E-TR-33-PA

MX SITING INVESTIGATION

GRAVITY SURVEY - PAHROC VALLEY

NEVADA

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E-TR-33-PA

MX SITING INVESTIGATION

GRAVITY SURVEY - PAHROC VALLEY

NEVADA

Prepared for:

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Measurements were made in this survey for Pahroc Valley, Nev. for purpose of estimating overall shape of structural basin, thickness of alluvial fill, + location of concealed faults. The valley is an equidimensional alluvial basin which is approximately 1400 feet deep at the northwestern end.

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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.

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1.0 INTRODUCTION

1.1 OBJECTIVE

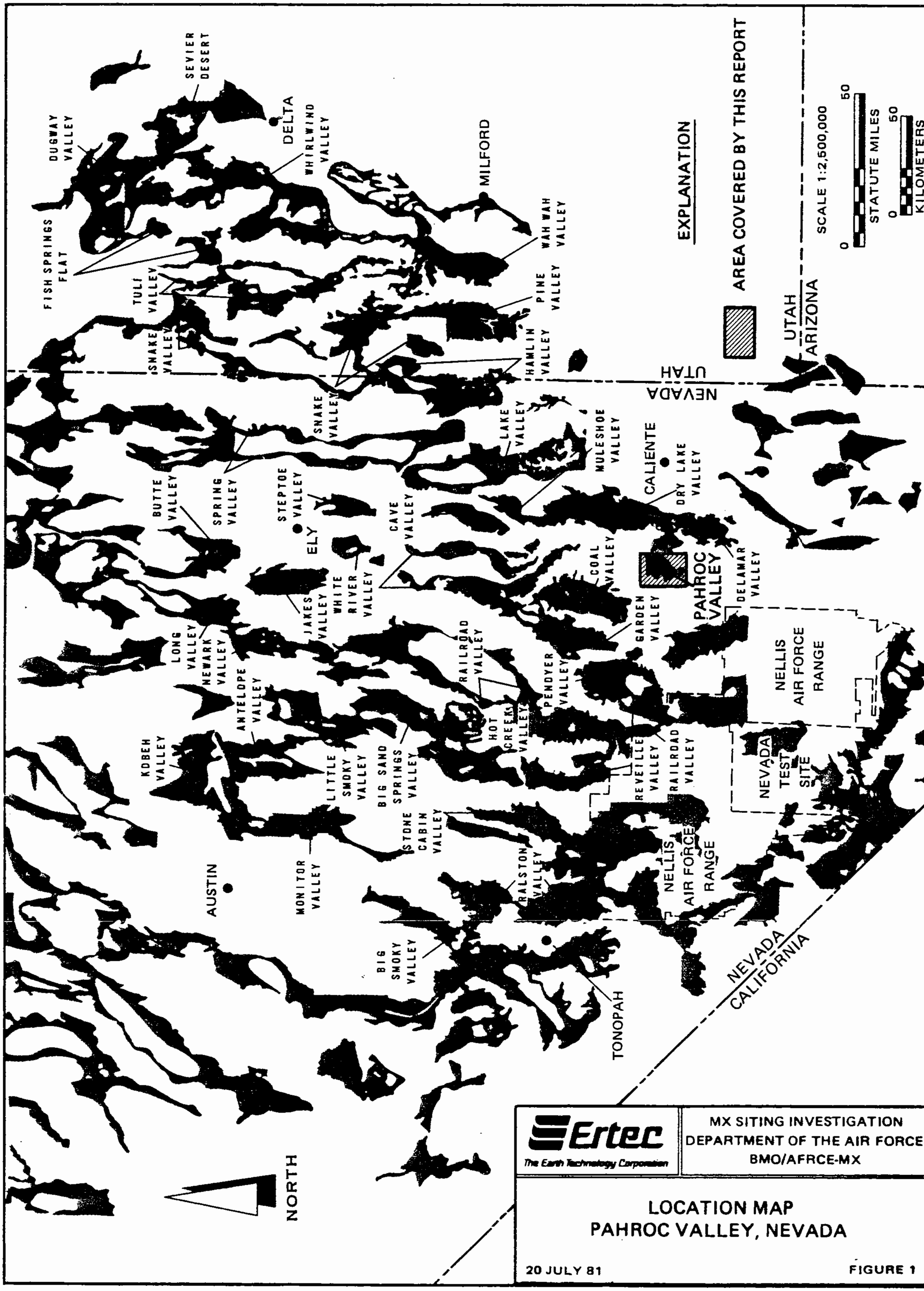
Gravity measurements were made in Pahroc Valley for the purpose of estimating the overall shape of the structural basin, the thickness of alluvial fill, and the location of concealed faults. The estimates will be useful in modeling the dynamic response of ground motion in the basin and in evaluating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

1.2 LOCATION

Pahroc Valley is located in southeastern Nevada (Figure 1). The town of Hiko (Figure 2) is located approximately 3 miles west of Pahroc Valley on Highway 38. Highway 93 passes through the valley from Crystal Spring northward. The Verification report (Ertec, 1981b) covering Pahroc Valley used the name to describe two topographic valleys joined at their northern ends by a narrow pass throug the South Pahroc Range. In that report, the western valley is called Sixmile Flat and the eastern valley is called East Pahroc Valley. This report covers only the western valley (Figure 2). This is due to the following considerations:

1. The western valley is a closed drainage basin; and
2. The residual gravity anomaly of the eastern valley appears to be connected with Delamar Valley, whereas, the western basin produces a separate anomaly.

Pahroc Valley is bounded on the west by the Hiko Range, on the east by the South Pahroc Range, and on the north by the North



