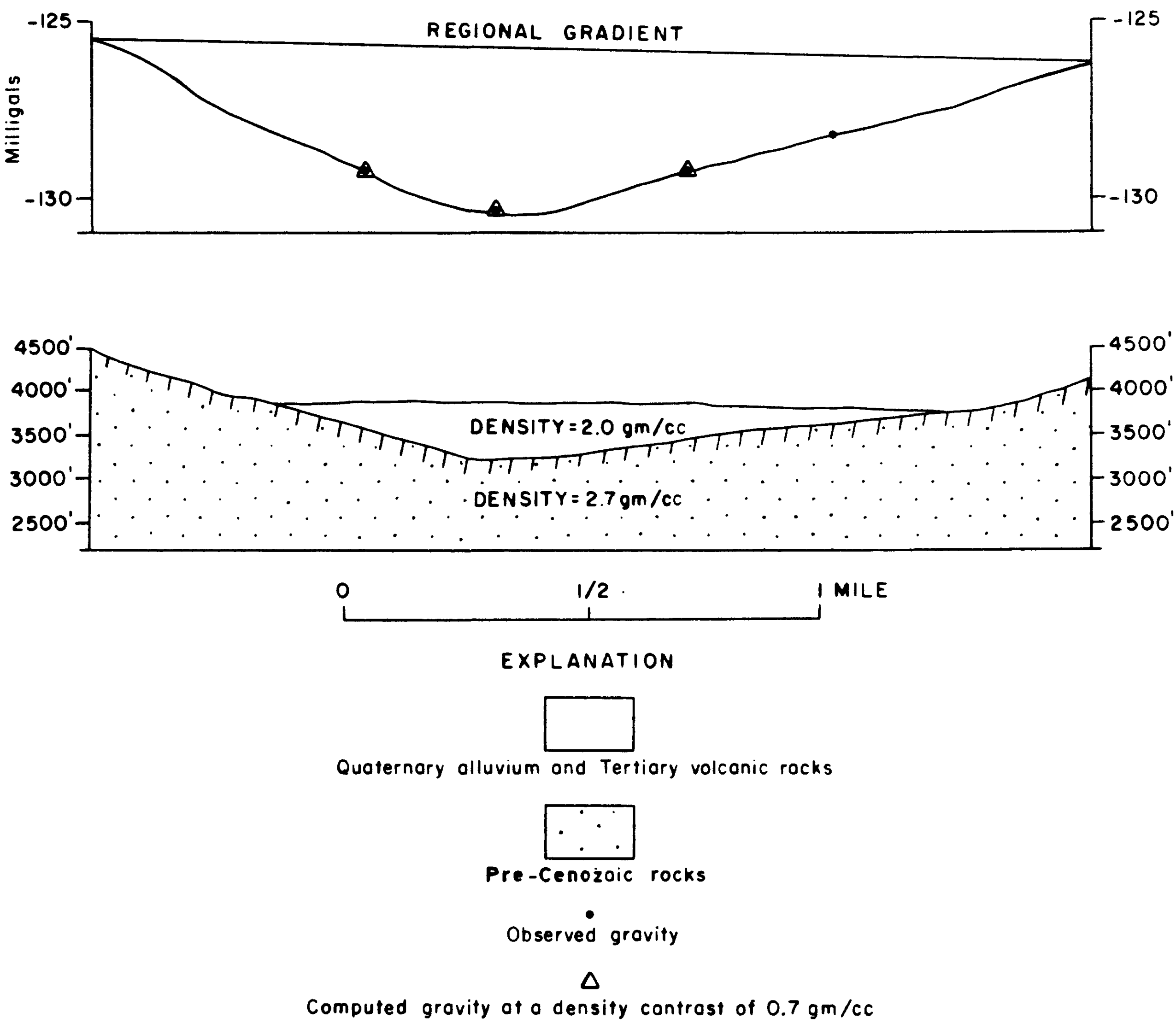

Figure 2. — A hypothetical two-dimensional graticule analysis of gravity data

The densities of a few samples of pre-Cenozoic rocks from the area average about 2.65 gm/cc; this is consistent with the average densities of many samples from the Yucca Valley area. It therefore seems reasonable to select a single density of 2.67 gm/cc for the pre-Cenozoic rocks.

The range in densities of known Cenozoic rocks of the area is from approximately 1.55 gm/cc for tuff to 2.71 gm/cc for andesite. Although no density samples of alluvium have been measured, it is expected that the range of densities would be much smaller than that of Cenozoic rocks and would be well within the extreme limits of the densities of Cenozoic rocks.

