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MX SITING INVESTIGATION GRAVITY SURVEY - GARDEN VALLEY, NEVADA.(U)

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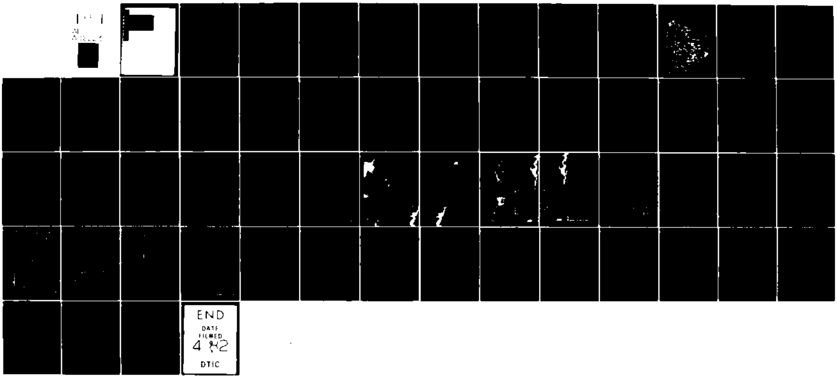

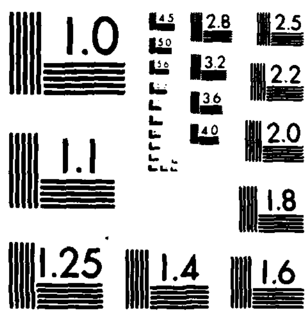

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MX SITING INVESTIGATION

GRAVITY SURVEY - GARDEN VALLEY

NEVADA

Prepared for:

U.S. Department of ir Force
Ballistic Missile C (BMO)
Norton Air Force Base, lifornia 92409

Prepared by:

Fugro National, Inc.
3777 Long Beach Boulevard
Long Beach, California 90807

30 May 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Gravity measurements were made in Garden 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.

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FOREWORD

Methodology and Characterization studies during fiscal years 1977 and 1978 included gravity surveys in ten valleys in Arizona (five), Nevada (two), New Mexico (two), and California (one). The gravity data were obtained for the purpose of estimating 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 Fugro National's Characterization Reports (FN-TR-26a through e).

During the FY 77 surveys, measurements were made to form an approximate one-mile grid over the study areas and contour maps showing interpreted depth to bedrock were made. In FY 79, the decision was made to concentrate 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, Reveille and Railroad valleys, a sufficient density of library data is 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 has been incorporated into the FY 80 program and the results are being summarized in a series of valley reports. In reports covering Nevada-Utah gravity studies will be numbered, "FN-TR-33-", followed by the abbreviation for the subject valley. In addition, more detailed reports of the results of FY 77 surveys in Dry Lake and Ralston valleys, Nevada are being prepared. Verification studies are continuing in FY 80 and gravity studies are included in the program. DMA will continue to obtain the field measurements and it is planned to return to the grid pattern. The interpretation of the grid data will allow the production of contour maps which will be valuable in the deep basin structural analysis needed for computer modeling in the water resources program. The gravity interpretations will also be useful in Nuclear Hardness and Survivability (NH&S) evaluations.

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

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

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1.0 INTRODUCTION

1.1 OBJECTIVE

Gravity measurements were made in Garden 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 ground-water resources.