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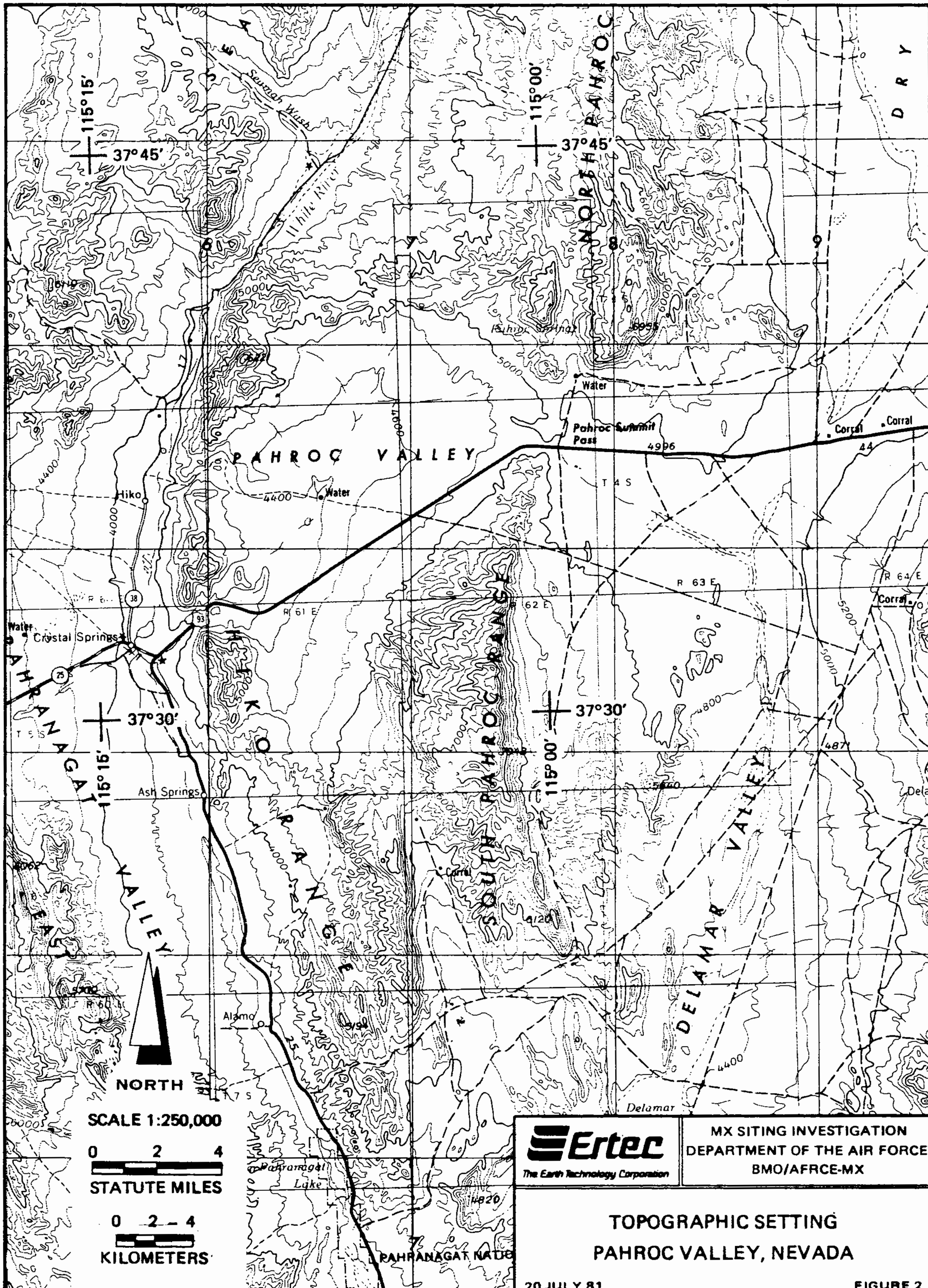
LOCATION MAP
PAHROC VALLEY, NEVADA

20 JULY 81

FIGURE 1



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TOPOGRAPHIC SETTING
PAHROC VALLEY, NEVADA

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FIGURE 2

Pahroc Range (Figure 2). The area covered in this report lies between North latitudes 37°25' and 37°45' and West longitudes 115°00' and 115°15'. Sixmile Flat is approximately 9 miles (14.6 km) long and up to 6 miles (9.8 km) wide.

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 geological data;
3. Evaluation of the regional field and residual separation;
4. Inverse modeling to estimate depth to bed rock; and
5. Interpretation of structural relationships.

The gravitational field within Pahroc Valley was defined by measurements from 164 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 113 gravity stations from its library, and 51 new gravity measurements were made by the Defense Mapping Agency Hydrographic Topographic Center/Geodetic Survey Squadron (DMAHTC/GSS).

Pahroc Valley and Delamar Valley were studied together, with the results presented in separate reports. The rectangular region containing both valleys is the area between North latitudes 37° 10' and 37°45' and West longitudes 114°40' and 115°15'. There are 516 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.

The CBA values and principle facts for the Pahroc Valley stations are listed in Appendix A2.0.

3.0 GEOLOGIC SUMMARY

In contrast to most basins in the Great Basin section of the Basin and Range Physiographic Province, Pahroc Valley is not an elongate, linear valley but rather a small subcircular basin. Pahroc Valley, as used in this gravity report, is synonymous with Sixmile Flat in the Pahroc Valley Verification Report (Ertec, 1981b). The area called Eastern Pahroc Valley in the Verification report has been included in the Delamar Valley gravity report (Ertec, 1981c).

The western foothills of the North Pahroc Range bound the valley on the north. They are comprised of carbonate rocks (dolomites) covered by middle to late Tertiary tuff (Stewart and Carlson, 1976; and Ekren and others, 1977). There are also isolated outcrops of late Tertiary basalt (Tschanz and Pampeyan, 1970). The Hiko Range forms the western and southern boundaries of Pahroc Valley. Carbonate rocks (dolomites and limestones) form the bulk of the Hiko Range on the western side of the valley (Tschanz and Pampeyan, 1970) but are in places, overlain by small outcrops of middle to late Tertiary tuff (Stewart and Carlson, 1976; and Ekren and others, 1977). The Hiko Range to the south and the South Pahroc Range, which forms the valley's eastern boundary, comprise entirely middle Tertiary intermediate volcanic lavas capped by middle and late Tertiary silicic ash flow and ash fall tuffs (Ekren and others, 1977).

The Pahroc Valley alluvial fill overlies the western side of a fault block which is tilted down to the northwest. The upthrown eastern side of the block forms the south Pahroc Range which is bounded on the east by the north-trending, Pahroc normal fault (Ertec 1981a, b, and c). Several faint fault scarps and lineaments occur in the northern end of the valley. These features strike northeasterly and align with bedrock faults in both the Hiko Range and the western foothills of the North Pahroc Range (Ertec, 1981b). These north-easterly trends are not typical of the prevalent north-south structural trends throughout the Great Basin but are consistent with earthquake focal mechanisms in the area (Smith and Lindh, 1978).

The basin fill in Pahroc Valley is composed of non-indurated sand and gravel with indurated sand layers overlying siliceous volcanics (State of Nevada Engineer's Office). These deposits are derived from erosion of the surrounding bed rock and deposited as alluvial fans or in stream channels within the enclosed basin.

