E-TR-33-CV

MX SITING INVESTIGATION

GRAVITY SURVEY - CAVE VALLEY

NEVADA

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FOREWORD

Methodology and Characterization studies during Fiscal Years 1977 and 1978 (FY 77 and 78) included gravity surveys in 10 valleys, five in Arizona, two in Nevada, two in New Mexico, and one in California. The gravity data were obtained for the purpose of estimating the 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 Ertec Western's (formerly Fugro National, Inc.) Characterization reports (FN-TR-26a through e).

During the FY 77 surveys, measurements were made to form an approximate 1-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 on verifying and refining 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 requested to provide gravity data from their library to supplement the gravity profiles. For Big Smoky, Hot Creek, and Big Sand Springs valleys, a sufficient density of library data was available to permit construction of interpreted contour maps instead of just two-dimensional cross sections.

In late summer of FY 79, supplementary funds became available to begin data reduction. At that time, inner zone terrain corrections were begun 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, Garden, and Coal valleys, Nevada, became available from the field in early October 1979.

A continuation of gravity interpretations was incorporated into the FY 80 and 81 programs, and the results are being summarized in a series of valley reports. Reports covering Nevada-Utah gravity studies are being numbered "E-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, were prepared. Verification studies were continued in FY 80, and gravity studies were included in the program. DMA continued to obtain the field measurements, and there was a return to the grid pattern. The interpretation of the grid data allows the production of contour maps which are valuable in the deep basin structural analysis needed for computer modeling in the water resources program. The gravity

interpretations will also be useful in Nuclear Hardness and Survivability (NH&S) evaluations.

The basic decisions governing the gravity program are made by BMO following consultation with TRW, Inc., Ertec Western, and the DMA. Conduct of the gravity studies is a joint effort between DMA and Ertec Western. 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, Missouri, calculates outer zone terrain corrections.

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

TABLE OF CONTENTS

		Page
FOREWORD		i
1.0	INTRODUCTION	1
	1.1 Objective	1
	1.2 Location	1
	1.3 Scope of Work	1
2.0	GRAVITY DATA REDUCTION	5
3.0	GEOLOGIC SUMMARY	6
4.0	INTERPRETATION	9
	4.1 Regional-Residual Separation	9
	4.2 Density Selection	10
	4.3 Modeling and Sources of Error	11
	4.4 Discussion of Results	12
5.0	CONCLUSIONS	18
REFERENCES		19

APPENDIX

APPENDIX		
A1.0	General Principles of Gravity Reduction	A1-1
A2.0	Methods of Interpretation	A2-1
A3.0	Cave Valley, Nevada, Gravity Data	A3-1

LIST OF FIGURES

Figure Number		
1	Location Map, Cave Valley, Nevada	2
2	Topographic Setting, Cave Valley, Nevada	3
3	Gravity Profile and Interpretation Across Northern Cave Valley	16
4	Schematic Geological Cross-Section, Cave Valley, Nevada	17

TABLE OF CONTENTS (cont.)

LIST OF DRAWINGS

Drawing Number		Page
1	Complete Bouguer Anomaly Contours, Cave Valley, Nevada	Drawings in Pocket at End of Report
2	Depth to Rock - Interpreted from Gravity Data	

1.0 INTRODUCTION

1.1 OBJECTIVE

Gravity measurements were made in Cave Valley for the purpose of estimating the overall shape of the structural basin, the thickness of alluvial fill, and the location of concealed faults. The estimates will be useful in modeling the dynamic response of ground motion in the basin and in evaluating groundwater resources.

1.2 LOCATION

Cave Valley is located in east-central Nevada (Figure 1). It is approximately half way between Caliente and Ely, Ely being about 55 miles (88 km) north of Cave Valley. It is bounded on the east by the Schell Creek Range, on the west by the Egan Range, and opens to the south into White River Valley (Figure 2). Cave Valley is separated from Steptoe Valley to the north by convergence of the Egan and Schell Creek ranges.

The area covered by this report lies between 38°15' and 38°45' North latitudes and 114°40' and 115°00' West longitudes.

1.3 SCOPE OF WORK

Five primary work elements were completed during this study. They are:

1. Computation and merging of terrain corrections;
2. Synthesis of regional and valley-specific geologic data;
3. Evaluation of the regional field and residual separation;
4. Inverse modeling to estimate depth to bedrock; and
5. Interpretation of structural relationships.

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LOCATION MAP
CAVE VALLEY, NEVADA

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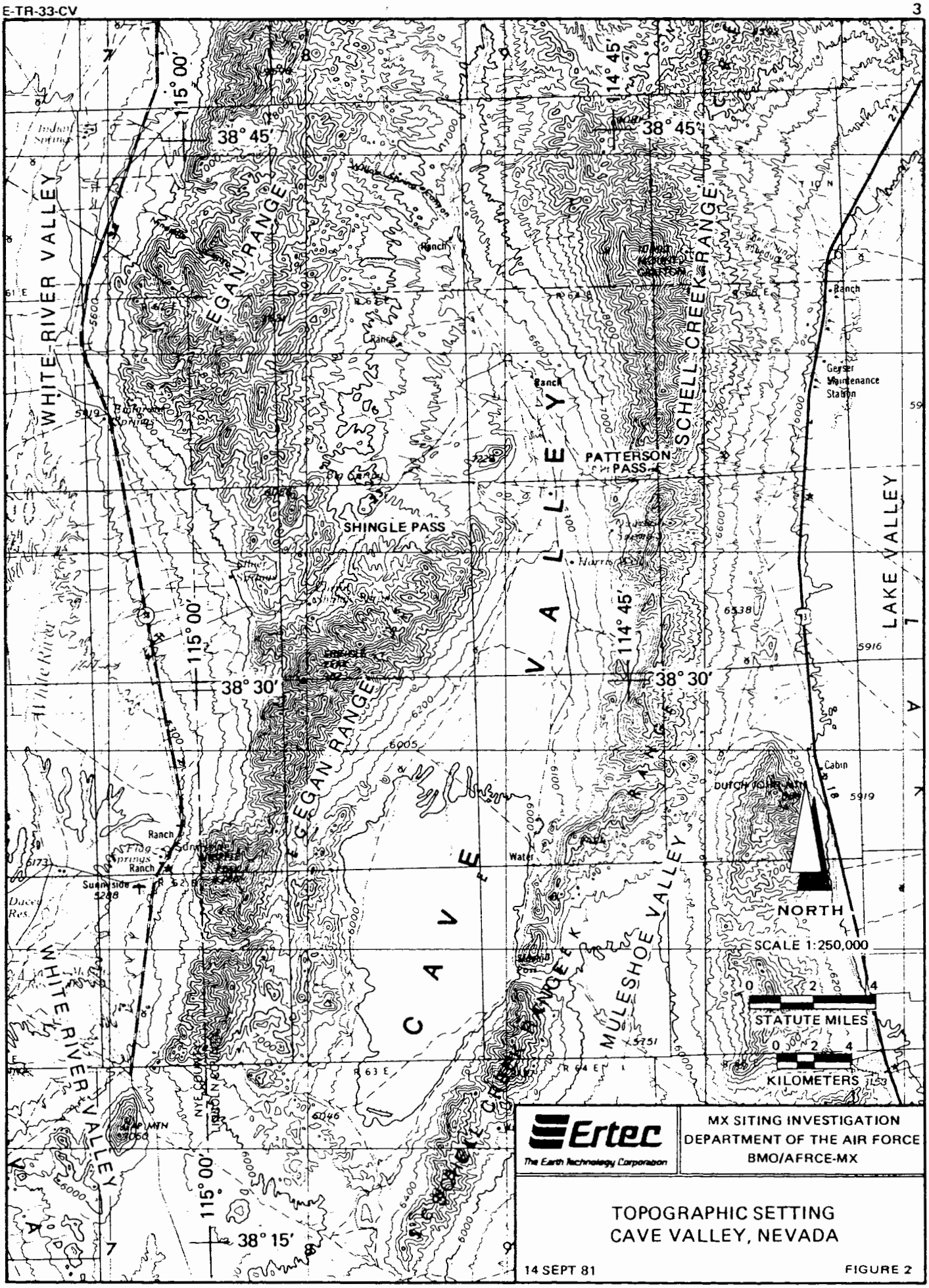
FIGURE 1


WHITE RIVER VALLEY
EGAN RANGE
SCHELL CREEK RANGE
PATTERSON PASS
SHINGLE PASS
LAKE VALLEY
CAVE VALLEY
MULESHOE VALLEY
DUTCH JOHN MTN
Geyser Maintenance Station
Cabin
Ranch
Sunnyside
Water
115° 00'
114° 45'
38° 45'
38° 30'
38° 15'
NORTH
SCALE 1:250,000
STATUTE MILES
KILOMETERS
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TOPOGRAPHIC SETTING
CAVE VALLEY, NEVADA
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FIGURE 2

The gravitational field within Cave Valley was defined by measurements from 374 stations. The principle facts for these stations are listed in Appendix A2.0, and their distribution is shown in Drawing 1.0. The Defense Mapping Agency Aerospace Center (DMAAC) supplied 143 gravity stations from its library, and 231 new gravity measurements were made by the Defense Mapping Agency Hydrographic Topographic Center/Geodetic Survey Squadron (DMAHTC/GSS).

Cave Valley and Muleshoe Valley were studied together, with the results presented in separate reports. The rectangular region containing both valleys is the area between North latitudes 38°05' and 38°45' and West longitudes 114°35' and 115°00'. There are 522 gravity stations in the region. All were used to establish a common regional gravity trend for the two valleys.

Following residual separation, the geologic modeling of the two valleys was done independently.

2.0 GRAVITY DATA REDUCTION

DMAHTC/GSS obtained the basic observations for the new stations and reduced them to Simple Bouguer Anomalies (SBA) as described in Appendix A1.0. Up to three levels of terrain corrections were applied to the new stations to convert the SBA to the Complete Bouguer Anomaly (CBA). Only the first two levels of terrain corrections described below were applied to the library stations.

