FN-TR-33-HV

Fugro Nat'l. Inc.
Item 1

MX SITING INVESTIGATION

GRAVITY SURVEY - HAMLIN VALLEY

NEVADA

FUGRO NATIONAL

CONSULTING ENGINEERS AND GEOLOGISTS

FN-TR-33-HV

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GRAVITY SURVEY - HAMLIN VALLEY

NEVADA

Prepared for:

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7 February 1980

FOREWORD

Methodology and Characterization Studies during fiscal years 1977 and 1978 included gravity surveys in ten valleys in Arizona (five), Nevada (two), New Mexico (two), and California (one). The gravity data were obtained for the purpose of estimating alluvial gross structure and shape of the basins and the thickness of the valley fill. There was also the possibility of detecting shallow rock in areas between boring locations. Generalized interpretations from these surveys were included in Fugro National's Characterization Reports (FN-TR-26a through e).

During the FY 77 surveys, the measurements were made to form an approximate one-mile grid over the study areas, and contour maps showing interpreted depth to bedrock were made. In FY 79, the decision was made to concentrate the available funds on the basic Verification Program to verify and refine suitable area boundaries. This decision resulted in a reduction in the gravity program. Instead of obtaining gravity data on a grid, the reduced program consisted of obtaining gravity measurements along profiles across the valleys where Verification Studies were also performed.

The Defense Mapping Agency (DMA), St. Louis, was also requested to provide gravity data from their library to supplement the gravity profiles. For Big Smoky, Reveille, and Railroad valleys, a sufficient density of library data is available to permit construction of interpreted contour maps instead of two-dimensional cross sections.

In late summer of FY 79, supplementary funds became available to begin data reduction. At this time, inner zone terrain corrections began on the library data and the profiles from Big Smoky Valley, Nevada, and Butler and La Posa valleys, Arizona. The profile data from Whirlwind, Hamlin, Snake East, White River and Garden Coal valleys, Nevada were available from the field in early October, 1979.

A continuation of gravity interpretations has been incorporated into the FY 80 contract and the results are being summarized in a series of valley reports. The reports covering Nevada-Utah gravity studies will be numbered, "FN-TR-33-", followed by the abbreviation for the subject valley. In addition, more detailed reports of the results of FY 77 surveys in Dry Lake and Ralston valleys, Nevada are being prepared. Verification Studies are continuing in FY 80 and gravity studies are included in the program. DMA will continue to obtain the field measurements and it is planned to return to the grid pattern. The interpretation of the grid data will allow the production of contour maps which will be valuable in the deep basin structural analysis needed for computer modeling in the Water Resources Program. The gravity interpretations will also be useful in the Nuclear Hardness and Survivability (NH&S) evaluations.

The basic decisions governing the gravity program are made by BMO following consultation with TRW Inc., Fugro National and the (DMA). Conduct of the gravity studies is a joint effort between DMA and Fugro National. The field work, including planning, logistics, surveying, and meter operation is done by the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC), headquartered in Cheyenne, Wyoming. DMAHTC reduces the data to Simple Bouguer Anomaly (see Section A1.4, Appendix A1.0). The Defense Mapping Agency Aerospace Center (DMAAC), St. Louis, calculates outer zone terrain corrections.

Fugro National provides DMA with schedules showing the valleys with the highest priorities. Fugro National also recommended locations for the profiles in the FY 79 studies within the constraints that they should follow existing roads or trails. Any required inner zone terrain corrections are calculated by Fugro National prior to making geologic interpretations.