4.0 INTERPRETATION

The basis of interpretation is the Complete Bouguer Anomaly (CBA). Locations of the gravity stations and contours of the CBA gravity field are shown in Drawing 1. The contours were generated by a computer program. Since contouring and other mathematical treatment of irregularly spaced data are inefficient, the station CBA and elevation data were first reduced to sets of values at uniformly spaced points (nodes) in geographic array, or grid. The value at a node was calculated from the station data within a circular area around the node. The algorithm which calculated the nodal value used a bell-shaped function to weight the station values. In this way, those station values nearest the node had the greatest influence on the calculated value. A node spacing of 1.2 miles (2 km) was chosen to match the average data spacing.

4.1 REGIONAL-RESIDUAL SEPARATION

A fundamental part of the gravity interpretation is the separation of regional effects from the local effects of the valley and its fill. The CBA contains long wavelength components from deep and broad geologic structures extending far beyond the valley. These long wavelength components, called the regional gravity, were approximated by upward continuation of the gravity field. Upward continuations were made to successively higher elevations until the negative anomaly from the valley was essentially smoothed out. The final continuation was calculated at an elevation of 170,000 feet (51,816 m). This regional field was subtracted from the CBA and the resulting residual gravity anomaly was adjusted by a constant -2.0 milligals so that the zero residual would approximately fit the existing rock outcrops.

4.2 DENSITY SELECTION

The construction of a geologic model from the residual anomaly requires selection of density values representative of the alluvial fill and of the underlying rock. Because only very generalized density information is available, the geologic interpretation of the gravity data can be only a coarse approximation. Information gathered from several borings (Table 1) in alluvial deposits taken during Verification studies indicate an average density of 1.9 g/cm^3. To account for compaction with depth (Woollard, 1962; and Grant and West, 1965), 2.3g/cm^3 was used in the modeling process.

The underlying basement material is thought to be predominantly Paleozoic carbonate rocks. Middle Tertiary volcanics probably lie between the alluvial basin deposits and the carbonate basement (Howard, 1978), but little is known about their thickness and density. The density of siliceous to intermediate volcanic rocks generally ranges between 2.0 to 2.5 g/cm^3 depending on the degree of welding, compaction, and alteration. The older volcanics in the Pahroc Valley area are probably at the higher end of this density range, being approximately equivalent to dense alluvium or between the density of alluvium and the density of bed rock. The information available regarding the

VERIFICATION BORING RESULTS			
BORING NUMBER	TOTAL HOLE DEPTH feet (meter)	DENSITY 9/cm3	REMARKS
PA-B-1	100/(30)	1.96	NO ROCK ENCOUNTERED
PA-B-2	100/(30)	1.93	NO ROCK ENCOUNTERED
PA-B-3	62/(19)	1.82	NO ROCK ENCOUNTERED

SELECTED VERIFICATION SEISMIC REFRACTION RESULTS*	
LINE NUMBER	DEEPEST LAYER fps/(mps) @ feet/(meter)
PA-S-5	7400/(2255) @ 75/(23)

*LOCATIONS MARKED IN DRAWING 2

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GEOTECHNICAL DATA
PAHROC VALLEY, NEVADA

20 JUL 81

TABLE 1

volume and characteristics of subsurface volcanic rocks in Pahroc Valley is insufficient to make an estimate of their effect on the gravitational field.

Published values for carbonate rocks typically range between 2.6 and 2.9 g/cm^3. The Paleozoic carbonate rocks in Nevada and Utah are generally reported to be relatively high in density, on the order of 2.8 g/cm^3. This value was selected to represent the density of the basement rock. A density contrast of -0.50 g/cm^3 was used for modeling.

4.3 MODELING

Modeling was done with the aid of a computer program which iteratively calculates a three-dimensional solution of gravity anomaly data (Cordell, 1970). The gravity anomaly is represented by discrete values on a two-dimensional grid. The source of the anomaly (the volume of low-density valley fill) is represented by a set of vertical prism elements. The tops of the prisms lie in a common horizontal plane. The bottoms of the prisms collectively represent the bottom of the valley fill. Each prism has a uniform density and a cross-sectional area equal to one grid square. A grid square of 1.2 miles by 1.2 miles (2 km by 2 km) was selected as representative of the gravity station distribution. Computations were made for three iterations of mutually interactive prism adjustments.

The calculated thickness of the valley fill depends upon the residual anomaly and the density contrast (i.e., fill density minus rock density) used. Since neither fill nor rock density is perfectly known, nor even uniform, the calculated thickness should be expected to contain a corresponding degree of uncertainty. A source of error in modeling Pahroc Valley as an alluvium/bedrock system is the possibility of buried volcanic rocks in the valley.

Three shallow borings, one seismic refraction line (Table 1), and six deep borings (Table 2) were used as constraints in the interpretation process. Their locations are marked in Drawing 2. Boring D (Table 2) and seismic refraction line PA-S-5 (Table 1) indicate the probable bedrock contact to be less than 200 feet deep in the southern portion of Pahroc Valley. The calculated thickness of fill (or depth to bed rock) is contoured in Drawing 2.

4.4 DISCUSSION OF RESULTS

The gravity data from Pahroc Valley provide a irregular contour pattern (Drawing 1). The interpreted depth-to-bedrock contour maps indicates a shallow, semicircular depression in the center of the northern part of the valley and broad, shallow pediments in the northwestern corner and southern part of the valley. Maximum depth to basement is about 1400 feet (427 m) in the northwestern part of the semicircular central depression. The northern edge of this shallow depression is steep compared to the southern and southeastern edge. This configuration suggests a northwesterly dipping bedrock surface below the alluvium. This is consistent with surface observations which indicate that the southwesterly dipping Tertiary volcanics in the South Pahroc

BORINGS FROM LITERATURE			
I. D.	COMPANY	LOCATION (TWP-RGE-SCC)	REMARKS
BORING (A)	NEVADA STATE ENGINEERS WELL LOGS	3S/61E-9ac	300 ft / (92m) CEMENTED GRAVEL
BORING (B)	NEVADA STATE ENGINEERS WELL LOGS	4S/61E-22ac	310 ft / (95m) SANDY – GRAVEL
BORING (C)	NEVADA STATE ENGINEERS WELL LOGS	4S/61E-23ad	160 ft / (49m) SANDY – GRAVEL
BORING (D)	NEVADA STATE ENGINEERS WELL LOGS	4S/61E-2CAC	1314 ft / (401m) RHYOLITE, DECOMPOSED GRAN–ITE AFTER 64 ft (19.5m)
BORING (E)	NEVADA STATE ENGINEERS WELL LOGS	4S/62E-9dd1	410 ft / (125m) IGNEOUS BEDROCK AFTER 35 ft (11m)
BORING (F)	NEVADA STATE ENGINEERS WELL LOGS	4S/62E-9dd2	240 ft / (73m) IGNEOUS BEDROCK AFTER 16 ft (5m)