1.2 LOCATION

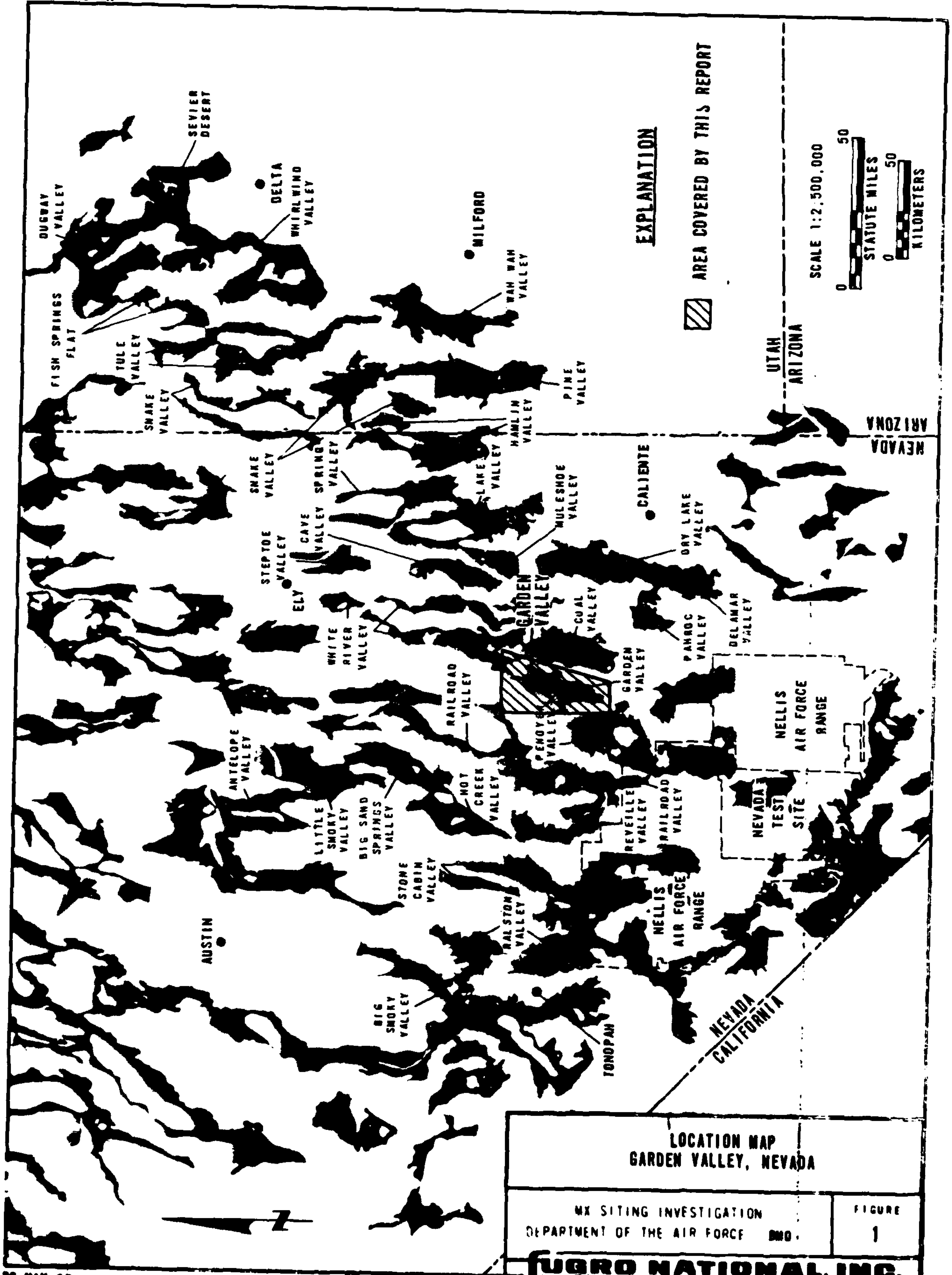
Garden Valley is located in central Nevada and covers part of Nye and Lincoln counties. The valley is accessible only by improved and unimproved dirt roads. Caliente, Nevada is located approximately 60 miles (97 km) east of the site on U.S. Highway 93 (Figure 1).

Garden Valley is bounded on the northwest and west by Quinn Canyon Range, to the southwest by the Worthington Mountains and to the east by the Golden Gate Range (Figure 2).

1.3 SCOPE OF STUDY

The Defense Mapping Agency Hydrographic-Topographic Center/ Geodetic Survey Squadron (DMAHTC/GSS) made the 60 gravity measurements for the three profiles used in this study (Appendix A2.0). Data from the DMA gravity library was also used to establish the regional gravity.