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1.0 INTRODUCTION

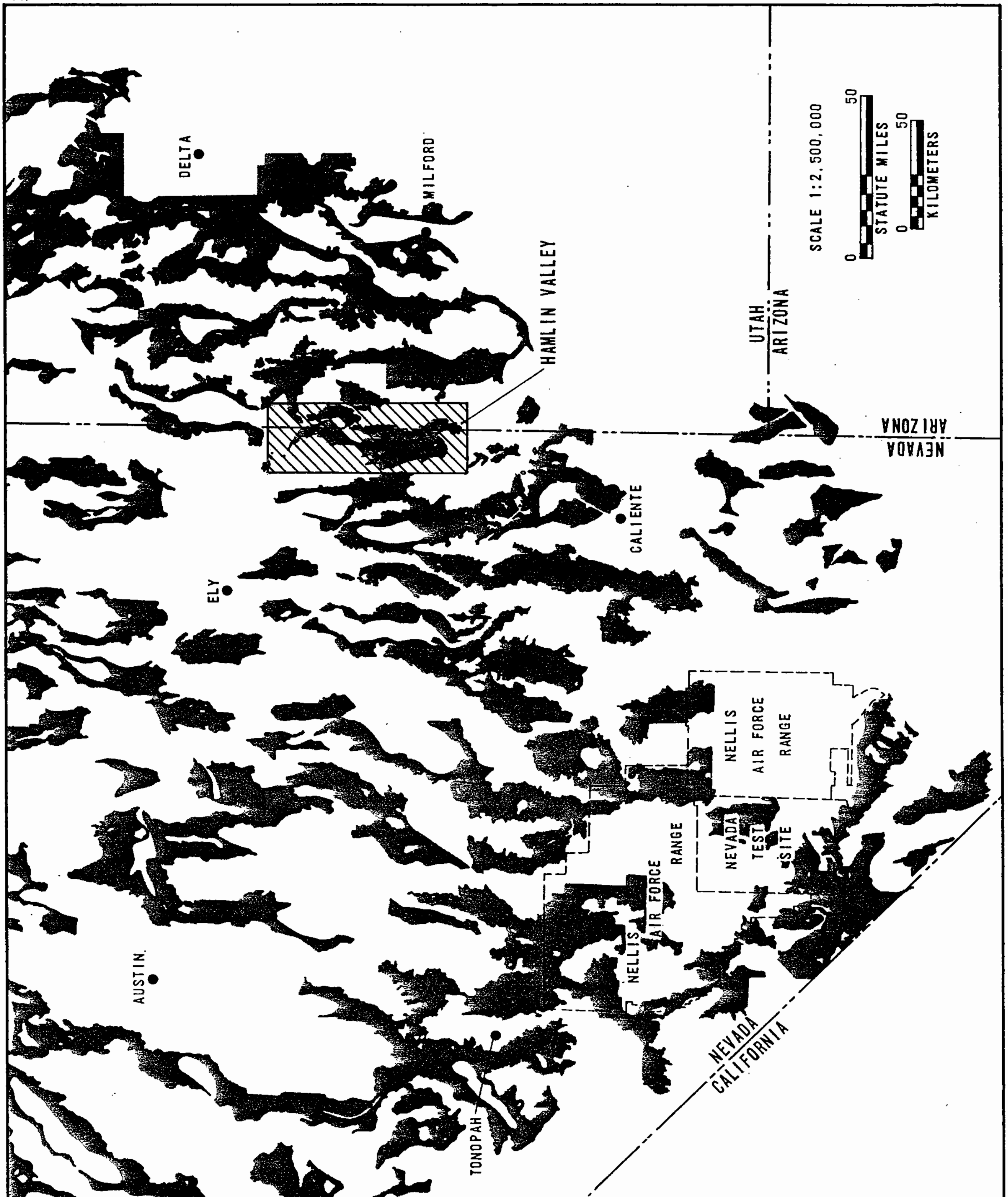
1.1 OBJECTIVE

Gravity measurements were made in Hamlin Valley for the purpose of estimating the overall shape of the structural basin and the thickness of alluvial fill. The estimates will be useful in modeling the dynamic response of ground motion in the basin and in evaluating ground-water resources.

1.2 LOCATION

Hamlin Valley is located principally in Lincoln and White Pine counties in east-central Nevada with portions in Millard, Beaver, and Iron counties, Utah (Figure 1). Hamlin Valley is approximately 180 miles (300 km) NNE of Las Vegas, Nevada. U.S. Highway 50 crosses the north end of the valley. There are no paved roads within the valley, but access is generally good along well maintained ranch and mine roads. The nearest towns are Baker, Nevada and Garrison, Utah, along Highway 73 near the northwest corner of the valley.

Hamlin Valley is bounded by mountain ranges on three sides and open to Snake Valley on the north (Figure 2). The Burbank Hills and the Needle Range form the eastern boundary of the valley. The Snake Range and the Limestone Hills comprise the western side, and the White Rock Mountains form the southern border. Most of the valley is undeveloped rangeland with several ranches and agricultural fields along Hamlin Wash.



LOCATION MAP
HAMLIN VALLEY, NEVADA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - BMO	FIGURE 1

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1.3 SCOPE OF STUDY

The Defense Mapping Agency Hydrographic/Topographic Center/-Geodetic Survey Squadron (DMAHTC/GSS) obtained 255 gravitational field measurements along nine cross valley profiles in Hamlin Valley. Profile positions are shown in Figure 2 and the locations of the individual stations are shown in Figure 3. The profiles are oriented approximately east-west. They are between 6 and 14 miles (11 to 23 km) long and are spaced approximately 5 miles (8.5 km) apart. The gravity sampling interval was 1 mile (1.6 km) over the central valley section and .25 mile (.4 km) near the valley boundaries. The more dense sampling was used on the valley flanks to define any steep gravity gradients associated with boundary faults and to resolve anomalies with high spatial frequency that could be associated with shallow bedrock.

The tolerance for establishing the station elevations was 5 feet (1.5 m), which limits the gravity precision to .3 milligals.

2.0 GRAVITY DATA REDUCTION

DMAHTC/GSS obtained the basic observations and reduced them to Simple Bouguer Anomalies (SBA) for each station as described in Appendix A1.0. Up to three levels of terrain corrections were applied to convert the SBA to the Complete Bouguer Anomaly (CBA). First, the Defense Mapping Agency Aerospace Center (DMAAC), St. Louis, used its library of digitized terrain data and a computer program to calculate terrain corrections out to 104 miles (167 km) from each station. When the program could not calculate the terrain effects near a station, a ring template was used to estimate the effect of terrain within approximately 3000 feet of the station. The third level of terrain corrections was applied to those stations where 10 feet or more of relief was observed within 130 feet. In these cases, the elevation differences were measured in the field at a distance of 130 feet along six directions from the stations. These data were used to calculate the effect of the very near relief. The CBA data for the Hamlin Valley stations are listed in Appendix A2.0.

3.0 GEOLOGIC SUMMARY

The structural geologic setting, major rock types, and depositional regime of the valley fill material are important considerations in the interpretation of gravitational field data.

Hamlin Valley is an elongate north-south trending alluvial basin exhibiting typical Basin and Range structure. Block faulting has formed this strong north-south physiographic framework. According to Hintze (1963), a fault concealed by alluvium parallels the eastern margin of the valley. Rocks in the Needle Range are cut by predominantly north-south trending faults. Most faults in the Snake Range, White Rock Mountains, and Limestone Hills have northwest or north-south orientations.

There is evidence of recent upwarping of the southern end of the valley. The southwestern lake beds are at a relatively high topographic level and are being actively eroded, and the drainage trends anomalously to the north. The alluvium is offset by numerous small faults in this part of the valley (Fugro National, 1979).

The mountains in the northern section of the valley are composed of an assemblage of Paleozoic limestones, dolomites, shales, and sandstones (Hintze, 1963; Hose and Blake, 1976; Tschanz and Pampeyan, 1970). The White Rock Range, on the south and the central portion of the Needle Range, on the east, are composed of undifferentiated Tertiary volcanic rocks.

Most of the surficial deposits in Hamlin Valley are late Tertiary and Quaternary alluvial fan and lake deposits. Basin fill deposits are described in the Verification Studies (FY 79, FN-TR-27-1A). Three relative ages of alluvial fans are recognized. The older fan deposits, consisting of well-indurated gravels and sandy gravels near the Needle and Snake Ranges, are the least extensive unit. Intermediate age alluvial fan deposits are the most extensive surficial unit. They are composed chiefly of silty to clayey sands. Younger alluvial fan, terrace, and modern stream channel deposits consist dominantly of silty sand, and generally occcur in the central part of the valley. Lacustrine deposits, primarily clayey sands, underlie about one-fifth of the valley and are generally restricted to the west side of Hamlin Wash (Fugro National, 1979).