* LOCATIONS MARKED IN DRAWING 2

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BORINGS FROM LITERATURE*
PAHROC VALLEY, NEVADA

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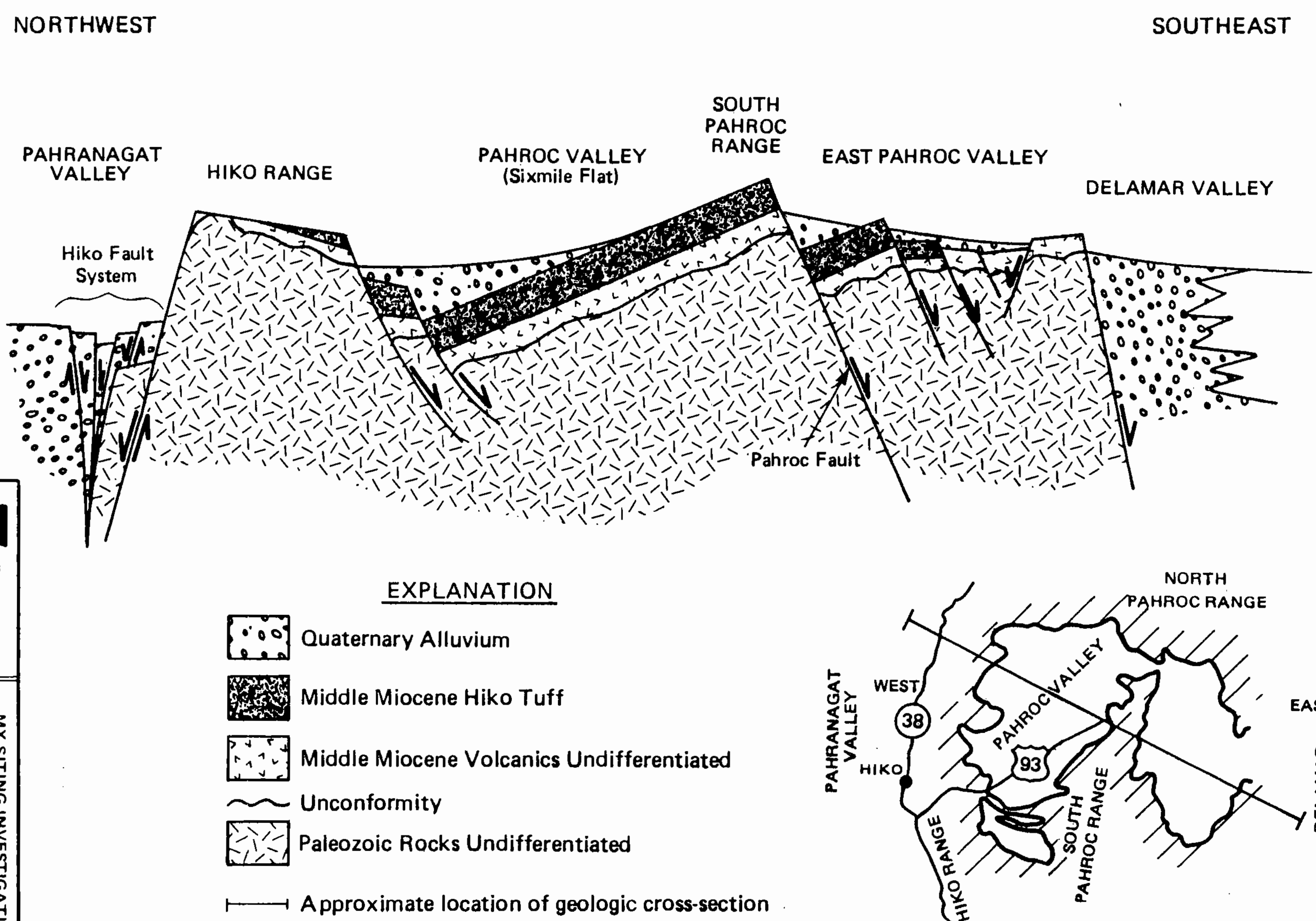
TABLE 2

Range continue unfaulted under the alluvial basin-fill sediments (Ertec, 1981a).

The surface geologic and geomorphic data indicate a series of young northeasterly trending normal faults crossing the north-western corner of the valley. Most of these faults are north of the central depression (Drawing 2) and are not indicated in the depth-to-rock contours. These faults were interpreted primarily from surface geologic data and the CBA contours (Drawing 1). They are thought to be small displacement features within and separating a shallow pediment in the north and northwestern part of the valley from the deeper central part of the valley. The apparent east-west trend of the deepest part of the basin (Drawing 2) seems anomalous but may be a result of complexly intersecting subsurface faults. Such an interpretation, however, must be regarded as speculative without borehole information.

The contours in Drawing 2 indicate that the narrow, southern part of Pahroc Valley contains only thin accumulations of alluvial fill (less than about 200 feet [61 m]). Irregularities in the CBA contours (Drawing 1) suggest two intersecting small displacement faults (Drawing 2).

A northwest-southeast cross section from Pahranagat Valley to Delamar Valley in (Figure 3) shows a concept of the structural configuration of Pahroc Valley and its relationship to adjoining valleys. The figure illustrates that the alluvium in Pahroc Valley is thin compared to the alluvium in typical Basin and Range grabens such as Delamar and Pahranagat valleys.



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SCHEMATIC GEOLOGIC CROSS-SECTION
PAHROC VALLEY, NEVADA

20 JUL 81

FIGURE 3

5.0 CONCLUSION

Gravity data indicate that Pahroc Valley is an equidimensional alluvial basin which is approximately 1400 feet (427 m) deep at its northwestern end. The alluvium overlies a down-to-the-west tilted fault block (Figure 3), and there is a broad, shallow pediment across the southern end of the valley.