The density contrasts, used outside of the altered and intruded area, mainly at Frenchman Flat and Mercury Valley, was estimated at 0.7 gm/cc (2.67-2.0 gm/cc) by comparison with the density contrast used at Yucca Valley. The comparison is made because the general geology and gravimetric characteristics of Frenchman Flat and Mercury Valley are similar to that of Yucca Valley and the accuracy of this contrast has been tested by drilling.

A density contrast of 0.3 gm/cc was used in the interpretation of the general altered and intruded area. It was found during two-dimensional interpretation of this area that a reasonable geologic situation could not be obtained with a density contrast of more than 0.4 gm/cc (2.67-2.27 gm/cc). Specifically, these preliminary attempts at fitting assumed geology to the observed gravity resulted in surface exposure of pre-Cenozoic (i.e., rocks of high density) where these rocks do not crop out. The contrast was also based on trial and error computation during and after completion of ground-water test well F and on the estimates of density contrasts (2.55-2.24 gm/cc) from geophysical well logs of the hole.

Problems and Accuracy

The problems affecting the two-dimensional interpretation of the gravity data are many and varied.

The gravity lows are not elongate but rather they tend to be irregularly circular. No pre-Cenozoic rocks crop out on opposing sides of the lows; rather pre-Cenozoic outcrops are restricted to the southern part of the area. This means that the regional gradient must be extended to the most convenient outcrops outside the area. Of necessity, therefore, some gravity cross sections do not traverse the gravity anomalies at right angles to the direction of elongation.

The densities of the section of volcanic rock and alluvium vary vertically and laterally. In addition to an inherent density change, the section of volcanic rocks in the western area (Wahmonie Flat-Jackass-Flats) has been intruded and hydrothermally altered. The alteration has usually resulted in an increase in density. The extent of alteration at depth is unknown. The intrusive stocks present a problem because the density of the intrusive granodiorite (average about 2.48 gm/cc) is similar to the density of pre-Cenozoic rocks (2.67 gm/cc). If this is the case, the interpretation, in places, shows the undifferentiated buried surface of the granodiorite and pre-Cenozoic rocks.

The lack of drilling and geophysical control makes the interpretation difficult and an estimation of depth accuracy uncertain. In essence, the accuracy of the interpreted gravity data has not been proved.

The accuracy of the interpreted pre-Cenozoic contours of the eastern part of the area is estimated by comparison with Yucca Valley. Comparison is made because the general geology and gravimetric characteristics of Frenchman Flat and Mercury Valley are similar to that of Yucca Valley and the accuracy of interpretation at Yucca Valley has been tested by drilling. The accuracy of interpretation of much of Frenchman Flat and Mercury Valley, is, therefore, estimated to be within ±500 ft with extremes generally within ±1,000 ft.

It is estimated that the accuracy of the interpreted pre-Cenozoic contours of the western area is generally within ±1,000 ft with extremes outside this limit.

BURIED SURFACE OF PRE-CENOZOIC ROCK

Plate 1 shows contours on the buried surface of pre-Cenozoic rocks as well as the outcrop areas of pre-Cenozoic rocks. Plate 1 may be best compared with the complete Bouguer map (pl. 2) by overlaying. The contours were derived from the interpretation of gravity data and are meant to show (1) the configuration and (2) depth of burial of the present buried surface of pre-Cenozoic rocks. The accuracy of the contours with long dashes are estimated to average within ±500 ft with extremes of as much as ±1,000 ft. The contours with short dashes in the western area are estimated to be generally accurate within ±1,000 ft with extremes outside this limit. Dotted contours for intervening 500-foot depths were added to convey the configuration more clearly.

Highs in the Present Surface of Pre-Cenozoic Rocks

An Outcropping Arcuate Feature

As previously noted, in Yucca Flat the structure is generally oriented north-south and is typical of the tilted fault blocks of Great Basin geology. However, as the buried highs and lows are traced southward, into the western two-thirds of the Frenchman Flat area they trend more southwest-northeast, in 45° opposition to the structure further north (R. M. Hazlewood, USGS, written commun., 1963). The buried highs and lows flatten and become indistinct as they are traced further southward toward the pre-Cenozoic terrane in the southern part of the map area.

There are two prominent highs in the buried pre-Cenozoic surface north of the pre-Cenozoic terrane; the Hampel Hill-Mount Salyer high and the Wahmonie high.

Hampel Hill-Mount Salyer

The Hampel Hill-Mount Salyer high extends northeastward from just north of the Hampel Hill between the C P Basin and Frenchman Flat lows. It plunges to the northeast and may form a slight saddle under the Barren Wash area. The northwest side of the high is parallel to the Cane Spring fault zone. The southwest end is truncated about 1 mi northeast of ground-water test well F and slopes steeply towards the basin in which the test well is located.