First, the DMAAC, St. Louis, Missouri, used its library of digitized terrain data and a computer program to calculate corrections out to 104 miles (167 km) from each station. When the program could not calculate the terrain effects near a station, Ertec Western used a ring template to estimate the effect of terrain within approximately 3000 feet (914 m) of the station. The third level of terrain corrections was applied to those stations where 10 feet (3 m) or more of relief was observed within 130 feet (40 m). In these cases, the elevation differences were measured in the field at a distance of 130 feet (40 m) along six directions from the stations. These data were used by Ertec Western to calculate the effect of the very near relief.

3.0 GEOLOGIC SUMMARY

Cave Valley is a north-northeasterly trending valley in the eastern portion of the Great Basin section of the Basin and Range physiographic province (Fenneman, 1931). It is bounded on the east by the Schell Creek Range and on the west by the Egan Range. On its southern boundary, Cave Valley is separated from White River Valley by rounded hills having low relief. On its northern boundary, it is separated from Steptoe Valley by a narrow gap between the Schell Creek and Egan ranges.

The Schell Creek Range is composed of faulted and deformed rocks which are uplifted relative to the surrounding area. In the southern part of the range surface exposures are Paleozoic in age. These rocks include as much as 15,000 feet (4572 m) of shale, sandstone, limestone, and dolomite that range in age from Upper Cambrian to Permian. Based on stratigraphic relationships in the northern part of the range, as much as 6000 feet (1829 m) of Lower Cambrian sediments and an unknown thickness of Precambrian sediments underlie the upper Paleozoic section. These older units are composed primarily of shale, sandstone, and quartzite. In the extreme southern part of the range, early Tertiary plutonic rocks have intruded the Paleozoic rocks.

In the central part of the Schell Creek Range, an unknown thickness of middle Tertiary volcanic rocks, andesite, and welded tuff covers most of the Paleozoic section except on the western flank of the range (Ekren and others, 1977; and Tschanz and

Pampeyan, 1970). Further north, the individual blocks making up the range have been uplifted to expose lower Cambrian rocks.

Like the Schell Creek Range, the Egan Range is composed of faulted and deformed blocks of rock. The surface rocks are generally Paleozoic carbonate, shale, and sandstone with the oldest rocks exposed anywhere in the range being upper Cambrian in age. There are about 26,000 feet (7925 m) of Paleozoic rock younger than lower Cambrian in the mountain range. About 80 percent of this is carbonate with the remaining being shale and sandstone (Kellogg, 1964). Volcanic rocks, mainly tuff, and sediments of middle Tertiary age cover the Paleozoic units in only a few areas (Kellogg, 1964).

The series of low hills that separate Cave Valley from White River Valley are composed largely of early to middle Tertiary volcanic rocks, but there are occasional outcrops of Paleozoic rock. Within Cave Valley itself, the surface is principally Quaternary age sediments although several blocks of Cambrian age rocks are exposed in the northern part of the valley. The sediments are principally nonindurated to partially indurated gravel, sand, silt, and conglomerate (Synder, 1964; and Mifflin and Wheat, 1979).

The present topographic relief of Cave Valley and the surrounding area is largely the result of late Cenozoic block faulting (Stewart, 1980). However, the effect of earlier tectonics, principally the Mesozoic overthrusting and early Cenozoic Laramide orogeny, is manifest in the absence of Mesozoic age

sediments and in the deformation of the Paleozoic and older sedimentary rocks.

4.0 INTERPRETATION

The basis of interpretation in this report is the Complete Bouguer Anomaly (CBA). Complete Bouguer anomaly contours and the gravity station locations are shown in Drawing 1.

The interpretation of irregularly spaced data is both difficult and inefficient. In order to simplify the interpretation, the CBA data were reduced to a set of values on the nodes of a regularly spaced grid. The value at each node was computed using a minimum curvature gridding program (Briggs, 1974; and Swain, 1976). Minimum curvature gridding is an iterative process, the purpose of which is to find the smoothest surface that fits the irregularly spaced data. This smooth surface is then used to interpolate between the existing data points. A 0.62-mile (1-km) grid spacing, which is slightly more dense than the average data spacing, was used throughout this analysis.

4.1 REGIONAL RESIDUAL SEPARATION

A fundamental difficulty in gravity interpretation is that the gravity expression of short wavelength, shallow, structural features of interest is overlapped and obscured by long wavelength features occurring at all depths. The purpose of a regional-residual separation is to remove the effect of the longer wavelength structures so that the features of interest may be correctly interpreted.

In order to estimate the form and magnitude of the long wavelength contribution (regional), the CBA was continued upward using a Fast Fourier Transform (FFT) and a frequency domain filter (Gunn, 1975). The data were continued upward to a height at which there could be seen no correlation between the upward continued CBA and the surface structure. This was at an altitude of 60,000 feet (18,288 m). The regional was then subtracted from the CBA and the resulting residual anomaly was further adjusted by a constant -8.0 mgal to make the zero residual contour approximately fit outcrops of Paleozoic carbonate rocks.

4.2 DENSITY SELECTION

The correct interpretation of the residual anomaly requires that one select density values that are truly representative of the subsurface rock. In this analysis, unfortunately, only very generalized density information was available. Three borings were drilled approximately 100 feet (30 m) into the alluvium of Muleshoe Valley during Verification studies (Ertec, 1981b). The average density measured at the bottom of these borings was slightly less than 2.0 g/cm^3. To account for compaction with depth (Woollard, 1962), a density of 2.3 g/cm^3 was assigned to the alluvium.

Basement rocks underlying the alluvium are assumed to be similar to rocks outcropping in the nearby mountains. These consist of Tertiary volcanic and plutonic rocks and Paleozoic carbonate and siliceous sedimentary rocks. Published values for the density

of the Paleozoic rocks typically range from 2.6 to 2.9 g/cm^3. Carbonate rocks in the Paleozoic section are the most dense with some in Nevada and Utah having values near 2.8 g/cm^3. The siliceous clastic sediments generally have densities in the range 2.6 to 2.7 g/cm^3. Densities representative of the Tertiary volcanic rocks range from 2.0 to 2.5 g/cm^3 for tuffaceous material, depending on the degree of welding, compaction, and alteration; 2.3 to 2.6 g/cm^3 for the andesite and rhyolite flows; and 2.6 to 2.7 g/cm^3 for the plutonic rocks.

4.3 MODELING AND SOURCES OF ERROR

Modeling was accomplished using three computer programs. Two of these programs compute the gravitational effect of two- and three-dimensional bodies (Talwani and others, 1959; and Plouff, 1975). The third program calculates an inverse three-dimensional solution (Cordell, 1970). The two forward modeling programs were used to augment the inverse modeling program because the inverse program is capable of handling only a single density contrast; whereas, there are several density contrasts that contribute to the form of the residual anomaly.

A contour map showing the thickness of alluvial fill, based on the results of the inversion program, is shown in Drawing 2. The density contrast between alluvium and bedrock used in this analysis was 0.5 g/cm^3. There is very little independent information with which to compare this interpretation. One well, 7N-63E-14ab, was drilled into limestone at a depth of 370 feet (113 m) (Ertec, 1981c). Its location is noted in Drawing 2.

There are three principal sources of error in this analysis. First, because there is no detailed study of the actual densities of rocks in the area, we have had to rely on estimates. Second, the inverse modeling program, upon which most of the thickness of alluvium interpretation is based, is capable of handling only a single density contrast; whereas, there are probably several density contrasts which contribute to the residual anomaly. Third, the distribution of gravity data is not uniform, leaving large areas in which all of the interpretation is based on interpreted or extrapolated trends of the data.

4.4 DISCUSSION OF RESULTS

For purposes of discussion, Cave Valley is divided into a southern part and a northern part. The division between these two areas is a line between Shingle Pass in the Egan Range and Patterson Pass in the Schell Creek Range (Figure 2). The reason for the division was two-fold. First, the gravity data in the southern area are relatively uniformly distributed, while the northern area has several large gaps in the data. Second, both the CBA (Drawing 1) and the residual anomaly contours in the southern area tend to follow the shape of the mountain ranges and valley, while this simple pattern disappears completely in the northern area.

The interpreted structure of the southern part of Cave Valley is shown in the thickness of alluvium contour map (Drawing 2). This interpretation is based on geological information from published reports, analysis of aerial photographs (Ertec, 1981a),

and geological field reconnaissance as well as gravity data. For example, wherever sufficient gravity data existed, the placement of faults could be guided by the maximum horizontal gravity gradients (zero second vertical derivative). However, in areas lacking detailed gravity data, faults were based entirely on geologic data. Major faults shown in Drawing 2 may actually be systems of smaller faults. This is particularly true near the ends of major faults which typically dissipate through systems of smaller faults into a nearly continuous deformation.

Drawing 2 shows that the southern part of Cave Valley has a relatively simple structure. It is basically an alluvial-filled graben that retains a nearly constant width from north to south. It is slightly deeper in the extreme southern part where as much as 7000 feet (2134 m) of alluvium may overly the bedrock. The gravity data and geology both indicate that the graben is tilted down slightly to the east. The depth contours in Drawing 2 rise much more slowly on the west side of the valley than they do on the east side of the valley.

The interpretation of the Bouguer anomaly in northern Cave Valley is somewhat complicated. The fact that the gravity contours no longer follow the mountain ranges is a reflection of structure in the basement rocks and also of very shallow alluvium through most of this part of the valley. Outcrops of Cambrian age basement through the alluvium in places further substantiates that the alluvium is thin. Furthermore, the appearance of lower Cambrian sedimentary rocks at the surface in the Schell

Creek Range shows that the block making up the mountain range, and perhaps part of the block beneath the alluvium as well, does not contain the younger Paleozoic carbonate rocks found elsewhere in the region (Shilling and Garside, 1968). The loss of this high-density section of rocks causes the east-west trend of the gravity contours in northern Cave Valley.