The calculated bedrock depths are necessarily approximate because the complex and imperfectly known density distribution has been represented by a simple two-density model. Also, the residual gravity anomaly is necessarily based on an interpreted regional field. An average density contrast of -0.50 g/cm^3 between the alluvium and bed rock was used to calculate the thickness of the valley-fill material. Future studies that acquire better density data or measure actual depths to bed rock 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/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 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. 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:

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

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. 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.

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

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

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

c. <u>Latitude Effect</u>: 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 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) 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. 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 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

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 create a regional field. 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. 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.

In Potential Theory, a field normal to a surface, regardless of its actual source, may be considered as originating in an areal distribution of mass on that surface. If the field strength is known the surface density of mass (grams per square centimeter) can be calculated. The observed gravity field at the surface of the earth approximately fulfills the requirements of this theory: thus the observed (Bouguer anomaly) field can be used to compute a surficial distribution of mass which would reproduce the field, and most importantly, account for the gravity field anywhere above the surface of observation. On this basis, the Bouguer anomaly field is readily "continued" to level surfaces above the ground.

An important property of such "upward continuation" is that the resultant field (which can be represented by a contour map), with increasing altitudes of continuation, 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 continuations produce "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. 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.

The second vertical derivative (SVD) of gravitational field is used to aid the interpreter in evaluating the subsurface mass distribution. Once the CBA field has been projected onto a uniform grid system, its SVD at the grid nodes is readily computed.

In accordance with LaPlace's Equation in Free Space, the negative of the second vertical derivative is equal to the sums of the second derivatives in the x-direction and in the y-direction. The second vertical derivative is an indication of the curvature of the Bouguer anomaly field. In particular the zero-value of the SVD indicates the inflection in the field as it changes from "concave-upward" (algebraically negative SVD) to "convex-upward" (algebraically positive SVD). In a general way the zero SVD falls on the tightest contours of the field and where contours are nearly parallel its location can be established by eye. However, where contours diverge, converge, or change direction this is not always so readily done. The zero SVD contour line may be an indicator of a line of faulting, the pinchout of a stratum, truncation of a stratum at an unconformity or merely a marked change in shape or in density of a geologic unit.

APPENDIX A2.0

PAHROC VALLEY, UTAH

GRAVITY DATA

PAHROC VALLEY GRAVITY DATA

STATION IDENT.	LAT. DEG MIN	LONG. DEG MIN / ELEV. +CODE	TER-COR. IN	TER-COR. OUT / NORTH UTM	EAST UTM / OBSV GRAV / THEO GRAV	FAA	CBA +1000
6625	372521	114560546690T	0	121414328	682811478351941 36	-2370	81821
6626	372732	114553846621T	0	128414721	683711477541944 43	-2820	81408
2327	372956	114572052100T	0	151415129	680941450841947 69	-660	81721
0999	373687	114564049961T	0	95416484	681821470271958 34	-1810	81245
1361	373713	114587349656T	0	101416524	678381474061958 72	-1750	81421
0997	373714	114595549711T	0	99416523	677171479501958 73	-1160	81989
0998	373732	114582250899T	0	108416561	679121471961958 99	-820	81928
0870	373896	114588651621T	0	208416862	678121475641961 38	-10	82588
0860	373936	114566556381T	166	279416943	681351443361961 97	1170	82395
0857	373960	114554255991T	0	195416992	683151453181962 32	1750	82855
0874	374043	114557760180T	0	332417144	682601424231963 53	2670	82492
7144	374310	114567557854T	0	284417635	681051442901967 42	1960	82524
0889	374432	114551456142T	0	197417865	683371461181969 20	2000	83057
6618	372579	115 39750030T	0	248414411	671101469711942 21	-180	83008
6610	372660	115110536030T	0	202414540	660631554211943 39	-5010	82902
2223	372740	115116036001T	0	225414686	659791561621944 55	-4420	83525
6611	372770	115 84142690T	0	229414751	664491519671944 99	-2360	83309
2319	372804	115 7059521T	0	408414837	675841411901945 48	2620	82748
1365	372864	115118836276T	0	227414915	659341552391946 35	-5250	82597
6609	372909	115120736611T	0	226414997	659041548901947 01	-5360	82376
2303	372961	115 54052621T	0	395415113	668851459951947 77	710	83175
2302	373121	115 88044121T	0	167415399	663781516211950 09	-1870	83247
2318	373158	115 5055341T	0	301415492	676001436011950 63	590	82031
2301	373139	115140038399T	0	168415510	656101547771951 08	-4200	82878
2	373139	115140338399T	0	169415510	656061547611951 08	-4220	82859
1364	373234	115139538159T	0	190415593	656161547131951 74	-4550	82630
2304	373304	115 54048950T	0	174415747	668721485241952 76	-700	82774
7428	373312	115111040200T	0	266415745	660331543661952 88	-3100	83456
2317	373335	115 5052920T	0	220415820	675931453451953 21	-190	81980
1363	373358	115 80342444T	0	162415839	664831528151953 55	-2600	83082
7406	373360	115136538448T	0	202415827	656561538601953 57	-5320	81772
2305	373366	115 70045269T	0	139415857	666341508711953 66	-1900	82799
1662	373560	115135038599T	0	209416197	656711538221956 49	-5510	81539
1378	373577	115136338606T	0	201416228	656511538531956 73	-5500	81541
7427	373585	115133638606T	0	201416244	656901538411956 85	-5520	81511
2306	373610	115104043579T	0	116416298	661251519841957 22	-2740	82516
1362	373615	115 25546398T	0	189416331	672801495491957 29	-2520	81839
2307	373734	115 5048862T	0	110416557	675771486201959 02	-1310	82130
2316	373888	115 64045610T	0	97416824	667031507491961 27	-2470	82077
7407	373980	115117040223T	0	262416979	659211532061962 61	-5210	81332