4.0 INTERPRETATION

A negative gravity anomaly over a valley such as Hamlin Valley is created when low density alluvial material filling the valley is surrounded by dense rock in the mountains. Gravity profiles across such a valley are often U-shaped, low in the middle where the fill is thickest, and high on the ends where the fill thins and disappears. Interpretation requires removal of regional trends leaving the gravity reflection of the valley fill. The gravity data and interpreted geologic model for the nine profiles across Hamlin Valley are shown in Figures 4 through 12.

4.1 REGIONAL - RESIDUAL SEPARATION

A fundamental step in gravity interpretation is isolation of the portion of the CBA which represents the geologic feature of interest, in this case the relatively low density valley fill. The portion of the CBA which corresponds to this alluvial material is called the 'residual anomaly'.

The residual anomaly was isolated by first estimating the way the CBA field would have appeared if there had been no valley fill present. This estimated field is called the 'regional' gravity. The regional gravity is subtracted from the CBA to produce the residual anomaly. For this study, the regional field was calculated by linear interpolation between the CBA values at bedrock stations on opposite ends of the profiles. Where only one end of a profile was on bedrock, the regional value on the other end was assigned a quantity consistent with the regional trend in the area. This separation technique is only approximate. Some regional effects may still remain after the subtraction but the error is probably small compared to the large residual anomaly values on these profiles.

The regional field used for each profile is shown together with the CBA in the top portion of Figures 4 through 12. The residual values along each profile are shown by the crosses (x) in the center portions of Figures 4 through 12.

4.2 DENSITY SELECTION

The construction of a geologic model to account for the residual anomaly requires selection of density values representative of the basin fill and of the underlying rock. Since only very generalized density information is available, the geologic interpretation of the gravity data can only be a coarse approximation. Average in situ density of the alluvial fill material was measured between a depth of 100 and 160 feet by six shallow borings in Hamlin Valley. The observed density range for the soil was 2.0 to 2.3 g/cm^3. These borings were drilled during the Verification Studies of Hamlin Valley (FY 79, FN-TR-27-IV). The larger density value was used in the modeling process to approximate the overall density increase in the alluvium due to compaction with depth (see Grant and West, 1965).

Published values for carbonate rocks typically range between 2.6 and 2.8 g/cm^3. The Paleozoic carbonate rocks in Nevada are generally reported to be relatively high in density, on the order of 2.8 g/cm^3. The Nevada volcanic rocks are highly variable in density, ranging between 2.2 and 2.5 g/cm^3.

The calculated basin depths are very dependent on the density values assigned to the various valley materials. A one percent change in the average alluvial fill density will result in a five percent change in the calculated fill thickness.

4.3 MODELING

An iterative computer program that calculates the gravitational field for two-dimensional models was used to establish a thickness of alluvium under each profile. The cross-sectional models appear as a set of either 1 or 0.5-km-wide blocks whose tops are at surface elevation and whose bottoms represent the alluvium-bedrock boundary. The elevations at the bottoms of the blocks were adjusted by iterative computation until the computed gravity anomaly for the valley fill differed by less than 1 milligal from the observed residual gravity anomaly. The computed gravity anomaly from the final model is shown as a continuous line in the center portion of Figures 4 through 12. The resulting basin models are shown in the lowest section of Figures 4 through 12. The cross sections have a five times vertical exaggeration so that gentle slopes appear steep.

The gravity survey of Hamlin Valley indicates a structural basin which was formed as a deep graben bounded by steep faults. The basin appears to be several thousand feet deeper in the center, near profiles HV-5 and HV-6, than it is at either end. Actually, it is effectively terminated near profile HV-8. Another basin appears to lie southeast of profile HV-8. Even though the basin is elongate N-S, there appears to be a component of E-W deformation. The rock outcrop lines strike approximately E-W for about 6 miles on both sides of the valley. On the east side, this trend occurs near profile HV-2 and on the west side it occurs near HV-3. South of profile HV-6, the strike of the rock outcrops is NW-SE. The gravity profiles indicate that the axis of the basin also shifts in direction, or is offset laterally, at several places in the valley. The axis at profile HV-1 (which may actually be the axis of Snake Valley) appears to be approximately 5 miles east of the axis at profile HV-2, and it apparently trends N-S between profiles HV-2 and HV-3. The basin appears to be wider and more complicated beneath profiles HV-4 and HV-5 and the location of the axis is subject to question. However, it seems to be a mile or so west of the axis at HV-3. The orientation of profiles HV-7 and HV-8 is such that they probably do not show the axis of the structural basin.

Steep gravity gradients in this basin and range valley are interpreted as being caused by bedrock faults. The faults are interpreted on the gravity profiles where the gradients are maximum. See Figure 13 for an interpretation of possible fault relationships between the profiles. Major-range bounding faults can be interpreted with confidence on profiles HV-2 through HV-6. The displacement associated with the boundary faults increases progressively from profiles HV-2 through HV-5, and decreases from HV-5 to HV-6. If these faults intersect profiles HV-7 and 8, they cross at oblique angles and show only a component of offset.

Neither of the boundary faults show clearly on profile HV-1. According to the trend established from profile HV-5 to HV-2, the offset at HV-1 would be relatively small and the gravity expression would be correspondingly subtle. If the suggestion that there has been E-W deformation between profiles HV-1 and HV-2 is correct, HV-1 may have crossed only the west-boundary fault.

Hintze (1963) shows a fault covered by alluvium along the eastern boundary of the valley. However, the gravity interpretation indicates that there is a pediment-like feature on the east side of the valley and that rock extends westward from the outcrop at shallow depths for 2 to 4 miles (3 to 7 km) before being faulted downward. No corresponding feature is shown on the western valley flanks, where the boundary fault appears to be much nearer the rock outcrop line.

Profiles HV-4 and HV-5 indicate that there may be one or more smaller faults within the basin, forming a local graben along the western boundary. The interpretation, Figure 13, shows a fault roughly parallel to and approximately 1 mile (1.6 km) east of the western boundary fault.

The gravity survey shows the southeastern end of the valley to suddenly become substantially shallower at Profile lines 7 and 8. The maximum depth of the basin shown on these profiles varies from about 1300 to 500 feet (397 to 153 m). The alluvial fill is very thin at the center of each of these profiles suggesting an E-W trending bedrock ridge extending toward the extrusive volcanic rock outcrops mapped in this area. This bedrock ridge could restrict north-south movement of ground water. An alternative interpretation of profiles HV-7 and 8 is that they cross a shallow flow of igneous material with a density greater than the alluvium. If this is the case there may be substantial thickness of alluvium beneath the flow.