Drawing 2 shows three inferred faults in northern Cave Valley. The inferred fault on the west side of the valley was placed on the basis of the juxtaposition of Cambrian and Permian sediments. The inferred fault on the east side of the valley was placed on the basis of aerial photos and field mapping (Howard, 1978). The only indication of either of these faults on the gravity contour map is the small gravity low enclosed by the -215 mgal contour on the east side of the valley (Drawing 1). The bend of the CBA contours in the central part of the valley correlate well with Kellogg's (1964) placement of the Shingle Pass fault.

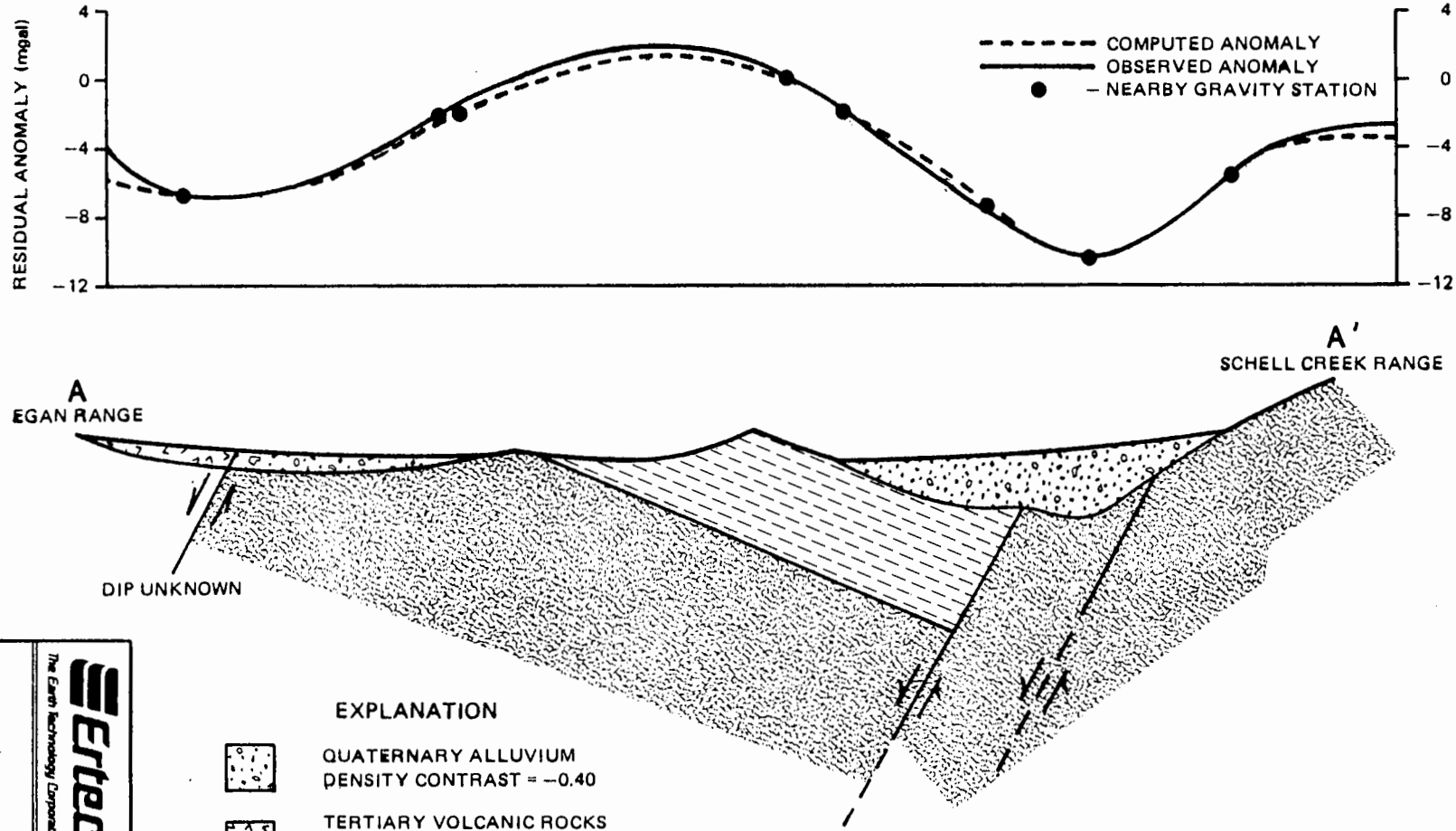
On the west side of the valley, the absence of any expression of faulting in the gravity data is probably caused by a lack of data. The lack of clear expression of faulting on the east side of the valley is caused more than anything else by a lack of density contrast across the fault which is another indication that Paleozoic carbonates are absent beneath much of the alluvium.

The small gravity low on the east side of northern Cave Valley was integrated to estimate the mass deficiency that causes it

(Grant and West, 1965). The integration resulted in a mass deficiency of 2.27 x 10^9 tons (2.5 x 10^{12} kg). If one assumes that this deficiency is caused by alluvium having a density contrast of 0.4 g/cm^3 with the Cambrian bedrock, one may conclude that the average depth of alluvium on the east side of the valley near the mountain front is about 1017 feet (310 m).

Figure 3 shows a gravity profile and interpreted cross section that crosses the northern part of the valley along section A-A' (Drawing 1). The calculations were made from a three-dimensional model of the subsurface. Figure 4 shows a more schematic cross-section across southern Cave Valley (profile B-B' in Drawing 1).

Because most of the gravity data in northern Cave Valley lie in its southern part, we have not attempted any interpretations of the extreme northern part of the valley. However, the gravity data that are available near the boundary between Cave Valley and Steptoe Valley indicate that there is probably more alluvial fill in the extreme northern part of Cave Valley than in the southern part of northern Cave Valley.



CROSS-SECTION A–A'
CAVE VALLEY, NEVADA

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FIGURE 3

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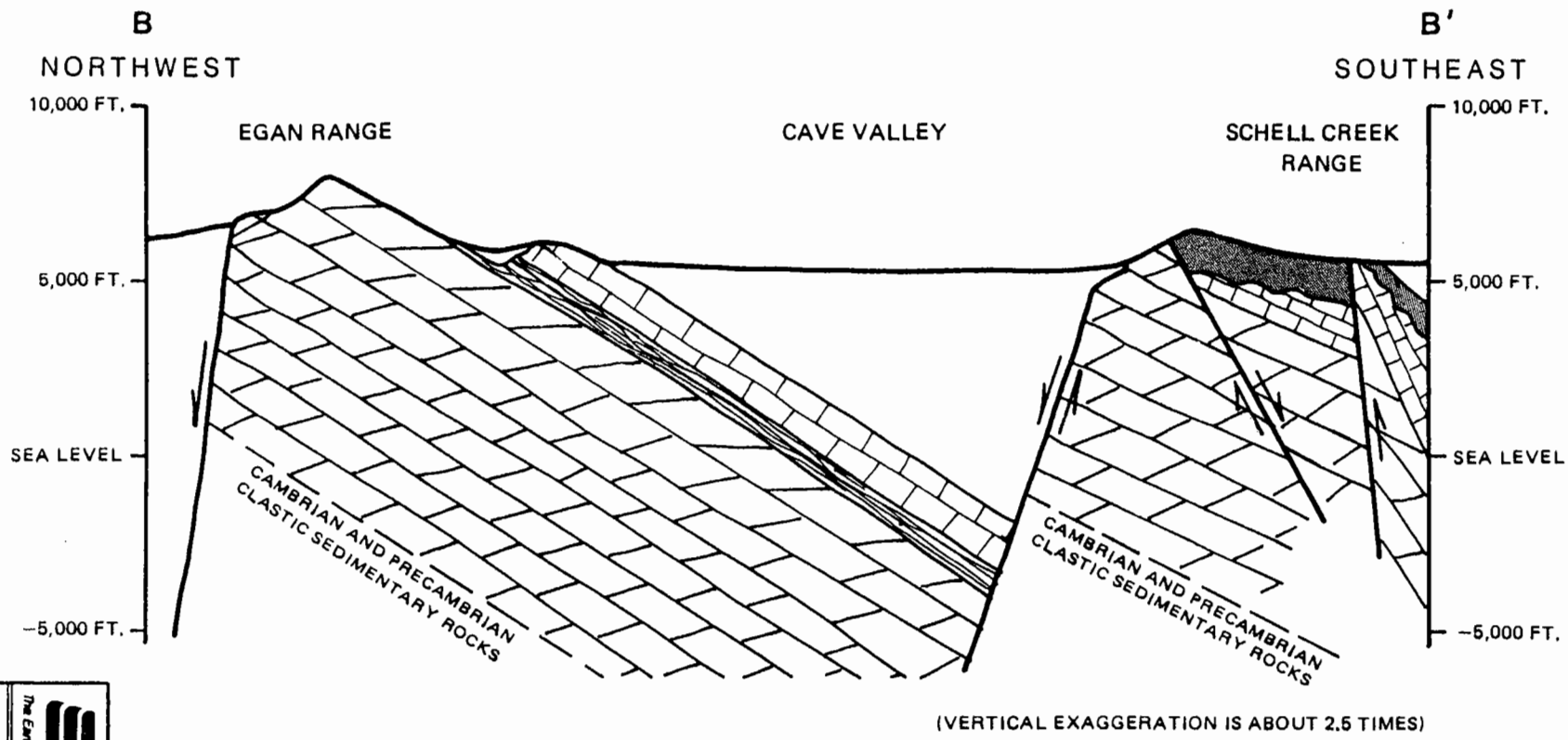

EXPLANATION

- QUATERNARY AND LATE TERTIARY (?) ALLUVIUM
- TERTIARY VOLCANIC ROCKS
- UPPER PALEOZOIC CARBONATES (PREDOMINANTLY LIMESTONE AND QUARTZITE)
- UPPER PALEOZOIC SHALES
- LOWER PALEOZOIC CARBONATES (PREDOMINANTLY DOLOMITE)

GENERALIZED GEOLOGIC CROSS-SECTION B–B'
SOUTHERN CAVE VALLEY, NEVADA

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FIGURE 4

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5.0 CONCLUSIONS

Gravity data indicate that Cave Valley may be divided into two structurally distinct regions. That part of Cave Valley lying south of a line connecting Shingle Pass in the Egan Range with Patterson Pass in the Schell Creek Range displays a structure that is common among Basin and Range province valleys. This southern part of Cave Valley is an elongated north to north-northeast trending graben that is filled with approximately 7000 feet (2134 m) of alluvium. There is some indication in both the gravity and geology that the block constituting the graben is tilted slightly to the east.