PAHROC 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
1663	373980	115118040220T	0 249416979	6590615316219 6261	-5250	81279
1379	374060	115117840121T	0 242417127	65906153140196377	-5480	81072
1874	374067	115 15054780T	0 235417170	67417145574196388	700	82275
1873	374074	115 50651060T	0 154417172	66893148274196398	-100	82654
1664	374210	115 97041440T	0 320417410	66206153812196596	-3790	82390
7408	374215	115 95041437T	0 329417420	66236153859196603	-3760	82439
2312	374291	115124045410T	0 183417552	65807151531196714	-2460	82233
2315	374444	115 19050751T	0 114417866	67343149246196937	40	82864
1380	374470	115 80041919T	0 199417896	66447152864196975	-4670	81239
1665	374490	115 75042579T	5 148417934	66519152452197004	-4490	81143
7409	374500	115 75042582T	4 143417953	66519152485197019	-4470	81157
DMV001	373567	115 69 5754S	252 466416248	67556142189195659	685	81778
DMV002	373314	115 129 6483C	671 696415778	67477136925195290	2654	81909
DMV004	373117	115 186 7668S10851910415412		67401128200195004	5376	82217
PRV002	373952	115 996 6221V	7221279416932	66177139551196220	1884	82667
PRV003	374118	115 960 5583C	393 582417240	66224144626196462	709	82642
PRV013	373936	115 492 4615S	1 102416917	66919150208196197	-2556	81806
PRV046	373190	115 623 4796V	28 194415534	66754149314195110	-660	83204
PRV067	373200	1151124 5357S	401 718415538	66016145070195124	362	83210
PRV071	372995	1151059 5022Y	314 366415161	66119147589194826	26	83578
PRV077	372802	115 392 6284S	227 599414823	67109138961194545	3561	82954
PRV080	372552	115 58 6570S	7581240414371	67611135608194182	3265	82855
DMV105	372595	1145500 4625Y	1 114414469	68433147518194244	-3201	81140
PRV024	374043	1145986 6652S	6341229417131	67659137133196353	3391	82566
PRV001	373806	1151102 5595C	20 947416659	66027144142196007	793	82677
PRV204	372661	115 177 6486C	15 776414569	67432137446194340	4154	82823
PRV203	373033	115 453 6282C	145 547415249	67011139023194881	3269	82534
PRV202	373258	115 410 5742C	9 357415666	67065142604195209	1437	82219
PRV078	372901	115 178 7950V	482460415013	67421126359194689	6505	81898
PRV074	372782	115 643 5483S	11 319414779	66740144263194516	1351	82980
PRV072	372839	115 879 4436Y	49 192414877	66390151100194599	-1752	83359
PRV070	373601	1151173 4858S	34 405416278	65930148286195708	-1703	82167
PRV069	373392	1151156 5590S	441227415892	65962143466195404	672	82878
PRV065	373387	1151029 4710S	32 240415886	66149150028195397	-1042	83165
PRV043	373195	115 488 5592C	30 368415547	66953143499195117	1012	82337
PRV035	373361	115 379 5423C	12 261415857	67107145035195359	715	82491
PRV021	374221	115 55 5792S	6 293417458	67550144017196612	1918	82462
PRV020	374184	115 201 5650S	20 343417385	67337144386196558	1003	82096
PRV015	374073	115 318 5636S	21 518417176	67170144179196396	827	82143
PRV014	374023	115 526 4847S	13 98417077	66866149991196323	-717	82863

PAHROC 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
PRV009	374086	115 719	5494S	20 398417188	66580145558196415	850	82529
PRV201	373633	115 895	4563S	5 101416354	66337150895195762	-1926	82617
PRV066	373095	115 967	4738S	6 165415348	66251149990194972	-392	83619
PRV023	373782	115 103	5086S	15 128416645	67497147342195972	-765	82031
PRV022	373952	115 131	5128S	6 141416958	67449148323196220	364	83021
PRV005	373873	115 870	4870C	12 133416790	66366149387196105	-886	82649
DMV119	372604	1145888	5542Y	1 404414473	67860142654194257	556	82059
DMV117	372956	1145724	5210Y	2 152415129	68088144642194769	-1094	81290
DMV005	373151	115 7	5581C	33 339415481	67663142994195053	467	81804
DMV109	372897	1145587	5348Y	22 331415024	68292143599194683	-752	81360
DMV111	372621	1145650	4884Y	27 187414512	68210146812194282	-1506	82050
DMV118	372979	1145891	5494Y	9 223415166	67841143152194803	56	81550
DMV003	373255	115 81	5488C	0 303415671	67550144125195205	571	82156
PRV004	373995	115 824	4833V	0 133417017	66429149325196283	-1474	82175
PRV006	373751	115 882	4566V	0 104416564	66352150259195927	-2698	81833
PRV007	373785	115 732	4492V	0 102416631	66572150231195977	-3472	81309
PRV008	373900	115 720	4628S	0 97416844	66585150405196144	-2185	82127
PRV010	373977	115 635	4641V	0 106416989	66707150377196256	-2204	82073
PRV011	373856	115 608	4508V	0 103416766	66752150940196080	-2716	82012
PRV012	373819	115 484	4547S	0 102416701	66935150176196026	-3059	81534
PRV016	373980	115 355	4801V	0 108417003	67119149322196261	-1757	81977
PRV017	373859	115 359	4666V	0 102416779	67118149959196084	-2214	81973
PRV018	373798	115 226	4762V	0 101416670	67316149626195995	-1554	82305
PRV025	373691	115 93	4919V	0 133416477	67515148350195840	-1196	82160
PRV027	373470	115 191	5233V	0 208416065	67360146068195518	-200	82160
PRV028	373569	115 208	5015V	0 124416247	67351147504195662	-961	82059
PRV029	373677	115 24347900T		0 102416446	67295149006195819	-1734	82031
PRV030	373736	115 374	4621V	0 103416551	67100149420195905	-2997	81345
PRV031	373620	115 360	4714V	0 105416337	67125149161195736	-2211	81816
PRV032	373508	115 331	4950C	0 135416131	67172147803195573	-1185	82067
PRV036	373436	115 444	4829C	0 162415994	67009148909195468	-1113	82578
PRV037	373538	115 484	4631C	0 116416182	66946149342195617	-2692	81629
PRV038	373651	115 486	4533C	0 106416391	66939150254195781	-2367	81778
PRV039	373738	115 593	4446V	0 109416548	66778150450195908	-3618	81327
PRV040	373610	115 585	4442V	0 120416312	66795150710195722	-3209	81761
PRV041	373409	115 545	4685C	0 150415941	66861149819195429	-1519	82652
PRV042	373304	115 548	4895C	0 171415747	66861148498195276	-711	82765
PRV044	373022	115 630	4918C	0 309415223	66750148312194865	-269	83266
PRV045	373097	115 727	4650C	0 178415359	66605149838194974	-1375	82943
PRV047	373222	115 733	4636V	0 143415590	66591150010195157	-1517	82814