Profile HV-9 crosses the southern end of the valley where it trends NW-SE. The profile extends across the Needle Range into Pine Valley. The pediment feature is absent here, and the gravity interpretation is consistent with the fault suggested by Hintze (1963) in this part of the valley. This portion of the Needle Range is interpreted to be a horst since a fault is interpreted also on the western flank of Pine Valley. A boundary fault is also suggested near the southwestern end of profile HV-9. It is assumed that this fault runs parallel to the northern boundary of the White Rock mountains. It may also be seen on the southern end of profile HV-8. The depth of the basin beneath profile HV-9 is about 2800 feet (853 m).

5.0 CONCLUSIONS

The interpretation of the gravity survey of Hamlin Valley indicates that there are major range bounding normal faults on both sides of the valley. The major graben block between these boundary faults is oriented NNE-SSW. It is calculated to be between 2450 feet (747 m) deep in the north end of the valley and 6700 feet (2042 m) deep near the valley center.

There may be a smaller graben trending NNW along the western side of the major block, near profiles HV-4 and HV-5. This smaller block appears to be from 1000 to 2000 feet (305 to 610 m) deeper than the main block.

A bedrock ridge, which could restrict all but the shallowest ground water movement is interpreted near profiles HV-7 and HV-8.

There is a large, well defined negative gravity anomaly associated with Hamlin Valley. An average density contrast of 0.50 g/cm^3 between the alluvium and bedrock was used to calculate the thickness of the valley fill material. The calculated bedrock depth can only be an approximation since little is known about the actual density distribution in and around the valley. Future studies that acquire better density data or depth to bedrock in deep parts of the valley can be used to refine the gravity interpretation.

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APPENDIX A1.0

GENERAL PRINCIPLES OF THE GRAVITY EXPLORATION METHOD

A1.0 GENERAL PRINCIPLES OF THE GRAVITY EXPLORATION METHOD

A1.1 GENERAL

A gravity survey involves measurement of differences in the gravitational field between various points on the earth's surface. The gravitational field values being measured are the same as those influencing all objects on the surface of the earth. They are generally associated with the force which causes a 1 gm mass to be accelerated at 980 cm/sec^2. This force is normally referred to as a 1 g force.

Even though in many applications the gravitational field at the earth's surface is assumed to be constant, small but distinguishable differences in gravity occur from point to point. In a gravity survey, the variations are measured in terms of milligals. A milligal is equal to 0.001 cm/second^2 or 0.00000102 g. The differences in gravity are caused by geometrical effects, such as differences in elevation and latitude, and by lateral variations in density within the earth. The lateral density variations are a result of changes in geologic conditions. For measurements at the surface of the earth, the largest factor influencing the pull of gravity is the density of all materials between the center of the earth and the point of measurement.

To detect changes produced by differing geological conditions, it is necessary to detect differences in the gravitational field as small as a few milligals. To recognize changes due to geological conditions, the measurements are "corrected" to account for changes due to differences in elevation and latitude.

Given this background, the basic concept of the gravitational exploration method, the anomaly, can be introduced. If, instead of being an oblate spheroid characterized by complex density variations, the earth were made up of concentric, homogeneous shells, the gravitational field would be the same at all points on the surface of the earth. The complexities in the earth's shape and material distribution are the reason that the pull of gravity is not the same from place to place. A difference in gravity between two points which is not caused by the effects of known geometrical differences, such as in elevation, latitude, and surrounding terrain, is referred to as an "anomaly."

An anomaly reflects lateral differences in material densities. The gravitational attraction is smaller at a place underlain by relatively low density material than it is at a place underlain by a relatively high density material. The term "negative gravity anomaly" describes a situation in which the pull of gravity within a prescribed area is small compared to the area surrounding it. Low-density alluvial deposits in basins such as those in the Nevada-Utah region produce negative gravity anomalies in relation to the gravity values in the surrounding mountains which are formed by more dense rocks.

The objective of gravity exploration is to deduce the variations in geologic conditions that produce the gravity anomalies identified during a gravity survey.

A1.2 INSTRUMENTS

The sensing element of a LaCoste and Romberg gravimeter is a mass suspended by a zero-length spring. Deflections of the mass from a null position are proportional to changes in gravitational attraction. These instruments are sealed and compensated for atmospheric pressure changes. They are maintained at a constant temperature by an internal heater element and thermostat. The absolute value of gravity is not measured directly by a gravimeter. It measures relative values of gravity between one point and the next. Gravitational differences as small as 0.01 milligal can be measured.

A1.3 FIELD PROCEDURES

The gravimeter readings were calibrated in terms of absolute gravity by taking readings twice daily at nearby USGS gravity base stations. Gravimeter readings fluctuate because of small time-related deviations due to the effect of earth tides and instrument drift. Field readings were corrected to account for these deviations. The magnitude of the tidal correction was calculated using an equation suggested by Goguel (1954):

$$C = P + N\cos\phi\,(\cos\phi + \sin\phi) + S\cos\phi\,(\cos\phi - \sin\phi)$$

where C is the tidal correction factor, P, N, and S are time-related variables, and ϕ is the latitude of the observation point. Tables giving the values of P, N, and S are published annually by the European Association of Exploration Geophysicists.

The meter drift correction was based on readings taken at a designated base station at the start and end of each day. Any difference between these two readings after they were corrected for tidal effects was considered to have been the result of instrumental drift. It was assumed that this drift occurred at a uniform rate between the two readings. Corrections for drift were typically only a few hundredths of a milligal. Readings corrected for tidal effects and instrumental drift represented the observed gravity at each station. The observed gravity values represent the total gravitational pull of the entire earth at the measurement stations.

A1.4 DATA REDUCTION

Several corrections or reductions are made to the observed gravity to isolate the portion of the gravitational pull which is due to the crustal and near-surface materials. The gravity remaining after these reductions is called the "Bouguer Anomaly." Bouguer Anomaly values are the basis for geologic interpretation. To obtain the Bouguer Anomaly, the observed gravity is adjusted to the value it would have had if it had been measured at the geoid, a theoretically defined surface which approximates the surface of mean sea level. The difference between the "adjusted" observed gravity and the gravity at the geoid calculated for a theoretically homogeneous earth is the Bouguer Anomaly.