In contrast, the northern part of Cave Valley is a rather complex structure of faulted blocks of bedrock that are relatively shallow. There is an average of 1000 feet (310 m) of alluvium on the eastern side of northern Cave Valley and about 650 feet (200 m) of alluvium on the western side of northern Cave Valley. Bouguer anomaly values in extreme northern Cave Valley indicate that the alluvium may be somewhat thicker in this area. However, the Bouguer anomaly in this area could also reflect Paleozoic carbonate rocks in the nearby mountains. The section of Paleozoic carbonate rocks is missing in the Schell Creek Range on the east side of northern Cave Valley. The carbonates probably are missing also beneath the alluvium throughout parts of northern Cave Valley.

REFERENCES

Briggs, I. C., 1974, Machine contouring using minimum curvature, Geophysics, v. 39, no. 1, p. 39-48.

Cordell, Lindreth, 1970, Iterative solution of three-dimensional gravity anomaly data, Geological Survey Computer Control No. 10.

Eakin, T. E., 1963, Ground-water appraisal of Pahranagat and Pahroc Valleys, U.S. Geological Survey, Ground Water Resources-Reconnaissance Series, Report 21, p. 35.

Ekren, E. B., Orkild, P. P., Sargent, K. A., and Dixon, C. L., 1977, Geologic map of Tertiary rocks, Lincoln County, Nevada, U.S. Geological Survey Map I-1041.

Ertec Western, Inc., 1981a, MX siting investigation, geotechnical evaluation, fault study summary of Cave Valley, Nevada, unpublished.

_____, 1981b, Verification study Muleshoe Valley, Nevada v. II, geotechnical data.

_____, 1981c, Cave Valley water resources study report, unpublished.

Fenneman, W. W., 1931, Physiography of the Western United States, New York: Mc Graw-Hill, Inc., p. 534.

Goguel, Jean, 1954, A universal table for the prediction of the lunar-solar correction in gravimetry (tidal gravity corrections); Geophysical Prospecting, v. II, Supplement, March.

Grant, F. S., and West, G. F., 1965, Interpretation theory in applied geophysics, New York: McGraw-Hill Book Co.

Gunn, P. J., 1975, Linear transformations of gravity and magnetic fields, Geophysical Prospecting v. 23, p. 300-312.

Howard, E. L., 1978, Geologic map of the eastern Great Basin, Nevada and Utah, Denver, Colorado, Terra Scan Group Ltd., scale 1:250,000.

Kellogg, H. E., 1964, Cenozoic stratigraphy, structure, Egan Range, Nevada, Geological Society of American Bulletin, v. 75, 19, p. 949-968.

Mifflin, M. D., and Wheat, M. M., 1979, Pluvial lakes and estimated Pluvial climates of Nevada, Nevada Bureau of Mines and Geological Bulletin, 94, p. 57.

Plouff, D., 1975, Derivation of formulas and Fortran programs to compute gravity anomalies of prisms, U. S. Geological Report No. USGS-GD-75-015.

Schilling, J. H., and Garside, L. J., 1968, Oil and gas developments in Nevada 1953-1967, Nevada Bureau of Mines and Geology, Report 18.

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

Swain, C. J., 1976, A FORTRAN IV program for interpolating irregularly spaced data using the difference equations for minimum curvature, Computers and Geoscience, v. 1, p. 231-240.

Synder, C. T., 1964, Pleistocene lakes in the Great Basin: U. S. Geological Survey Inventory Map I-416.

Talwani, J., Worzel, J. L., and Landisman, M., 1959, Rapid computations for two-dimension bodies with application to the Mendocino Submarine Fracture Zone, J. Geophysical research, v. 64, p 49-59.

Tschanz, C. M., and Pampeyan, E. H., 1970, Geology and mineral deposits of Lincoln County, Nevada, Nevada Bureau of Mines Bulletin 73, p. 188.

Woollard, G. P., 1962, The relation of gravity anomalies to surface elevation, crustal structure, and geology, University of Wisconsin, Department of Geology, Geophysical and Polar Research Center, Madison, Wisconsin, Report 62-9.

APPENDIX A1.0

GENERAL PRINCIPLES OF GRAVITY REDUCTION

A1.0 GENERAL PRINCIPLES OF GRAVITY REDUCTION

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/sec^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 another. 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.

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. Free-Air Effect: 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 mg/ft (-0.3086 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. Bouguer Effect: 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.

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

$B_c = 0.04185\ (2.67)\ h_m$ (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 values of gravity 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, gravity at the higher latitudes is larger. As the earth spins, the centrifugal acceleration causes a slight decrease in the measured value of gravity. At the higher latitudes where the earth's 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) adjust the observed gravity to the value it would have at the geoid (sea level). The theoretical value at the geoid for the latitude of the station is subtracted from the adjusted observed gravity and the remainder is called the Simple Bouguer Anomaly (SBA). Most of this 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) around the station.

d. Terrain Effect: 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 are 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.

APPENDIX A2.0

METHODS OF INTERPRETATION

A2.0 METHODS OF INTERPRETATION

A2.1 REGIONAL - RESIDUAL SEPARATION

To interpret the gravity data, the portion of the CBA that might be caused by the light-weight, basin-fill material must be separated from that caused by the heavier bedrock material which forms the surrounding mountains and presumably the basin floor. The first step is to estimate a regional field. This is an estimation of the values the CBA would have if the light-weight sediments (the anomaly) were not there. Since the valley-fill sediments are absent at the stations read in the mountains, one approach is to use the CBA values at bedrock stations as the basis for constructing a second order polynomial surface to represent a regional field over the valley.

Where there are insufficient bedrock stations to define a satisfactory regional trend, another approach is to estimate the regional by the process of upward continuation of the CBA field. A principal result of potential field theory is that a field quantity satisfying Laplace's equation in a three-dimensional volume of space is specified completely by the value it has on the surface bounding that volume (Grant and West, 1965). Since the gravitational field satisfies Laplace's equation, its value anywhere above the surface of the earth can be found using only the value of gravity on the surface of the earth, regardless of the mass distribution that produces the value of gravity in the first place. On this basis, the Bouguer anomaly is readily continued to level surfaces above the ground.

An important property of upward continuation is that the resultant field (which can be represented by a contour map), changes more with respect to shallow sources than it does with respect to deeper sources. The anomalous parts of the field ascribed to shallow density distribution tend to vanish as the continuation is carried upward; whereas the field produced by deeper sources changes only slightly, so that upward continuation produces regional-type fields.

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.

A2.2 INTERPRETATION OF THE RESIDUAL ANOMALY

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 exactly, an accurate calculation of the thickness could be made. Generally, the densities are not well known and vary within the study area. Therefore, it is necessary to use densities typical of 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.

Once the density contrast between the alluvium and bedrock is established, there are several methods available for determining the form of the alluvium-bedrock interface. One way is to use an iterative computer program which will yield some simple model of the interface approximately explaining the residual gravity anomaly (Cordell, 1970). An alternative approach is to assume the form of the interface a priori and, calculate what effect this would have on the residual gravity anomaly. By continually adjusting the model, one may obtain a reasonable estimate of the interface. There are computer programs that will calculate the gravitational effect of two-dimensional (Talwani et al, 1959) and three-dimensional (Plouff, 1975) bodies.

APPENDIX A3.0

CAVE VALLEY, UTAH

GRAVITY DATA

CAVE 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
0132	38	504	114	511	1251240T	0	133421711	68839150565199947			-1180	81483
0262	38	520	114	407	455889T	0	138421777	70356146709199970			-680	80388
0263	38	531	114	414	254629T	0	132421795	70256147609199986			-990	80512
0130	38	537	114	516	851739T	0	120421770	68756150246199995			-1080	81400
1046	38	563	114	533	553369T	15	111421812	68510149123200033			-710	81216
1047	38	563	114	543	754659T	9	93421809	68361148252200033			-360	81092
0282	38	564	114	427	452881T	0	136421851	70061149557200035			-730	81366
0275	38	593	114	402	556280T	0	145421914	70424146313200077			-820	80125
0129	38	601	114	515	1151699T	0	102421889	68778150053200089			-1400	81072
0278	38	602	114	417	554062T	0	128421925	70204147913200090			-1320	80368
0128	38	603	114	524	152431T	0	124421890	68646150008200092			-760	81484
0144	38	619	114	503	450869T	0	106421926	68948150239200115			-2020	80736
7413	38	620	114	507	851401T	0	96421926	68884149884200117			-1880	80686
5029	38	622	114	413	254511T	0	137421963	70266147426200120			-1410	80137
0294	38	623	114	449	152500T	0	121421952	69741149611200121			-1120	81091
0274	38	627	114	406	255600T	0	135421975	70368146706200127			-1120	80055
1914	38	640	114	489	250951T	0	92421970	69155149925200146			-2290	80422
0157	38	658	114	478	351161T	0	96422007	69313149692200172			-2350	80296
0154	38	675	114	467	551801T	0	101422042	69470149198200197			-2270	80161
0127	38	676	114	513	451601T	0	106422028	68799149767200199			-1890	80616
0146	38	695	114	500	351129T	0	101422049	68990150015200212			-2100	80561
0297	38	697	114	423	755000T	0	122422080	70110147246200215			-1230	80132
1051	38	691	114	537	954301T	0	140422048	68441148380200221			-760	80860
0158	38	692	114	456	152530T	0	107422078	69636149307200222			-1500	80687
0126	38	700	114	523	252999T	0	125422069	68655149385200234			-990	81055
0295	38	705	114	443	353930T	0	123422106	69822148584200241			-920	80803
0296	38	710	114	432	055230T	0	129422119	69987147473200248			-820	80469
7412	38	710	114	441	153930T	0	127422116	69854148611200248			-900	80837
7414	38	710	114	579	053770T	0	98422069	67839147808200248			-1850	79908
0276	38	711	114	412	156220T	0	121422128	70278146571200250			-790	80151
1053	38	715	114	554	055620T	0	100422087	68204147761200256			-170	80960
0145	38	716	114	505	751401T	0	105422105	68910149825200257			-2080	80495
0156	38	721	114	476	051709T	0	105422124	69344149708200265			-1910	80555
1052	38	743	114	545	755659T	0	130422141	68325147945200297			0	81160
0008	38	751	114	450	555479T	0	113422189	69715147515200308			-600	80593
0781	38	761	114	430	357749T	0	126422214	70010146652200323			650	81086
0780	38	762	114	438	556181T	0	107422213	69890146994200325			-480	80467
0001	38	767	114	523	453770T	0	127422193	68649148277200332			-1470	80317
0782	38	771	114	422	556270T	0	124422236	70123146360200338			-1040	79884
0002	38	771	114	511	752251T	0	107422204	68820149331200338			-1850	80437
1006	38	776	114	574	855371T	0	101422193	67898146936200345			-1320	79901