PAHROC 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
PRV048	373349	115 675	4603V	0	136415826	66672150545195341	-1478	82959
PRV049	373499	115 652	4429V	0	153416104	66700150752195560	-3128	81919
PRV050	373576	115 692	4344V	0	146416246	66638151117195672	-3674	81655
PRV051	373664	115 691	4367V	0	128416408	66637151342195800	-3362	81872
PRV052	373642	115 813	4393S	0	101416364	66458151573195768	-2853	82265
PRV053	373525	115 787	4277S	0	124416149	66501151862195598	-3486	82051
PRV054	373422	115 76743861T		0	126415959	66534151749195448	-2422	82744
PRV055	373301	115 791	4482V	0	129415734	66503150854195271	-2238	82604
PRV056	373025	115 841	4533V	0	156415222	66439151078194870	-1132	83563
PRV057	373163	115 881	4410S	0	163415476	66375151508195071	-2060	83061
PRV058	373292	115 921	4264Y	0	132415714	66312152709195258	-2422	83167
RPRV059	373387	115 930	4185S	0	138415889	66295153196195397	-2817	83047
PRV060	373474	115 926	4229S	0	127416050	66298152402195523	-3324	82379
PRV061	373552	115 920	4289S	0	118416195	66304151840195637	-3434	82055
PRV063	373609	1151044	4358S	0	115416296	66119151975195720	-2733	82518
PRV064	373487	1151053	4398V	0	131416071	66110151908195542	-2245	82885
PRV068	373303	115109740200T		0	254415729	66052154350195274	-3093	83449
PRV073	372898	115 788	4681S	0	187414989	66522149814194685	-818	83404
PRV075	372900	115 627	5165S	0	257414998	66759146658194688	580	83221
PRV076	372960	115 491	6058S	0	623415113	66957140678194775	2920	82881
DMV006	373049	1145920	5317Y	0	184415295	67795144576194905	-288	81761
DMV007	373302	1145932	5148Y	0	139415762	67768145668195273	-1156	81425
DMV008	373409	1145945	5061Y	0	125415960	67744146385195429	-1413	81450
DMV009	373551	1145952	4963Y	0	105416222	67728147357195636	-1571	81606
DMV010	373644	1145822	4927Y	0	99416398	67916147343195771	-2060	81235
DMV011	373469	1145822	4948Y	0	101416075	6792 146949195516	-2000	81225
DMV012	373358	1145802	5016Y	0	104415870	6795 146241195355	-1907	81089
DMV013	373217	1145849	5150Y	0	131415608	67893145450195149	-1231	81335
DMV014	373130	1145848	5206Y	0	146415447	67898145085195023	-942	81448
DMV015	373045	1145764	5137Y	0	138415292	68025145344194899	-1208	81409
DMV016	373134	1145723	5080Y	0	118415458	68082145580195028	-1639	81153
DMV017	373273	1145723	5018Y	0	103415715	68077145993195231	-2012	80976
DMV018	373407	1145684	4930Y	0	102415964	68129146663195426	-2366	80921
DMV019	373555	1145712	4888Y	0	103416237	68081147338195641	-2301	81130
DMV020	373598	1145603	4918Y	0	95416320	68240147291195704	-2129	81192
DMV021	373468	1145600	4877Y	0	102416080	68250147253195515	-2363	81105
DMV022	373293	1145601	4939Y	0	93415756	68255146351195260	-2427	80826
DMV023	373183	1145649	4998Y	0	103415551	68189146021195100	-2041	81015
DMV024	373050	1145649	5025U	0	112415305	68195146013194906	-1601	81372
DMV025	373017	1145535	4937Y	0	111415248	68364146276194858	-2119	81153

PAHROC VALLEY GRAVITY DATA

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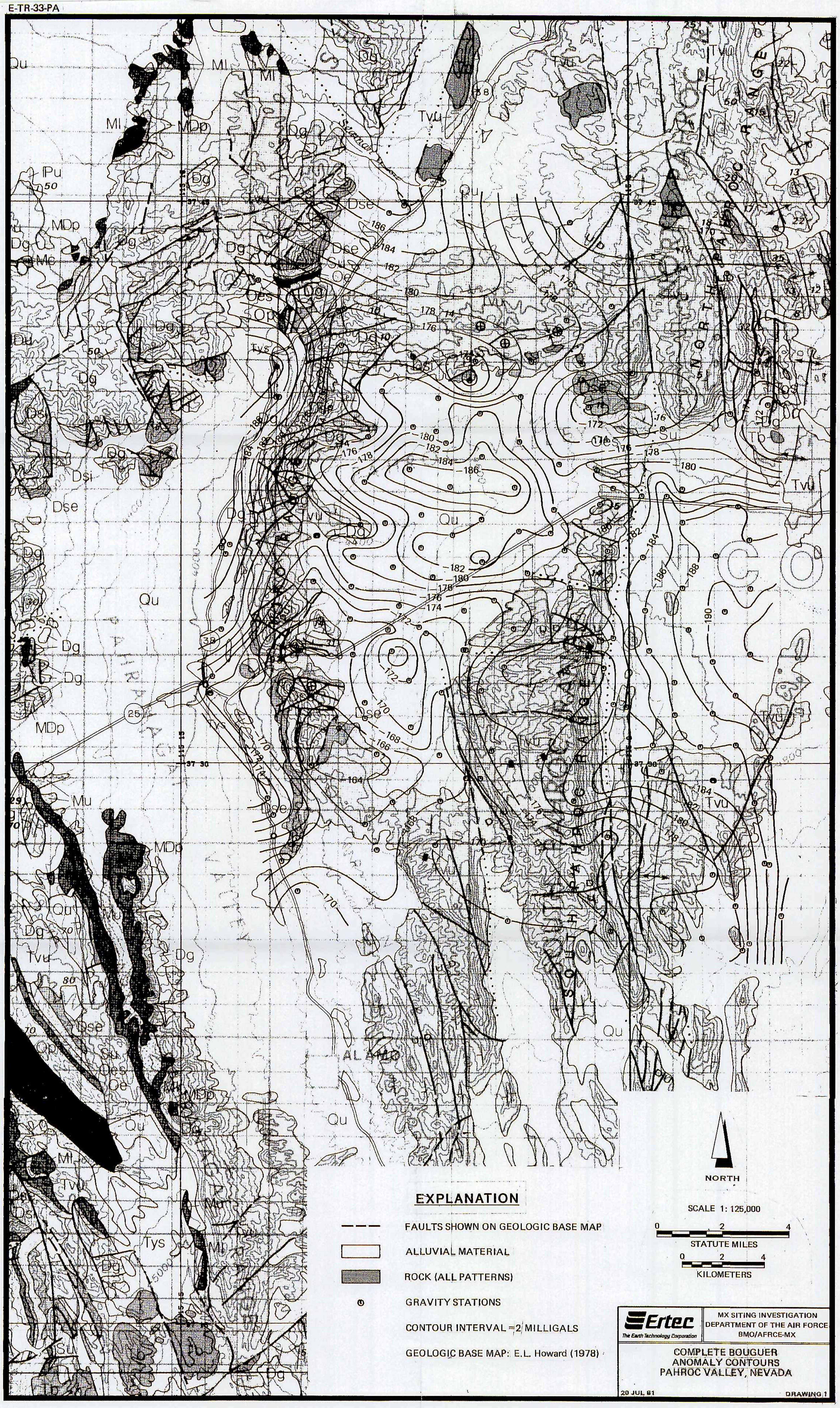
DMV110	372735	1145554	4673Y	0	132	414726	68347	147825	194448	-2645	81549
DMV112	372501	1145628	4690Y	0	134	414291	68248	147875	194107	-2094	82043
DMV115	372535	1145759	4863V	0	202	414349	68053	146909	194157	-1481	82135
DMV116	372704	1145724	4962V	0	164	414663	68098	146799	194403	-905	82335