Profile positions are shown in Figure 2 and the locations of the individual stations are shown on Drawing 1. The profile lengths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ARIZONA
NEVADA
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SEVIER DESERT
DELTA
WHIRLWIND VALLEY
DUGWAY VALLEY
MILFORD
WAH WAH VALLEY
FISH SPRINGS FLAT
TULE VALLEY
SNAKE VALLEY
PINE VALLEY
HAMLIN VALLEY
SPRING VALLEY
LAKE VALLEY
MULESHOE VALLEY
CALIENTE
DRY LAKE VALLEY
CAVE VALLEY
STEPTOE VALLEY
ELY
GARDEN VALLEY
COAL VALLEY
PAHROC VALLEY
DELAMAR VALLEY
WHITE RIVER VALLEY
RAILROAD VALLEY
NELLIS AIR FORCE RANGE
PENOYER VALLEY
ANTELOPE VALLEY
HOT CREEK VALLEY
REVEILLE VALLEY
NEVADA TEST SITE
LITTLE SMOKY VALLEY
BIG SAND SPRINGS VALLEY
STONE CABIN VALLEY
RALSTON VALLEY
AUSTIN
BIG SMOKY VALLEY
TONOPAH
LOCATION MAP
GARDEN VALLEY, NEVADA
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE
FIGURE 1
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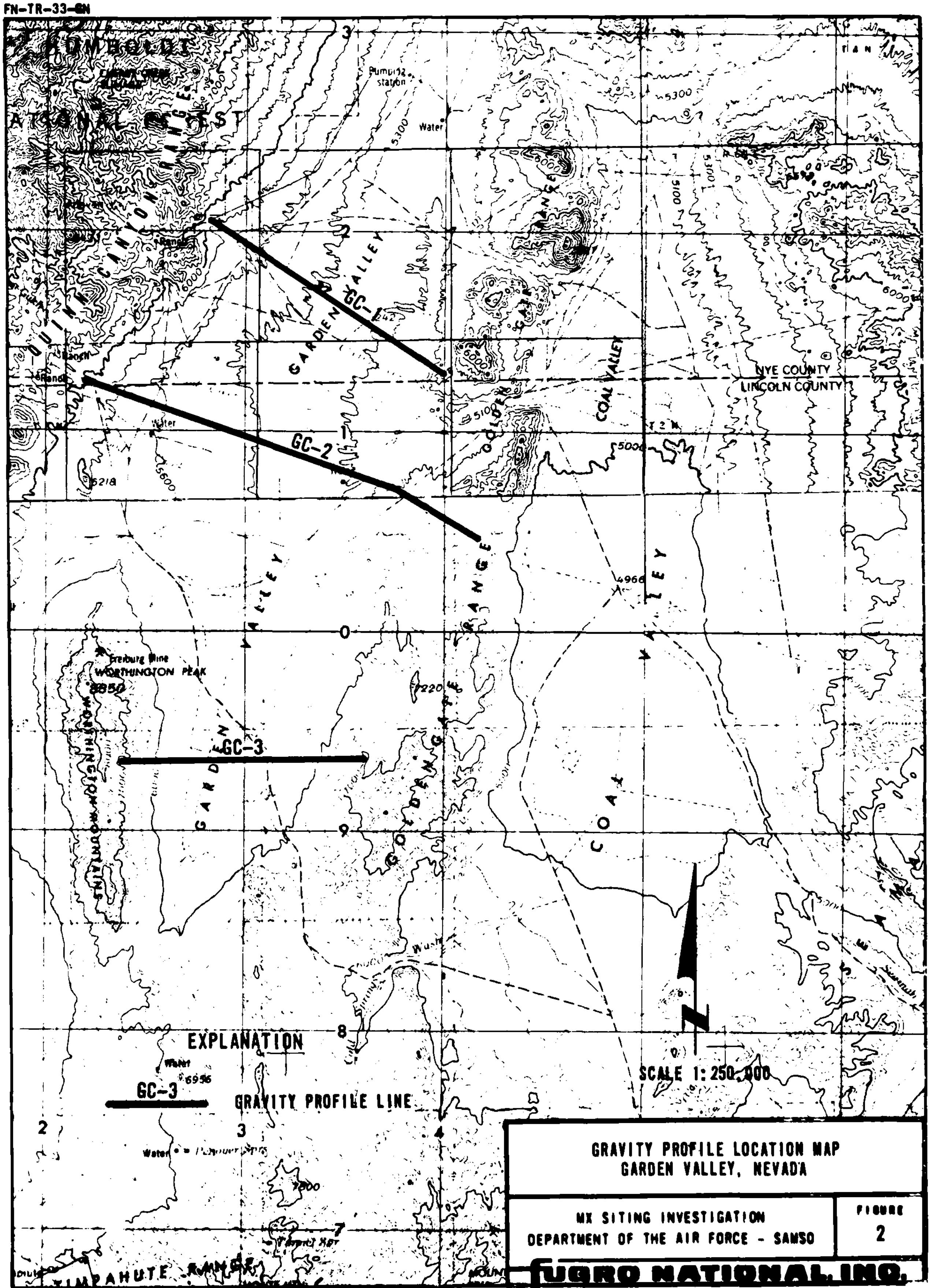

GRAVITY PROFILE LOCATION MAP
GARDEN VALLEY, NEVADA

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FIGURE 2

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range between 6 miles (10 km) and 8 miles (14 km), crossing from bedrock to bedrock over the valley fill. The gravity sampling interval is approximately 1 mile (1.6 km) over the central valley and .25 mile (0.4 km) near the valley boundaries. The denser sampling was used near the valley flanks to define any steep gravity gradients associated with boundary faults, and to resolve anomalies with high spatial frequency that could be associated with shallow bedrock.

The tolerance for establishing station elevations was 5 feet (1.5 m). The tolerance for elevation control limits the gravity precision to 0.3 milligals.

2.0 GRAVITY DATA REDUCTION

DMAHTC/GSS obtained the basic observations and reduced them to Simple Bouguer Anomalies (SBA) for each station as described in Appendix A1.0. Up to three levels of terrain corrections were applied to convert the SBA to the Complete Bouguer Anomaly (CBA). First, the Defense Mapping Agency Aerospace Center (DMAAC), St. Louis, used its library of digitized terrain data and a computer program to calculate corrections out to 104 miles (167 km) from each station. When the program could not calculate the terrain effects near a station, a ring template was used to estimate the effect of terrain within approximately 3000 feet (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 to calculate the effect of the very near relief. The CBA data for the Garden Valley stations are listed in Appendix A2.0.