CAVE 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
0003	38	793	114	501551591	T	0	103422249	689681497892003	70		-2050	80463
1014	38	803	114	552057221	T	0	125422250	682301469622003	85		400	81015
1020	38	805	114	528954869	T	0	131422262	685671480402003	87		-730	80691
0784	38	807	114	442158560	T	0	147422295	698351454672003	90		160	80337
0005	38	808	114	485256339	T	0	197422282	692061470102003	92		-380	80597
0783	38	815	114	427456870	T	0	126422315	700501463862004	02		-520	80216
0785	38	819	114	449157021	T	0	122422315	697331465252004	08		-240	80432
0004	38	833	114	499751509	T	0	119422323	689931498822004	28		-2090	80459
0015	38	848	114	519953852	T	0	109422344	686971490392004	50		-750	80989
1011	38	853	114	569357881	T	0	114422337	679751462422004	58		220	80604
0009	38	861	114	455056650	T	0	115422391	696451468982004	69		-280	80515
1021	38	864	114	531055600	T	0	163422370	685341476162004	74		-550	80643
1007	38	864	114	574956781	T	0	113422356	678931465762004	74		-480	80263
0014	38	869	114	511853041	T	0	110422386	688141487632004	81		-1820	80200
0786	38	873	114	435257470	T	0	122422420	699331463432004	87		-80	80442
1013	38	874	114	557459029	T	0	138422380	681481458042004	89		830	80848
0010	38	880	114	467256001	T	0	112422421	694651473212004	97		-500	80512
0800	38	892	114	427660341	T	0	149422458	700431447012005	15		940	80519
0011	38	892	114	477355840	T	0	111422440	693171473482005	15		-640	80431
0012	38	899	114	489852510	T	0	105422449	691351496782005	25		-1450	80745
1022	38	906	114	536258520	T	0	136422446	684571460462005	35		550	80736
0013	38	914	114	499951860	T	0	132422473	689861499112005	47		-1850	80592
0787	38	922	114	444556850	T	0	135422507	697951466892005	59		-390	80355
1010	38	928	114	565558911	T	0	138422477	680281458842005	68		720	80778
0016	38	929	114	519554380	T	0	122422494	686991482522005	69		-1160	80412
0018	38	939	114	493455850	T	0	152422521	690801472622005	84		-780	80322
1016	38	942	114	552061499	T	0	152422507	682241444002005	88		1660	80842
0020	38	944	114	466958261	T	0	131422540	694671459192005	91		120	80391
0021	38	946	114	455859341	T	0	175422547	696291451872005	94		410	80355
1008	38	952	114	574958150	T	0	126422518	678891461882006	03		280	80576
0017	38	955	114	511653540	T	0	126422545	688141486142006	07		-1630	80236
0804	38	963	114	432361171	T	0	163422587	699711446942006	19		1610	80923
0019	38	966	114	483754692	T	0	94422575	692211483052006	23		-870	80574
0022	38	991	114	457258471	T	0	119422630	696071458992006	60		230	80419
0803	38	997	114	440060732	T	0	150422647	698571447822006	69		1230	80680
1024	38	998	114	540860390	T	0	174422615	683851447232006	70		850	80444
1015	381001		114	557861440	T	0	173422615	681371446672006	74		1780	81003
0026	381003		114	498252251	T	0	128422638	690071497402006	77		-1780	80518
0805	381005		114	426366581	T	0	386422667	700571411112006	80		3050	80736
0027	381011		114	512854239	T	0	123422648	687941483652006	89		-1300	80323
0028	381012		114	522355801	T	0	136422647	686551478012006	91		-400	80706

CAVE VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG	MIN	LONG. DEG	MIN	ELEV. +CODE	TER-COR. IN/OUT	NORTH EAST UTM	UTM	OBSV GRAV	THEO GRAV	FAA	CBA +1000
0024	38	1013	114	475254491T		0	128422665	693431483982006 92	-1030		80508	
1009	38	1023	114	571563711T		0	264422651	679361430852007 07	2300		80844	
0023	38	1024	114	465856280T		0	97422688	694801470152007 08	-750		80147	
0025	38	1034	114	487656319T		0	111422699	691611468652007 23	-880		80021	
7442	38	1055	114	436860397T		0	140422756	699021454982007 54	1550		81110	
0819	38	1068	114	442559531T		0	125422778	698181457222007 73	940		80775	
0032	38	1074	114	476256969T		0	114422777	693251464492007 81	-740		79944	
0034	38	1079	114	457057110T		0	103422793	696061471982007 89	120		80763	
0033	38	1084	114	467255341T		0	100422799	694561478482007 96	-890		80340	
0031	38	1090	114	495752710T		0	126422800	690401490042008 05	-2210		79936	
0030	38	1104	114	506954449T		0	128422822	688761485262008 25	-1080		80478	
0820	38	1149	114	443961680T		0	161422927	697941437842008 91	910		80041	
7415	38	1220	114	599056539T		0	96423006	675271470652009 95	-740		80076	
7440	38	1410	114	483853960T		0	132423396	692001479512012 74	-2560		79172	
7444	38	1490	114	558260052T		0	118423519	681111460032013 91	1090		80748	
7441	38	1515	114	422060843T		0	121423612	700971444282014 27	220		79611	
7443	38	1775	114	496062487T		0	191424067	690061450592018 08	2020		80921	
7424	38	1825	114	419059551T		0	195424186	701261452282018 82	-630		79255	
7423	38	2020	114	433557799T		0	273424542	699061460552021 68	-1730		78823	
7418	38	2100	114	504059911T		0	206424665	688751469942022 85	1060		80846	
7221	38	2105	114	504059918T		0	198424674	688751469902022 92	1050		80828	
7281	38	2305	114	548259790T		0	201425029	682231473652025 86	1000		80831	
7283	38	2535	114	433862221T		0	169425494	698781447192029 23	320		79289	
7419	38	2545	114	486560312T		0	135425494	691111473342029 38	1120		80705	
7220	38	2550	114	486560285T		0	134425503	691101473352029 45	1090		80684	
H611	38	2691	114	589058930T		0	337425730	676131486962031 52	970		81227	
7282	38	2835	114	526060105T		0	220426017	685231473692033 63	530		80270	
7285	38	3050	114	408062087T		0	162426456	702291454802036 79	190		79192	
7420	38	3050	114	477260840T		0	152426431	692241463402036 79	-110		79292	
7267	38	3082	114	501660659T		0	215426482	688681472952037 26	610		80165	
7269	38	3094	114	597355551T		0	223426473	674761498772037 44	-1610		79673	
H231	38	3111	114	585857710T		0	391426508	676431492002037 69	-280		80441	
5027	38	3207	114	476561152T		0	169426722	692271461452039 10	-230		79079	
785	38	3344	114	548567779T		0	301426951	681751423232041 11	1960		79161	
H148	38	3428	114	592060157T		0	241427092	675401477682042 34	120		79861	
7421	38	3515	114	476562251T		0	196427292	692131459172043 62	100		79086	
7268	38	3533	114	546269091T		0	209427301	682001416522043 89	2240		78909	
7219	38	3570	114	435074003T		0	543427408	698131389632044 43	4120		79443	
7422	38	3580	114	425569649T		0	472427430	699511414832044 58	2530		79262	
5026	38	3602	114	480262671T		0	196427451	691561460822044 90	530		79376	
7270	38	3675	114	518566119T		0	147427573	685961441092045 97	1690		79307	