END OF LIST

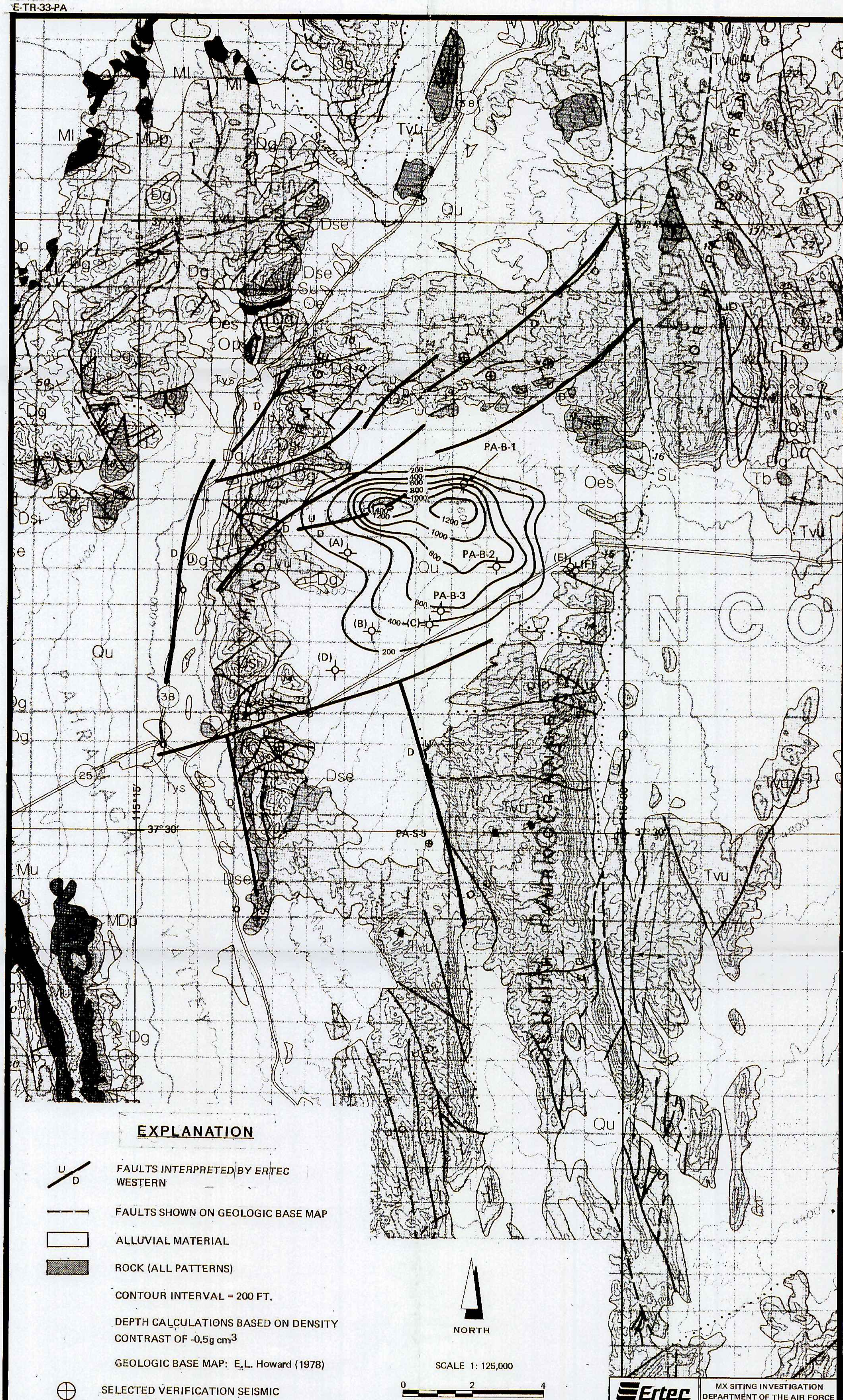
E-TR-33-PA



NORTH
EXPLANATION
FAULTS SHOWN ON GEOLOGIC BASE MAP
ALLUVIAL MATERIAL
ROCK (ALL PATTERNS)
GRAVITY STATIONS
CONTOUR INTERVAL = 2 MILLIGALS
GEOLOGIC BASE MAP: E.L. Howard (1978)
SCALE 1: 125,000
0 2 4
STATUTE MILES
0 2 4
KILOMETERS
Ertec
The Earth Technology Corporation
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE
BMO/AFRCE-MX
COMPLETE BOUGUER
ANOMALY CONTOURS
PAHROC VALLEY, NEVADA
20 JUL 81
DRAWING 1

1 2

E-TR-33-PA



EXPLANATION

- U/D FAULTS INTERPRETED BY ERTEC WESTERN
- FAULTS SHOWN ON GEOLOGIC BASE MAP
- ALLUVIAL MATERIAL
- ROCK (ALL PATTERNS)

CONTOUR INTERVAL = 200 FT.

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

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

- ⊕ SELECTED VERIFICATION SEISMIC REFRACTION RESULTS
- BORINGS FROM LITERATURE

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DEPTH TO ROCK INTERPRETED FROM GRAVITY DATA PAHROC VALLEY, NEVADA

20 JUL 81 — DRAWING 2

3 4