Four separate reductions, to account for four geometrical effects, are made to the observed gravity at each station to arrive at its Bouguer Anomaly value.

a. <u>Free-Air Effect</u>: Gravitational attraction varies inversely as the square of the distance from the center of the earth. Thus corrections must be applied for elevation. Observed gravity levels are corrected for elevation using the normal vertical gradient of:

$$FA = -0.09406 \text{ mg/ft } (-0.3086 \text{ milligals/meter})$$

where FA is the free-air effect (the rate of change of gravity with distance from the center of the earth). The free-air correction is positive in sign since the correction is opposite the effect.

b. <u>Bouguer Effect</u>: Like the free-air effect, the Bouguer effect is a function of the elevation of the station, but it considers the influence of a slab of earth materials between the observation point on the surface of the earth and the corresponding point on the geoid (sea level). Normal practice, which is to assume that the density of the slab is 2.67 grams per cubic centimeter was followed in these studies. The Bouguer correction (B_c), which is opposite in sign to the free-air correction, was defined according to the following formula.

$$B_c = 0.01276\ (2.67)\ h_f \text{ (milligals per foot)}$$

$$B_c = 0.04185\ (2.67)\ h_m \text{ (milligals per meter)}$$

where h_f is the height above sea level in feet and h_m is the height in meters.

c. Latitude Effect: Points at different latitudes will have different "gravities" for two reasons. The earth (and the geoid) is spheroidal, or flattened at the poles. Since points at higher latitudes are closer to the center of the earth than points near the equator, the gravity at the higher latitudes is larger. As the earth spins, the centrifugal acceleration causes a slight decrease in gravity. At the higher latitudes where the radii of the circles of latitude are smaller, the centrifugal acceleration diminishes. The gravity formula for the Geodetic Reference System, 1967, gives the theoretical value of gravity at the geoid as a function of latitude. It is:

$$g = 978.0381\ (1 + 0.0053204 \sin^2 \phi - 0.0000058 \sin^2 2\phi) \text{ gals}$$

where g is the theoretical acceleration of gravity and ϕ is the latitude in degrees. The positive term accounts for the spheroidal shape of the earth. The negative term adjusts for the centrifugal acceleration.

The previous two corrections (free air and Bouguer) have adjusted the observed gravity to the value it would have had at the geoid (sea level). The theoretical value at the geoid for the latitude of the station is then subtracted from the adjusted observed gravity. The remainder is called the Simple Bouguer Anomaly (SBA). Most of this gravity represents the effect of material beneath the station, but part of it may be due to irregularities in terrain (upper part of the Bouguer slab) away from the station.

d. <u>Terrain Effect</u>: Topographic relief around the station has a negative effect on the gravitational force at the station. A nearby hill has upward gravitational pull and a nearby valley contributes less downward attraction than a nearby material would have. Therefore, the corrections are always positive. Corrections are made to the SBA when the terrain effects were 0.1 milligal or larger. Terrain corrected Bouguer values are called the Complete Bouguer Anomaly (CBA). When the CBA is obtained, the reduction of gravity at individual measurement points (stations) is complete.

A1.5 INTERPRETATION

The first step in interpretation is to separate the portion of the CBA that might be caused by the lightweight, basin-fill material overlying the heavier bedrock material which forms the surrounding mountains and presumably the basin floor. Since the valley-fill sediments are absent at the stations read in the mountains, the CBA values at these bedrock stations are used as the basis for constructing a regional field over the valley. A regional field is an estimation of the values the CBA would have had if the light weight sediments (the anomaly) had not been there.

The difference between the CBA and the regional field is called the "residual" field or residual anomaly. The residual field is the interpreter's estimation of the gravitational effect of the geologic anomaly. The zero value of the residual anomaly is not exactly at the rock outcrop line but at some distance on the "rock" side of the contact. The reason for this is found in the explanation of the terrain effect. There is a component of gravitational attraction from material which is not directly beneath a point.

If the "regional" is well chosen, the magnitude of the residual anomaly is a function of the thickness of the anomalous (fill) material and the density contrast. The density contrast is the difference in density between the alluvial and bedrock material. If this contrast were known, an accurate calculation of the thickness could be made. In most cases, the densities are not well known and they also vary within the study area. In these cases, it is necessary to use typical densities for materials similar to those in the study area.

If the selected average density contrast is smaller than the actual density contrast, the computed depth to bedrock will be greater than the actual depth and vice-versa. The computed depth is inversely proportional to the density contrast. A ten percent error in density contrast produces a ten percent error in computed depth. An iterative computer program is used to calculate a subsurface model which will yield a gravitational field to match (approximately) the residual gravity anomaly.

APPENDIX A2.0

HAMLIN VALLEY

GRAVITY DATA

PROFILE #1
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG	MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
HV0101	385147	114	962	6733B	3	476430463	74641145080206763	1692	79205
HV0102	385159	114	865	6531V	4	435430489	74781146526206780	1212	79377
HV0103	385155	114	769	6463B	0	286430486	74920147655206774	1708	79951
HV0104	385147	114	735	6286V	0	325430473	74969148195206763	597	79481
HV0105	385143	114	699	6237B	0	281430467	75022148581206756	520	79530
HV0106	385138	114	671	6183B	0	288430459	75063148951206749	392	79592
HV0107	385128	114	641	6126B	0	271430442	75107149353206734	277	79653
HV0108	385123	114	613	6095B	0	258430434	75147149624206727	265	79733
HV0109	385106	114	593	6141B	0	222430403	75177149299206702	392	79670
HV0110	385109	114	561	6094B	0	209430411	75223149637206706	285	79709
HV0111	385112	114	531	6043V	0	199430417	75267149980206711	139	79728
HV0112	385114	114	495	5978V	0	189430423	75319150424206714	-34	79767
HV0113	385113	114	465	5929V	0	182430422	75362150775206713	-138	79822
HV0114	385109	114	435	5892B	0	174430416	75406151008206706	-245	79832
HV0115	385106	114	345	5751B	0	157430415	75536152191206702	-386	80156
HV0116	385120	114	258	5651V	0	144430445	75661152753206723	-791	80081
HV0117	385140	114	175	5563B	0	134430486	75780153440206752	-958	80203
HV0118	385205	114	81	5439S	0	136430611	75912154466206848	-1194	80391
HV0119	385250	114	18	5377B	1	149430697	76000155310206914	-1000	80810