CAVE VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN +CODE	ELEV.	TER-COR. IN/OUT	NORTH UTM	EAST UTM	OBSV GRAV	THEO GRAV	FAA	CBA +1000
7291	383805	1144300899	34T	0	1445427845	698751283	18204788		8110	78905
N761	383838	1144893641	37T	0	212427977	690111453	30204910		750	79102
7271	383908	1145336689	80T	0	195427999	683671416	16204940		1550	78235
7274	383962	1144839658	69T	0	253428116	690861443	60205019		1290	79093
5025	384159	1144887694	82T	0	237428479	690081422	05205309		2250	78807
N760	384286	1145046664	57T	0	208428708	687721438	02205496		820	78378
7272	384330	1145455727	49T	0	265428776	681771411	46205560		4010	79485
7208	384400	1145057673	10T	0	214428919	687511433	69205663		1010	78284
LV0162	382686	1144012	8860V	463635425785		703451272	01203145		7461	80923
CAV021	383599	1144473	8426C	592307427457		696331312	41204486		6072	79699
CAV023	383492	1144381	9145C	813513427263		697721252	13204328		6973	79376
CAV022	383558	1144406	72339T	0	585427384	697321398	87204425		3551	79463
CAV051	382756	1145674	8152C	242173425857		679251336	99203247		7188	81580
CAV052	382694	1145498	6176B	0	259425748	681831465	93203156		1564	80759
CAV057	382481	1145375	5978S	0	123425359	683711466	28202844		47	79781
CAV073	382274	1144861	7406C	322236424993		691281373	44202540		4514	81522
CAV075	382399	1144875	60420T	0	241425224	691021471	25202724		1267	80901
CAV086	382676	1144560	7383V	38	951425747	695491376	67203130		4030	79838
CAV093	382030	1144947	8114C	673245424539		690141318	91202182		6086	81724
CAV099	381806	1145153	7745V	402034424117		687231347	50201854		5799	81457
LV0041	384006	1144310	9695C	252229428216		698511233	36205084		9522	78709
LV0064	383142	1144376	8266C	241706426616		697951325	36203814		6532	80069
CAV120	383404	1144938	6921C	12	620427080	689671423	37204199		3280	80306
CAV039	383629	1144940	7229S	451087427497		689541398	22204530		3335	79811
CAV028	383532	1144563	6635S	0	371427330	695061436	42204387		1704	79445
CAV026	383288	1144565	6503B	0	375426879	695141444	33204029		1610	79806
CAV001	383902	1145495	7382C	8	292427983	681371391	11204931		3663	78785
CAV020	383849	1144466	8535S	251127427920		696321317	65204853		7254	79296
CAV024	383212	1144424	8263C	441580426743		697221324	81203917		6345	79786
CAV049	383426	1145394	7166C	4	234427106	683041401	61204231		3379	79176
CAV085	382461	1144769	7048C	94	573425342	692541395	56202814		3080	79708
CAV089	382998	1145245	6555C	14	343426319	685381447	97203603		2891	80890
CAV108	381580	1145462	6559V	6	245423689	682821431	25201523		3337	81217
CAV114	382233	1145652	7252V	22	630424891	679781394	29202480		5209	81126
CAV118	382029	1145739	7418C	19	810424511	678601378	59202181		5501	81030
CAV119	382511	1145613	7023C	11	482425406	680241411	67202888		4382	80921
CAV007	384186	1145173	6845C	3	173428519	685921423	97205349		1474	78304
CAV048	383644	1145398	7100C	2	219427509	682891405	47204552		2824	78829
CAV116	381796	1145701	6563C	3	220424081	679251426	24201839		2556	80394
CAV015	384139	1144840	7256C	29	337428443	690771402	54205279		3271	78889
CAV047	383285	1145194	8365C	61313426852		686001329	79204024		7697	80485

CAVE 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
LV0035	384254		1144276		7695C	4	649428676	698891370932054 49			4076	78483
LV0059	383377		1144300		7319C	14	403427053	69895139199204159			3930	79384
LV0156	382896		1144382		7574C	16	591426160	69797137075203453			4914	79688
LV0165	382428		1144070		7048C	6	347425306	70273141407202766			4979	81293
LV0170	382090		1144031		8613C	122214424682		70345128958202270			7766	80615
LV0293	383714		1144147		6897C	17	483427682	70101141784204655			2046	79022
CAV002	384004		1145348		69373	0	209428176	68346141603205081			1815	78364
CAV003	383827		1145379		7008C	0	200427848	68308141336204821			2477	78775
CAV004	383791		1145202		6703C	0	158427787	68567143514204768			1836	79132
CAV005	383927		1145206		6777S	0	166428039	68555142902204968			1721	78772
CAV006	384057		1145248		6975C	0	188428278	68489141397205159			1889	78287
CAV008	384094		1145026		6587S	0	173428354	68809143859205213			643	78349
CAV009	383959		1145054		6624C	0	153428103	68774143809205015			1140	78701
CAV010	383824		1145054		6541S	0	146427853	68780144389204816			1136	78973
CAV011	383760		1144974		6441S	0	162427738	68899145264204722			1164	79357
CAV012	383829		1144878		6384S	0	204427869	69035145478204824			740	79170
CAV013	383961		1144838		6587S	0	253428114	69087144332205018			1311	79098
CAV014	384041		1144899		6788C	0	219428260	68995143347205135			2101	79168
CAV016	384044		1144726		7129C	0	379428272	69246140687205140			2648	78712
CAV017	383870		1144726		6724C	0	304427950	69254143393204884			1796	79166
CAV018	383785		1144612		6816C	0	422427797	69423141887204759			1281	78456
CAV019	383960		1144615		7500C	0	576428120	69411138129205016			3708	78703
CAV025	383099		1144556		6720C	0	325426530	69535143299203751			2798	80203
CAV027	383418		1144576		6499B	0	305427119	69492144061204220			1010	79148
CAV029	383648		1144537		68232	0	653427546	69538141022204558			684	78065
CAV030	383654		1144697		6404B	0	261427551	69306144766204566			474	78893
CAV031	383529		1144733		6237C	0	210427319	69259145853204383			172	79109
CAV032	383342		1144724		6168S	0	190426973	69280145984204108			-72	79080
CAV033	383175		1144695		6145C	0	188426665	69330146012203863			-15	79214
CAV034	383013		1144704		6087B	0	183426365	69324146299203625			-36	79386
CAV035	383110		1144835		6077B	0	155426540	69129146323203767			-249	79179
CAV036	383226		1144801		6120B	0	167426756	69174146311203938			-27	79266
CAV037	383429		1144799		6207B	0	179427132	69168146308204236			492	79500
CAV038	383661		1144859		63363	0	204427559	69070145839204577			896	79490
CAV040	383538		1144891		6301B	0	174427330	69029145953204396			861	79544
CAV041	383357		1144876		6185C	0	209426996	69059146667204130			749	79862
CAV042	383226		1144909		6107C	0	212426752	69017146916203938			456	79838
CAV043	383113		1144995		6071B	0	226426540	68897147289203772			656	80176
CAV045	383550		1145076		6444B	0	163427346	68760145550204414			1787	79971
CAV046	383631		1145179		6559B	0	150427492	68607144451204533			1652	79431
CAV054	382397		1145553		6204B	0	274425197	68116146123202721			1793	80907

CAVE 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
CAV055	38	2307	114	5372	5970S	0	117425037	683831463122025 89			-89	79666
CAV056	38	2394	114	5442	5975S	0	143425195	682771472012027 16			720	80484
CAV058	38	2581	114	5384	5984C	0	142425543	683541470852029 91			414	80146
CAV059	38	2683	114	5332	6005C	0	159425734	684251472862031 40			663	80341
CAV060	38	2567	114	5261	5983S	0	117425521	685331462472029 70			-413	79297
CAV061	38	2394	114	5262	5970S	0	105425201	685391455262027 16			-1003	78740
CAV062	38	2307	114	5151	5971S	0	101425044	687051450432025 89			-1349	78387
CAV063	38	2482	114	5154	5978S	0	102425368	686931449242028 45			-1658	78055
CAV064	38	2650	114	5173	5990S	0	118425678	686581458392030 92			-877	78811
CAV065	38	2754	114	5127	6004S	0	129425872	687201461112032 45			-626	79025
CAV066	38	2820	114	5238	6012C	0	193425990	685561473582033 41			600	80288
CAV067	38	2905	114	5150	6025S	0	193426150	686801472342034 66			474	80117
CAV068	38	2993	114	5055	6043C	0	189426316	688151468822035 95			162	79740
CAV069	38	2859	114	5030	6020S	0	134426069	688571457492033 99			-991	78610
CAV070	38	2764	114	4992	6010S	0	114425895	689161453142032 59			-1381	78234
CAV071	38	2569	114	5045	5986S	0	106425532	688481448862029 73			-1749	77941
CAV072	38	2395	114	5041	5976S	0	103425211	688611449042027 18			-1569	78151
CAV074	38	2317	114	491760321T		0	176425071	690451468612026 03			1030	80632
CAV076	38	2482	114	4933	5981S	0	117425375	690141459822028 45			-573	79145
CAV077	38	2572	114	4950	5990S	0	109425541	689861455492029 77			-1053	78626
CAV078	38	2668	114	4947	6001C	0	111425719	689861454342031 18			-1205	78438
CAV079	38	2789	114	4886	6018S	0	121425945	690691454512032 96			-1205	78390
CAV080	38	2895	114	4903	6030S	0	127426140	690401452732034 51			-1426	78134
CAV081	38	2983	114	4868	6043S	0	138426304	690871455882035 81			-1118	78409
CAV082	38	2885	114	476260420T		0	154426127	692451460842034 37			-487	79059
CAV083	38	2678	114	4803	6022C	0	142425742	691951470482031 33			592	80195
CAV084	38	2547	114	484460312T		0	157425499	691411473212029 41			1142	80729
CAV087	38	2764	114	4642	6321C	0	218425907	694251457712032 59			2004	80663
CAV088	38	2866	114	4620	6401B	0	248426096	694531452792034 09			2116	80532
CAV091	38	2196	114	485061089T		0	225424849	691481466572024 26			1728	81117
CAV092	38	2164	114	495960200T		0	345424786	689901470562023 79			1336	81148
CAV094	38	2105	114	502859911T		0	223424675	688931469642022 92			1057	80847
CAV095	38	2222	114	5042	5970S	0	119424891	688671459542024 64			-322	79435
CAV096	38	2135	114	5152	5970S	0	115424726	687111458742023 36			-275	79478
CAV097	38	2063	114	512259701T		0	151424594	687571466202022 31			577	80366
CAV098	38	1961	114	5152	6042C	0	184424404	687181465312020 81			1316	80892
CAV100	38	1856	114	5243	6068C	0	185424207	685901460362019 27			1219	80708
CAV101	38	2047	114	5262	5973S	0	110424560	685541461392022 07			148	79885
CAV102	38	2220	114	5261	5970S	0	104424880	685481455292024 61			-745	78997
CAV103	38	2133	114	5371	5975S	0	113424715	683921462212023 33			122	79856
CAV104	38	1960	114	5372	5975S	0	110424395	683981461402020 80			295	80026