The greatest altitude on the Hampel Hill-Mount Salyer high is just north of Hampel Hill and appears to be relatively near-surface, even though the interpretation was made with a density contrast of only 0.3 gm/cc. The Cenozoic section at this point, however, is considered to be several thousand feet thick and is apparently outside the Wahmonie altered zone. It seems possible that the apparent apex of the pre-Cenozoic high may be caused by a high density altered or intrusive body. There is no particular correlation of this high with the aeromagnetic data.

The southwest end of the Hampel Hill-Mount Salyer high has a northwest and a southern extension.

The northwest extension is somewhat circular in plan and is interpreted as being relatively near surface, although it is on the down-side of the Cane Spring fault zone. There are several explanations for the position of this high, aside from the obvious conclusion that it is a block of pre-Cenozoic rocks. It may represent high density altered or intrusive rocks from similar rocks on the opposite side of the fault about 2 mi to the northeast. The aeromagnetic data do not support or deny this explanation. This fault zone is known from surface mapping to have 1 to 2 mi of left-lateral offset (Poole and others, 1965).

The southern extension of the buried Hampel Hill-Mount Salyer high seems to be connected with a broad feature of little relief under Rock Valley.

Skull Mountain-Lookout Peak

The buried high in the pre-Cenozoic surface between the Skull Mountain and Lookout Peak areas extends from the southern end of Skull Mountain to the northern border of the map. Although this high has roughly the same dimensions as the equivalent gravity anomaly, it is much more featureless. the Skull Mountain anomalous gravity low, for example, has been removed and the interpretation shows that the buried high extends beneath the southern end of Skull Mountain.

Although the high seems to generally coincide with the southern part of the Wahmonie altered area it deviates considerably at the northern part. It may represent either the upper surface of pre-Cenozoic rock, the high density granodiorite, or both.

Although the known Cenozoic section of this area is several thousand feet thick, that part of the high at the valley between Skull Mountain and the Wahmonie mining area is relatively near surface and could possibly be granodiorite superimposed upon pre-Cenozoic rock. This appears to be indicated by the granodiorite that crops out just north of the mining area and along the axis of the buried high.

The aeromagnetic data show a magnetic high centered at the Wahmonie mining area. This magnetic high likewise correlates with the general trend of the interpreted gravity of the Wahmonie high.

Pre-Cenozoic Lows

Frenchman Basin

Frenchman basin is the interpreted structural equivalent of the gravity low anomaly associated with Frenchman Flat. This basin is the most prominent low in the area. It is elongate in the southwest direction, toward Rock Valley, and is about 15 mi in length with a maximum width of 9 mi. The basin is bounded by the Ranger Mountains and Mercury Ridge outcrops on the south and east; by the Hampel Hill-Mount Salyer high on the west and northwest; and by the southern extension of the latter high on the southwest across Rock Valley.

The Frenchman basin is centered some 3 mi north of the playa and is buried by about 4,500 ft of Cenozoic deposits. The thickest deposits of undifferentiated volcanic rocks and alluvium do not coincide with the present center of deposition in Frenchman Flat and the thickest section of alluvium is probably in the low part of the basin rather than beneath the present playa.

C P Basin Extension

A southwest-trending extension of C P Basin (R. M. Hazlewood, USGS, written commun., 1963) is near the northern boundary of plate 1. The most apparent part of the extension is a narrow, elongate feature little more than a mile in width. However, the feature broadens to form a generalized low between the north ends of the Hampel Hill-Mount Salyer high and the Skull Mountain-Lookout Peak high. The low part of the basin extension appears to be about 1,500 ft in altitude with an overlying thickness of volcanic rock and alluvium of about 2,100 ft.

Kiwi Mesa

A sharp depression is defined beneath the southeast end of Kiwi Mesa in the northwest part of the area; and is subsidiary to the broad basin beneath Jackass Flats.

This buried low appears redundant because of the association with a topographic high and because of the relatively great depth of burial compared with the small perimeter. However, the mesa is capped with basalt which would have the effect of shallowing the interpretation. Furthermore, the interpretation was done with a density contrast of 0.7 gm/cc. This contrast as compared with a contrast of 0.3 gm/cc that was used immediately to the east would also have the effect of shallowing the interpretation. Therefore, the buried low appears to be real and the depth of burial shown would seem to be a minimum.

The slope of the sides of this interpreted low is as much as 1:1 (45°). This slope is compatible with the measured dips of outcropping volcanic rocks at Kiwi Mesa and the first ridge east. These rocks dip toward and under the basalt of Kiwi Mesa at angles of about 13° to 40° (Ekren and Sargent, 1965).