END OF LIST

PROFILE #2
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG	MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
HV0201	384820	114	891	6678B	2	484429861	74763145380206281	1956	79664
HV0202	384805	114	868	6582B	1	458429834	74797145877206259	1563	79574
HV0203	384795	114	844	6475B	1	426429817	74832146479206245	1179	79521
HV0204	384787	114	818	6347B	0	407429803	74870147206206233	714	79472
HV0205	384784	114	791	6247B	0	374429799	74910147726206228	291	79359
HV0206	384783	114	762	6153B	0	340429798	74952148147206227	-173	79182
HV0207	384775	114	737	6075B	0	321429785	74988148444206215	-593	79007
HV0208	384772	114	705	5993B	0	291429780	75035148771206210	-1032	78817
HV0209	384763	114	673	5913B	0	274429765	75082149124206197	-1419	78686
HV0210	384759	114	645	5851B	0	253429759	75122149442206191	-1683	78614
HV0211	384745	114	620	5797B	0	242429734	75159149717206170	-1900	78572
HV0212	384730	114	595	5734B	0	231429708	75196150023206148	-2159	78514
HV0213	384719	114	571	5690B	0	218429689	75232150261206132	-2320	78490
HV0214	384712	114	515	5622B	0	195429676	75313150712206122	-2499	78520
HV0215	384697	114	404	5525V	0	156429656	75475152318206100	-1784	79527
HV0216	384686	114	339	5478V	0	145429638	75570152966206084	-1562	79699
HV0217	384650	114	293	5461S	0	136429574	75639153371206030	-1265	80245
HV0218	384588	114	292	5439S	0	136429459	75644153403205940	-1349	80236
HV0219	384528	114	258	5480S	0	127429350	75697153095205852	-1182	80254

END OF LIST

PROFILE #3
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM OBSV GRAV THEO GRAV	FAA	CBA +1000
HV0301	384226	1141064	6921B	0	489428754	74546143749205407	3480	80365
HV0302	384212	1141046	6737B	0	380428729	74573144935205387	2953	80357
HV0303	384194	1141029	6582B	0	352428697	74599145903205360	2495	80397
HV0304	384177	1141014	6473B	0	351428666	74621146585205335	2173	80446
HV0305	384168	114 989	6342B	0	351428650	74658147375205322	1742	80463
HV0306	384155	114 968	6262V	0	299428627	74689147845205302	1484	80423
HV0307	384137	114 951	6166V	0	252428595	74715148420205276	1174	80396
HV0308	384125	114 929	6073B	0	255428573	74748148933205259	835	80375
HV0309	384118	114 902	5973B	0	227428562	74787149402205248	365	80221
HV0310	384117	114 874	5880B	0	218428561	74828149834205247	-76	80088
HV0311	384113	114 847	5795S	0	204428555	74867150190205241	-512	79927
HV0312	384113	114 767	5661S	0	176428559	74983150428205241	-1535	79333
HV0313	384067	114 680	5608B	0	143428477	75112150058205173	-2340	78677
HV0314	384019	114 608	5598V	0	129428392	75219150438205102	-1980	79055
HV0315	383975	114 530	5581Y	0	128428314	75335151203205038	-1310	79783
HV0316	383972	114 460	5610B	0	133428312	75437151436205034	-802	80197
HV0317	383942	114 366	5760B	0	141428261	75575150994204989	218	80712
HV0318	383913	114 310	5877B	0	152428210	75658150464204947	831	80938
HV0319	383906	114 283	5933V	0	155428198	75697150189204937	1088	81009
HV0320	383898	114 259	5989V	0	162428184	75733149872204925	1314	81049
HV0321	383888	114 235	6057B	0	171428167	75768149517204910	1613	81126
HV0322	383875	114 214	6117B	0	188428144	75799149222204891	1902	81227
HV0323	383864	114 191	6181B	0	189428125	75833148868204875	2166	81274
HV0324	383850	114 169	6248B	0	204428100	75866148520204654	2471	81364
HV0325	383844	114 143	6323B	0	216428090	75904148052204845	2714	81367
HV0326	383840	114 117	6386B	1	252428084	75942147773204839	3036	81508

END OF LIST

PROFILE #4
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTH	EAST UTM OBSV GRAV THEO GRAV	FAA	CBA +1000
HV0401	383440	1141564	6132B	8	303427278	738651475532O4252	1015	80411
HV0402	383441	1141536	6012B	0	152427281	73905148260204253	595	80240
HV0403	383439	1141508	5935B	0	146427279	73946148531204250	138	80041
HV0404	383438	1141479	5861B	0	135427278	73988148805204248	-283	79862
HV0405	383439	1141457	5825B	0	130427281	74020148940204250	-486	79776
HV0406	383436	1141423	5776B	0	126427277	74070149112204245	-775	79652
HV0407	383435	1141387	5748V	0	119427277	74122149120204245	-1031	79485
HV0408	383436	1141352	5731S	0	115427280	74173148995204245	-1314	79254
HV0409	383437	1141317	5722S	0	110427283	74224148828204247	-1567	79026
HV0410	383436	1141281	5717S	0	106427283	74276148716204245	-1725	78882
HV0411	383437	1141245	5705Y	0	104427287	74328148630204247	-1925	78721
HV0412	383476	1141197	5708Y	0	102427361	74396148820204305	-1764	78869
HV0413	383511	1141153	5707Y	0	99427428	74458148820204356	-1825	78809
HV0414	383508	1141070	5688S	0	98427426	74578148761204352	-2059	78639
HV0415	383507	114 985	5667Y	0	98427428	74702148729204350	-2287	78483
HV0416	383517	114 862	5672Y	0	98427452	74880148598204365	-2365	78367
HV0417	383533	114 813	5661Y	0	102427484	74950148789204388	-2321	78472
HV0418	383546	114 723	5657Y	0	104427512	75080149365204407	-1603	79007
HV0419	383552	114 651566111T		0	108427526	75184149991204416	-1148	79652
HV0420	383529	114 575	5726V	0	111427487	75296150093204382	-400	80181
HV0421	383511	114 499	5796Y	0	126427457	75407150167204356	360	80717
HV0422	383504	114 388	5941B	0	139427449	75569149477204345	1039	80917
HV0423	383506	114 277	6135B	0	165427458	75730148413204348	1809	81047
HV0424	383506	114 236	6222Y	0	180427460	75789147871204348	2083	81041
HV0425	383513	114 209	6287V	0	189427474	75828147421204359	2238	80983
HV0426	383521	114 183	6351B	0	213427490	75866147028204370	2436	80986
HV0427	383528	114 155	6423B	0	216427505	75906146647204381	2720	81029
HV0428	383537	114 130	6491V	0	231427523	75942146294204394	2994	81086
HV0429	383542	114 103	6571V	0	253427533	75980145922204402	3365	81207
HV0430	383556	114 70	6674Y	3	286427560	76028145772204422	4166	81692