CAVE 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
CAV105	381839		1145381		5990S	0	115424171	683901457592019	02		233	79918
CAV106	381731		1145306		6206C	0	161423974	685031450352017	44		1701	80695
CAV107	381638		1145407		6219B	0	129423798	683601453202016	08		2245	81163
CAV109	381755		1145490		6170C	0	114424012	682341449982017	79		1289	80359
CAV110	381856		114553760331T			0	118424197	681611463842019	27		1237	80778
CAV111	381961		1145482		6010C	0	121424393	682371465022020	81		986	80608
CAV112	382046		1145482		6081C	0	130424550	682341462352022	06		1262	80652
CAV113	382220		1145481		6082C	0	167424872	682281467362024	61		1517	80940
CAV115	381961		1145592		6158C	0	142424390	680771460942020	81		1971	81110
CAV117	381891		114574463389T			0	174424255	678581444302019	78		2113	80667
LV0036	384216		1144090		68292	0	358428613	701601423702053	93		1253	78320
LV0042	383968		1144069		6950C	0	461428155	702021415802050	28		1967	78724
LV0050	383614		1144082		6414C	0	277427499	702001446892045	08		550	78951
LV0051	383568		114427369649T			0	538427407	699251414682044	40		2584	79367
LV0052	383494		1144102		6330C	0	244427277	701771446402043	31		-114	78540
LV0053	383456		1144010		6121C	0	184427210	703121456952042	75		-971	78336
LV0058	383362		1144041		6185C	0	181427035	702711449072041	37		-1018	78067
LV0060	383238		1144078		6246C	0	175426804	702231453652039	55		196	79068
LV0065	383043		1144073		6204C	0	156426444	702401454622036	69		184	79180
LV0154	382927		1144004		6097C	0	153426231	703461461652034	99		50	79408
LV0155	382930		1144103		6220C	0	164426233	702021452572035	03		296	79245
LV0157	382794		1144171		6316C	0	212425979	701091447772033	03		919	79589
LV0158	382846		1144046		6246B	0	209426080	702881455702033	80		977	79883
LV0167	382326		1144027		6445Y	0	206425119	703401449532026	16		2997	81221
WRV242	381039		1145689		6430S	162	237422681	679731428522007	30		2642	81110
MSV076	381303		1144439		5847V	23	114423212	697871454692011	17		-618	79577
MSV075	381149		1144439		6168S	201	159422927	697941438052008	91		966	80289
MSV055	381564		1145212		6900C	690	423423668	686481408332014	99		4278	81857
CAV086	382676		1144560		7383C	238	634425747	695491376762031	30		4040	79730
CAV090	382946		1144466		8269S	4051503426250		696731322282035	26		6539	80244
CAV093	382030		1144947		8114C	9742209424539		690141318882021	82		6084	81592
MSV013	382314		1144120		6652S	10	198425093	702051437402025	99		3751	81271
MSV014	382161		1144047		8396S	5992016424813		703191304862023	74		7146	81124
MSV021	381935		1144165		7396S	609	874424391	701571369042020	43		4477	80734
MSV052	381849		1144961		7190C	27	787424204	690011383292019	17		4088	80379
MSV057	381295		1145215		6489S	9	330423170	686551426512011	05		2621	80828
MSV080	381213		1144109		7239S	22	698423057	702721361852009	85		3337	79367
WRV239	381131		1145804		6147S	102	204422848	678021450872008	65		2077	81417
WRV235	381350		1145702		6445Y	112	234423256	679421429362011	86		2411	80775
WRV087	382029		1145739		7418C	174	812424511	678601378562021	81		5498	81183
WRV090	381578		1145891		6318C	3	291423672	676571445912015	20		2536	81281

CAVE VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN +CODE	ELEV.	TER-COR. IN/OUT	NORTH UTM	EAST UTM	OBSV GRAV	THEO GRAV	FAA	CBA +1000
WRV248	38 627	1145745	5893C	166	313421917	67908144464200127			-200	80180
CAV026	383288	1144565	6445B	0	328426879	69514144684204029			1316	79662
CAV085	382461	1144769	7048C	0	576425342	69254139553202814			3077	79614
CAV091	382196	114485061089T		0	219424849	69148146653202426			1724	81107
MSV001	382271	1144651	6039V	0	114424995	69434145796202536			97	79614
MSV002	382330	1144664	6150C	0	131425196	69410145525202696			712	79867
MSV003	382423	1144540	6202C	0	125425280	69589144875202759			488	79460
MSV004	382295	1144515	6002C	0	114425044	69631145270202571			-812	78831
MSV005	382308	1144390	6088S	0	136425073	69813145024202590			-267	79104
MSV006	382441	1144379	6134S	0	145425319	69823144979202785			-74	79149
MSV007	382538	1144346	6230S	0	167425500	69866144692202928			401	79319
MSV008	382655	1144272	6396S	0	203425719	69968144182203099			1282	79670
MSV009	382725	1144209	6445S	0	220425850	70057144036203202			1494	79732
MSV011	382416	1144273	6338S	0	171425277	69978144376202748			1281	79635
MSV012	382285	1144276	6356C	0	179425034	69980144494202556			1760	80260
MSV017	381547	1144098	6255S	0	139423676	70273143308201474			706	79510
MSV018	381728	1144139	6310S	0	158424009	70205143858201740			1508	80144
MSV019	381830	114412462300T		0	175424198	70222144744201889			1491	80418
MSV020	381874	114404664071T		0	203424282	70334143725201954			2074	80425
MSV022	382182	1144269	6390V	0	211424844	69995144371202405			2108	80524
MSV023	382073	1144268	6410S	0	214424642	70001144215202245			2301	80652
MSV024	381954	1144233	6347S	0	224424423	70057144075202071			1742	80318
MSV025	381843	114422861519T		0	161424218	70070144788201908			781	79959
MSV026	381645	1144218	6146B	0	124423852	70094144522201618			749	79911
MSV027	381547	1144318	5981C	0	111423668	69952144473201474			-710	79001
MSV028	381620	1144382	5899V	0	108423800	69856144698201581			-1364	78624
MSV029	381735	1144323	5964V	0	115424015	69936144709201750			-909	78864
MSV030	381894	114431260289T		0	154424310	69945144992201983			-248	79343
MSV031	381937	114438759550T		0	131424386	69834145203202046			-796	79024
MSV032	382069	1144398	6013S	0	140424630	69812145439202239			-207	79424
MSV033	382211	1144437	5997S	0	131424891	69749145132202448			-873	78804
MSV034	381817	1144465	5842V	0	112424162	69726145292201870			-1595	78591
MSV035	381680	1144483	5798S	0	104423908	69706145184201669			-1917	78412
MSV036	381592	1144556	5722V	0	103423742	69603145524201540			-2163	78424
MSV037	381557	114475255121T		0	117423671	69319147018201489			-2595	78722
MSV038	381635	114469855571T		0	112423817	69394146756201603			-2547	78611
MSV039	381710	114465756010T		0	112423957	69450146517201713			-2483	78526
MSV040	381786	1144607	5647C	0	114424099	69520146435201825			-2243	78611
MSV041	381926	1144556	5722C	0	120424360	69588146193202030			-1984	78620
MSV042	382038	1144579	5805C	0	119424566	69550146109202194			-1450	78869
MSV043	382139	1144530	5905C	0	116424755	69616145386202342			-1380	78595