Test Well F Depression

The low in the vicinity of test well F is bounded on the northeast by the Cane Spring fault. The lowest point on the pre-Cenozoic surface is thought to be near test well F. This hole penetrates 3,137 ft of Cenozoic rock and 265 ft of pre-Cenozoic dolomite. The altitude of the top pre-Cenozoic rocks is 1,006 ft above sea level.

The case history of gravity interpretation around test well F is typical of the problem encountered in the western part of the area of this report. The complete Bouguer map is relatively featureless around the drill hole and the magnitude of the anomaly is not indicative of the depth to pre-Cenozoic rock. Prior to the drilling of the test well F an estimate of depth at the site was made with various density contrasts, all of which proved to be too great, and the resulting estimates were too shallow. The present low was interpreted using a density contrast of 0.3 gm/cc. This is the average density contrast of Cenozoic rocks in test well F although the hole is outside the known altered and intruded area.

Mercury and Northwest Mercury basins

Northwest Mercury basin and the northern part of Mercury basin are shown in Mercury Valley at the south-central part of plate 1.

SUMMARY

This report presents the results and the interpretation of a gravity survey in Frenchman Flat and vicinity, Nevada Test Site. About 950 gravity stations were set in an area of approximately 300 sq mi.

The gravity observations were made at points of known horizontal and vertical position; the least accurate of these components is about 250 ft and 5 ft, respectively. The gravity values were referenced to a station with known absolute value and reduced to a sea level datum. A combined free-air and Bouguer elevation factor of 0.06 mGal/ft, which corresponds to a density of 2.67 gm/cc, was applied and the standard corrections for latitude and terrain were made.

The gravity data were summarized as a complete Bouguer map and the broad geologic features associated with the complete Bouguer anomalies were interpreted and also summarized in map form.

The interpretation was done with density contrasts of 0.7 gm/cc in the eastern and southern parts of the area and 0.3 gm/cc in the western altered and intruded area. The alteration and intrusion in the western area appears to have increased the density of Cenozoic rocks.

Depth control in the area is meager but some control was provided by seismic refraction and electrical resistivity surveys at Frenchman Flat and by test well F and an aeromagnetic survey in the altered and intruded area.

The problems affecting the two-dimensional interpretation of the gravity data are many and varied. These problems include: irregularly shaped valleys without outcrops of pre-Cenozoic rocks at opposite sides of the valley; high density altered rocks and intrusions that may be interpreted as buried pre-Cenozoic rock; the lack of drilling and geophysical control. The accuracy of depth interpretation of much of Frenchman Flat and Mercury Valley is estimated to be within ±500 ft with extremes generally within ±1,000 ft. It is estimated that the accuracy of the interpreted pre-Cenozoic contours of the western area is generally within ±1,000 ft with extremes outside this limit.

The Hampel Hill-Mount Salyer gravity high and equivalent interpreted high extends northeast from Hampel Hill. The greatest altitude on the high is just north of Hampel Hill and appears to be near surface, but subject to further study. The northwest side of the entire high is parallel to the Cane Spring fault zone. A northwest extension of this high is on the opposite and down side of the fault and may be caused by high density altered rocks that have been offset 1 or 2 mi from the northeast.

The interpreted buried high between Skull Mountain and Lookout Peak generally coincides with the Wahmonie mining area (altered) and some granodiorite stocks further north. This indicates that the near surface high under the valley between Skull Mountain and the Wahmonie mining area is either the upper surface of pre-Cenozoic rock, the high density granodiorite, or both.

Frenchman basin is the interpreted structural equivalent of the gravity low anomaly associated with Frenchman Flat. This basin is about 15 mi in length with a maximum width of 9 mi. It attains a maximum depth of burial of about 4,500 ft by volcanic rocks and alluvium some 3 mi north of the present playa.

A buried low interpreted beneath Kiwi Mesa appears redundant because of its steep slopes and association with a sharp topographic feature. However, considering the shallowing effect of the basalt cap of the mesa and of the small density contrast and the known inclination of volcanic rocks that dip under the mesa, this low seems to be real.

A low in the vicinity of test well F is thought to have its lowest point on the pre-Cenozoic surface near the well. Before and during the drilling of this hole, estimates of depth from gravity data were too shallow. This hole penetrates 3,137 ft of Cenozoic rock before entering dolomite. Consequently, the present low is interpreted at a density contrast of 0.3 gm/cc in order to obtain a reasonable fit, although the hole is outside the known altered and intruded area.

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