END OF LIST

PROFILE #5
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
HV0501	382964	1141369	6248B	1	277426406	74175146183203552	1440	80406
HV0502	382970	1141340	6163V	1	210426419	74216146599203561	1041	80232
HV0503	382980	1141314	6078V	1	184426438	74254146902203576	527	79983
HV0504	382992	1141291	6000B	0	176426461	74286147349203594	226	79937
HV0505	383004	1141266	5922B	0	164426485	74322147663203611	-214	79752
HV0506	383018	1141245	5862Y	0	152426512	74352147887203632	-574	79584
HV0507	383033	1141200	5779Y	0	137426541	74416147580203654	-1685	78742
HV0508	383050	1141167	5769B	0	124426574	74463146928203679	-2458	77990
HV0509	383059	1141141	5763Y	0	118426592	74501146663203692	-2790	77672
HV0510	383085	1141057	5759Y	0	106426644	74621146645203730	-2885	77579
HV0511	383083	114 977	5767Y	0	100426644	74738146683203727	-2768	77662
HV0512	383075	114 910	5774S	0	99426632	74836146761203716	-2613	77793
HV0513	383082	114 844	5779Y	0	99426648	74931147017203726	-2320	78068
HV0514	383089	114 742	5744Y	0	107426665	75079147915203736	-1762	78754
HV0515	383085	114	63658140T	0	110426663	75233148362203730	-650	79631
HV0516	383097	114 606	5851B	0	113426686	75276148385203748	-293	79863
HV0517	383107	114 573	5901Y	0	116426706	75323148249203763	24	80013
HV0518	383102	114 542	5960B	0	123426699	75369148011203755	351	80145
HV0519	383100	114 512	5995B	0	123426696	75413147811203752	479	80155
HV0520	383096	114 481	6039B	0	133426690	75458147632203746	719	80256
HV0521	383096	114 451	6085B	0	137426692	75501147588203746	1107	80491
HV0522	383103	114 422	6130B	0	144426706	75543147467203756	1402	80639
HV0523	383110	114 391	6176Y	0	147426720	75588147462203767	1822	80904
HV0524	383112	114 362	6219B	0	153426725	75630147479203770	2239	81181
HV0527	383098	114 275	6350Y	0	0426704	75757146930203749	2946	81288
HV0528	383046	114 207	6529Y	0	186426611	75859145597203673	3375	81292
HV0529	383042	114 93	6781Y	0	241426609	76025143557203667	3714	80827
HV0530	383050	114 13	7067Y	0	323426627	76141142208203679	5046	81265

END OF LIST

PROFILE #6

HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM OBSV GRAV THEO GRAV	FAA	CBA +1000
HV0601	382595	1141493	6520C	0	159425718	74015142870203011	1226	79147
HV0602	382596	1141466	6512C	0	153425721	74054143314203013	1592	79535
HV0603	382602	1141440	6462B	0	156425733	74091143950203021	1749	79865
HV0604	382604	1141414	6416B	0	161425738	74129144276203024	1640	79917
HV0605	382606	1141385	6417B	0	152425743	74171144241203027	1609	79875
HV0606	382609	1141358	6389B	0	153425750	74210144303203031	1407	79768
HV0607	382610	1141330	6350Y	0	159425753	74251144502203033	1234	79735
HV0608	382613	1141301	6320B	0	173425760	74293144810203038	1256	79873
HV0609	382611	1141272	6290B	0	173425757	74335145004203034	1170	79890
HV0610	382608	1141242	6257B	0	159425753	74379145218203030	1075	79894
HV0611	382607	1141214	6244B	0	145425753	74420145371203028	1109	79958
HV0612	382610	1141184	6220B	0	138425760	74463145485203033	998	79919
HV0613	382606	1141155	6183Y	0	133425753	74506145606203027	772	79816
HV0614	382611	1141110	6157B	0	127425765	74571145191203034	109	79235
HV0615	382592	1141029	6084Y	0	117425733	74690144976203006	-774	78594
HV0616	382586	114 916	5997B	0	109425727	74855145232202998	-1327	78329
HV0617	382578	114 842	5970Y	0	107425716	74963145479202986	-1320	78425
HV0618	382569	114 777	5955Y	0	106425702	75058145814202973	-1113	78682
HV0619	382596	114 674	5866S	0	112425757	75206146788203013	-1016	79089
HV0620	382634	114 577	5974B	0	111425831	75345146306203068	-538	79197
HV0621	382643	114 497	6059Y	0	122425852	75461146135203081	79	79536
HV0622	382642	114 416	6152Y	0	126425854	75579145765203080	584	79727
HV0623	382632	114 386	6197B	0	128425836	75623145510203065	768	79760
HV0624	382644	114 354	6230B	0	131425860	75669145422203083	971	79855
HV0625	382647	114 317	6275Y	0	133425867	75723145177203087	1149	79880
HV0626	382644	114 288	6320B	0	140425863	75765144942203083	1338	79924
HV0627	382648	114 259	6357B	0	142425872	75807144885203088	1632	80090
HV0628	382651	114 230	6393B	0	148425879	75849144839203093	1913	80257
HV0629	382646	114 200	6427B	0	151425871	75893144660203086	2070	80298