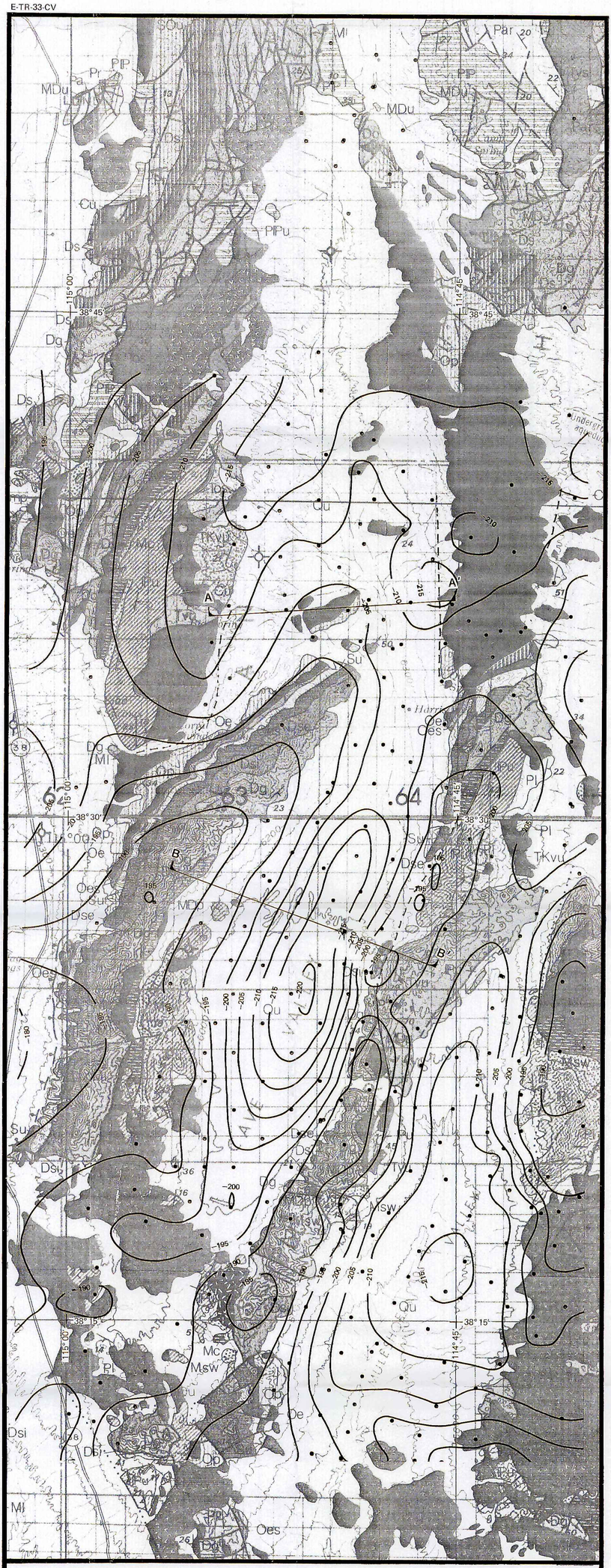
CAVE VALLEY GRAVITY DATA

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
MSV044	382143		114467459130T			0	131424757	694061462822023 48			-415	79548
MSV045	382191		114475160699T			0	139424843	692921461842024 18			895	80331
MSV046	381951		1144691		5982C	0	143424402	693901454192020 66			-347	79393
MSV047	381825		1144775		5915C	0	143424166	692731453472018 82			-865	79104
MSV048	381757		1144836		5892C	0	139424038	691871454132017 82			-916	79127
MSV049	381650		1144876		5782C	0	125423838	691341459832016 25			-1224	79180
MSV050	381514		1144919		5595C	0	119423585	690771469952014 26			-1774	79262
MSV051	381765		1144951		6110C	0	174424049	690191454402017 94			1152	80487
MSV053	381655		1145033		6110V	0	179423842	689051453042016 33			1178	80517
MSV054	381544		1145093		5957V	0	174423635	688221460252014 70			621	80477
MSV056	381376		1145156		5890V	0	184423322	687371462502012 24			461	80556
MSV058	381103		1145069		5445Y	0	125422820	688761485502008 24			-1029	80525
MSV059	381219		1145037		5508V	0	135423036	689181478552009 94			-1301	80048
MSV060	381295		1145003		5509Y	0	126423177	689641474532011 05			-1805	79531
MSV061	381407		1144956		5552Y	0	115423386	690281471592012 69			-1858	79321
MSV062	381435		1144818		5468Y	0	118423443	692281474322013 10			-2416	79052
MSV063	381338		114487453970T			0	128423261	691501479312011 68			-2444	79276
MSV064	381252		114490453599T			0	118423101	691101484952010 42			-2103	79734
MSV065	381169		114493053271T			0	122422947	690761486502009 20			-2137	79816
MSV066	381089		114495752710T			0	124422798	690401490162008 03			-2181	79965
MSV067	381074		1144762		5697Y	0	113422777	693251464672007 81			-697	79985
MSV068	381203		1144760		5453V	0	104423016	693231483442009 70			-1306	80199
MSV069	381334		1144723		5516V	0	99423259	693711472412011 62			-2007	79278
MSV070	381479		1144622		5649V	0	97423531	695121461122013 75			-2096	78734
MSV071	381380		1144559		5692V	0	100423350	696081460312012 30			-1628	79058
MSV072	381247		1144589		5632V	0	108423103	695701465962010 35			-1433	79466
MSV073	381160		1144654		5539V	0	104422940	694791477582009 07			-1020	80192
MSV074	381080		1144570		5711Y	0	105422795	696061472182007 90			177	80803
MSV077	381490		1144467		5806Y	0	102423557	697371451842013 91			-1563	78736
MSV078	381376		1144347		6005Y	0	116423350	699181437952012 24			-911	78723
MSV079	381460		1144208		6107S	0	131423511	701171442402013 47			372	79674
MSV081	382521		1144111		7834C	0	1120425477	702091358872029 03			6725	81126
WRV088	381834		114591960400T			0	130424144	676061461822018 95			1134	80663
WRV089	381658		1145884		5948C	0	102423820	676641464752016 37			819	80634
WRV234	381409		1145929		5749V	0	102423358	676081474392012 72			274	80767
WRV236	381315		1145870		5894V	0	113423186	676981464812011 34			819	80829
WRV237	381243		1145740		6057B	0	151423057	678911455772010 29			1555	81048
WRV238	381198		1145895		5761V	0	119422969	676661471542009 63			412	80881
WRV240	381079		1145974		5543V	0	106422746	675561482092007 89			-412	80788
WRV241	381020		1145814		5826S	0	134422642	677921465102007 02			640	80903
WRV243	38	952	1145749		5815S	0	127422518	678891462042006 03			330	80623

CAVE 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
WRV244	38	952	1145972		5459S	0	101422511	67564147956200603		-1270		80212
WRV245	38	852	1145834		5535S	0	105422331	67769147035200456		-1329		79898
WRV246	38	730	1145961		5240V	0	100422101	67589147942200278		-3020		79208
WRV247	38	704	114579653770T			0	96422058	67831147779200240		-1856		79901
WRV249	38	581	114586452549T			0	98421829	67736148305200060		-2298		79877

E-TR-33-CV



EXPLANATION

- FAULTS SHOWN ON GEOLOGIC BASE MAP
- INFERRED FAULTS SHOWN ON GEOLOGIC BASE MAP
- ALLUVIAL MATERIAL
- ROCK (ALL PATTERNS)
- GRAVITY STATIONS
- A — A' LOCATION OF PROFILE
- CONTOUR INTERVAL = 5 MILLIGALS
- GEOLOGIC BASE MAP: E.L. Howard (1978)

NORTH

SCALE 1: 125,000

0 2 4 STATUTE MILES

0 2 4 KILOMETERS

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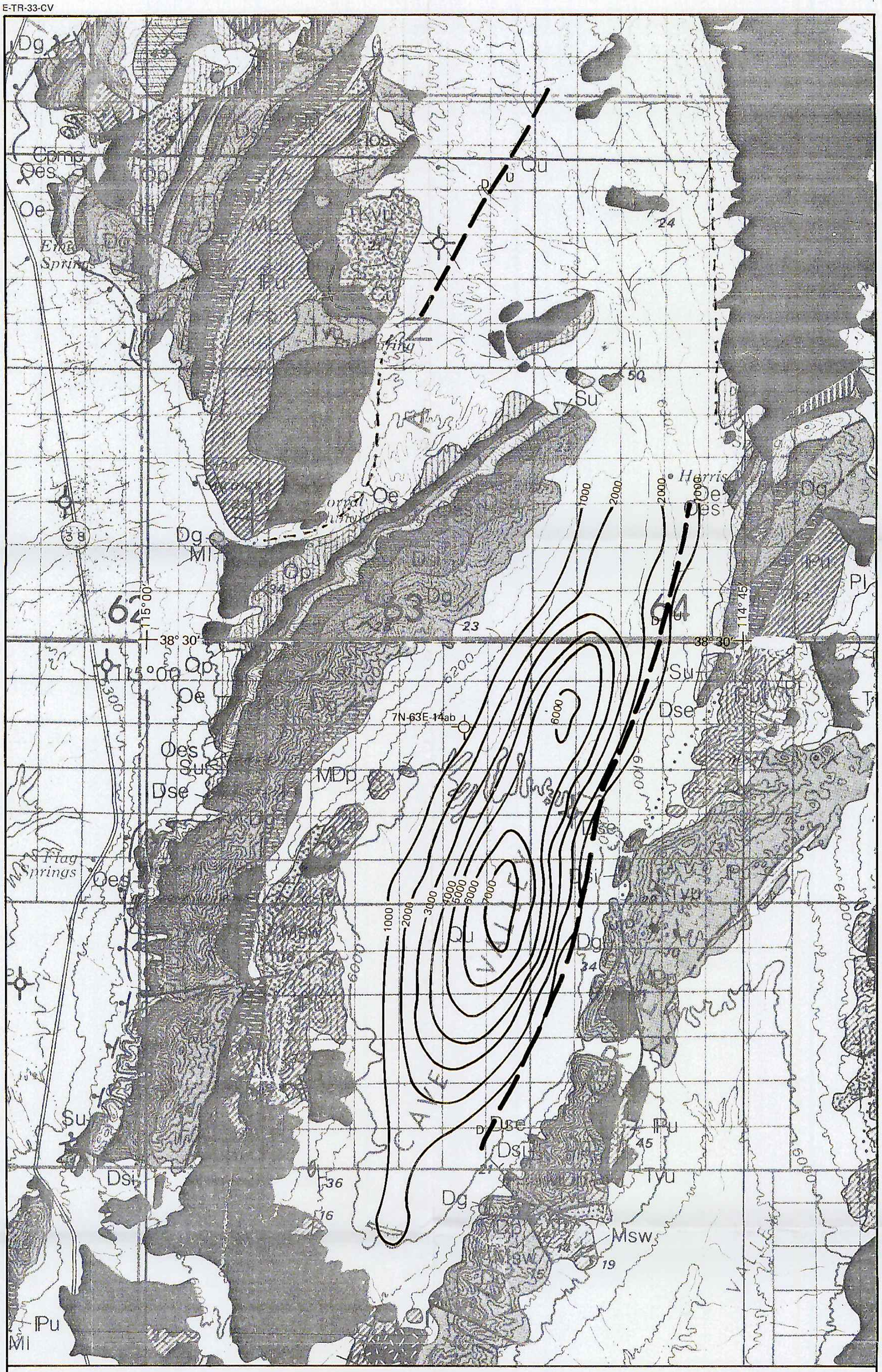
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE
BMO/AFRCE-MX

COMPLETE BOUGUER ANOMALY CONTOURS CAVE VALLEY, NEVADA

14 SEPT 81

DRAWING 1

E-TR-33-CV



EXPLANATION

D / U — FAULTS INFERRED FROM GRAVITY DATA

FAULTS SHOWN ON GEOLOGIC BASE MAP

ALLUVIAL MATERIAL

ROCK (ALL PATTERNS)

CONTOUR INTERVAL = 1000 FT.

DEPTH CALCULATIONS BASED ON DENSITY CONTRAST OF -0.5g/cm^3

WELL

GEOLOGIC BASE MAP: E. L. Howard (1978)

NORTH

SCALE 1: 125,000

0 2 4 STATUTE MILES

0 2 4 KILOMETERS

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MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE
BMO/AFRCE-MX

DEPTH TO ROCK
INTERPRETED FROM GRAVITY DATA
CAVE VALLEY, NEVADA

14 SEPT 81 — DRAWING 2