END OF LIST

PROFILE #7

HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG	MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM OBSV GRAV THEO GRAV	FAA	CBA +1000
HV0701	381915	114	892	6488B	0	218424487	74928141801202013	646	78939
HV0702	381943	114	895	6420B	6	217424539	74922142281202055	650	78976
HV0703	381970	114	900	6369B	0	182424588	74913142527202094	373	78834
HV0704	381996	114	893	6329B	0	166424637	74922142716202132	151	78731
HV0705	382022	114	892	6298S	0	153424685	74922142888202170	-6	78666
HV0707	382188	114	803	6150B	0	120424996	75042144171202413	-358	78785
HV0708	382263	114	744	6106B	0	114425137	75124145041202523	-19	79271
HV0709	382341	114	700	6042B	0	110425284	75183146268202638	494	79997
HV0710	382410	114	634	5969Y	0	110425414	75275146926202739	364	80116
HV0711	382435	114	527	5919Y	0	124425465	75430147044202776	-25	79911
HV0712	382483	114	437	6079B	0	121425556	75558145909202846	276	79663
HV0713	382531	114	344	6178Y	0	122425652	75690145441202917	670	79721
HV0714	382566	114	300	6255Y	0	131425718	75752145188202968	1091	79886
HV0715	382578	114	274	6294B	0	133425742	75789145091202986	1342	80008
HV0716	382588	114	249	6325B	0	145425761	75625145010203001	1541	80113
HV0717	382602	114	223	6360B	0	142425789	75862144911203021	1746	80197
HV0718	382616	114	201	6400B	0	145425815	75893144742203041	1937	80253
HV0719	382630	114	177	6455Y	0	153425842	75928144506203063	2198	80335
HV0720	382641	114	157	6493B	0	158425864	75956144394203078	2430	80441
HV0721	382653	114	136	6535Y	0	164425887	75986144159203096	2571	80446

END OF LIST

PROFILE #8
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG	MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
HV0801	381923	114	785	6430D	0	189424507	750841417402020 25	234	78492
HV0802	381941	114	769	6475S	0	192424541	75106142076202052	967	79074
HV0803	381962	114	760	6382D	0	168424580	75118142722202082	707	79108
HV0804	381983	114	754	6348D	0	154424619	75125142929202113	563	79066
HV0805	382007	114	753	6294B	0	146424663	75125143195202148	281	78962
HV0806	382022	114	744	6262B	0	139424692	75138143333202170	102	78882
HV0807	382042	114	732	6249B	0	133424729	75154143487202199	102	78922
HV0808	382060	114	720	6215B	0	131424763	75170143798202226	67	79000
HV0809	382077	114	704	6193B	0	126424795	75193143988202251	26	79029
HV0810	382095	114	687	6171S	0	123424829	75216144263202277	65	79141
HV0811	382122	114	613	6119B	0	119424883	75323144646202317	-80	79169
HV0812	382157	114	546	6064B	0	119424950	75418145124202368	-174	79263
HV0813	382186	114	495	6054S	0	116425006	75491145324202411	-109	79359
HV0814	382241	114	391	5972S	0	122425113	75639146378202491	93	79846
HV0815	382246	114	338	5983S	0	129425125	75716146183202498	-6	79717
HV0816	382245	114	269	6142B	0	122425126	75816145030202497	342	79514
HV0817	382280	114	164	6295B	0	132425196	75967144091202548	792	79454
HV0818	382289	114	138	6334B	0	133425213	76005143891202562	942	79472
HV0819	382300	114	115	6364Y	0	142425235	76037143801202578	1120	79556
HV0820	382317	114	97	6392B	0	140425267	76063143791202603	1349	79688
HV0821	382334	114	77	6427B	0	140425300	76091143773202628	1630	79850
HV0822	382344	114	51	6462Y	0	146425319	76128143689202642	1666	79972

END OF LIST

PROFILE #9
HAMLIN VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
HV0901	381623	114 279	65778	6	246423975	75639141028201585	1345	79165
HV0902	381642	114 265	64828	1	233424011	75858141253201613	650	78775
HV0903	381659	114 250	64198	0	213424043	75879141612201638	388	78708
HV0904	381664	114 220	63748	0	193424053	75922141812201645	154	78609
HV0905	381673	114 190	63148	0	180424072	75966142124201659	-107	78538
HV0906	381686	114 162	62808	0	171424097	76006142317201677	-245	78504
HV0907	381699	114 134	62458	0	164424122	76046142490201697	-432	78433
HV0908	381720	114 115	62038	0	160424162	76072142744201727	-599	78403
HV0909	381742	114 100	61298	0	169424203	76093143237201759	-840	78425
HV0910	381764	114 86	61068	0	171424245	76112143407201792	-920	78426
HV0911	381761	114 54	61319T	0	166424241	76159143257201788	-817	78434
HV0912	381768	1135958	6252S	0	161424258	76298142693201796	-262	78575
HV0913	381805	1135860	64528	0	175424331	76439141977201852	656	79023
HV0914	381851	1135790	66528	0	196424420	76538141451201920	2139	79648
HV0915	381889	1135726	6814S	0	212424493	76629141247201975	3407	80378
HV0916	381917	1135644	69298	0	254424549	76747140719202016	3925	80544
HV0917	381983	1135572	72688	0	340424674	76848138345202113	4639	80191
HV0918	382063	1135528	74858	0	287424825	76907136866202230	5086	79845
HV0919	382099	1135435	7115S	0	260424896	77040139080202283	3766	79759
HV0920	382105	1135410	70558	0	206424908	77076139525202292	3639	79782
HV0921	382112	1135382	70358	0	193424922	77117139742202302	3653	79852
HV0922	382120	1135356	69638	0	191424938	77154140158202314	3378	79822
HV0923	382129	1135331	69108	0	186424956	77190140479202327	3191	79809
HV0924	382140	1135308	68648	0	176424978	77223140769202343	3030	79795
HV0925	382152	1135284	68168	0	171425001	77257141128202361	2917	79842
HV0926	382167	1135265	67558	0	167425030	77284141550202383	2744	79872
HV0927	382183	1135246	67188	0	166425060	77310141849202406	2674	79927
HV0928	382201	1135227	66678	0	164425095	77337142227202433	2545	79970
HV0929	382216	1135211	66880T	0	159425123	77359142141202455	2634	79982

END OF LIST