3.0 GEOLOGY SUMMARY

The Grant Range consists primarily of east-southeast dipping lower Paleozoic limestone, dolomite, and quartzite which are cut by north-south trending thrust faults and normal faults (Howard, 1978). Except for the lower Paleozoic rocks which extend south from the Grant Range, the Quinn Canyon Range is almost entirely Tertiary volcanic rocks. The structure of the Quinn Canyon Range is fairly simple except where the Paleozoic rocks are exposed beneath the volcanics (Tschanz and Pampeyan, 1970). The Worthington Mountains consist of Ordovician to Mississippian-aged limestones, dolomites, and quartzites. Structurally, these mountains consist of westward dipping strata which have been thrust eastward over east dipping formations of the same or younger age (Tschanz and Pampeyan, 1970). The Golden Gate Range is a westward dipping fault block broken by northeast trending faults. The range consists of limestone and dolomite overlain in the north by Tertiary ash flow tuffs and Quaternary basalt (Howard, 1978).

The western margin of Garden Valley has numerous, short, late Quaternary and possibly Holocene faults (Fugro National, 1980). These faults form discontinuous, north-south trending breaks very near the foot of the Worthington, Quinn Canyon, and Grant Ranges. No range bounding faults have been noted along the eastern margin of the valley.

Valley-fill sediments in Garden Valley consist of alluvial fan deposits of silt, sand, and gravel with some Pleistocene lake deposits at the extreme northern end (Fugro National FY 78 and 79 geology and drilling data). At the surface, fan units comprise approximately 90 percent of the valley and lake sediments make up about ten percent. Eakin (1963) states that sediment thickness in Garden Valley is at least several hundred feet thick and may be more than one thousand feet thick.

4.0 INTERPRETATION

A valley filled with alluvium which has a low-density relative to the surrounding bedrock creates a negative gravity anomaly. Gravity profiles across such valleys are often U-shaped, low in the middle of the valley where the fill is thickest and high on the ends where the fill thins and bedrock emerges. Interpretation requires removal of regional trends leaving the gravity reflection of the valley fill. The gravity data and interpreted geologic models for the three profiles across Garden Valley are shown in Figures 3 through 5.

4.1 REGIONAL-RESIDUAL SEPARATION

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

The CBA contains long-wavelength components from deep and broad geologic structures extending far beyond the valley. These long-wavelength components, called the regional gravity, have been approximated by linear interpolation between CBA values at bedrock stations on opposite ends of the profiles. Where only one end of a profile was on bedrock, the regional value on the other end was assigned a quantity consistent with the regional trend of the valley. The regional gravity was subtracted from the CBA and the resulting residual anomaly profiles were used to model the valley. This regional separation technique is only approximate. Some regional effects may still remain after the subtraction but the error is probably small compared to the large residual anomaly values of these profiles.

The CBA values and the straight line regional field for each profile is shown in the top portion of Figures 3 through 5. The residual gravity anomaly (interpolated at evenly spaced points) is shown by the crosses (x) in the center portion of Figures 3 through 5.

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. Since only very generalized density information is available, the geologic interpretation of the gravity data can only be a coarse approximation. Average in situ density of the fill material was measured between depths of 100 to 160 feet (30 to 49 m) in six shallow borings. The observed density range for the soil was 1.7 to 2.3 g/cm^3. The largest measured density value was used in the modeling process, instead of the average, because the overall alluvium density is expected to increase due to compaction with depth (compaction with depth and age is discussed by Woollard, 1962 and Grant and West, 1965).

The basement material underlying the Garden basin is thought to be the Paleozoic carbonate rocks which are found in the surrounding mountain ranges. Published values for carbonate rocks typically range between 2.6 and 2.8 g/cm^3. The Paleozoic carbonate rocks in Nevada are generally reported to be relatively high in density, on the order of 2.8 g/cm^3. This value was selected to represent the density of the basement rock.

Relative to a given basement density, the calculated basin depth is inversely proportional to the density value assigned to the valley fill materials. A one percent change in the average alluvial fill density will result in a five percent change in the calculated fill thickness.

4.3 MODELING

An iterative computer program that calculates the gravitational field for two-dimensional models was used to approximate the thickness of alluvium beneath each profile. The cross-sectional models appear as a set of 0.5-km-wide blocks whose tops are at surface elevation and whose bottoms represent the alluvium-bedrock boundary. The elevations at the bottoms of the blocks were adjusted by iterative computation until the computed gravity anomaly for the valley fill differed by less than one milligal from the observed residual anomaly.

The computed gravity anomaly from the final model is shown as a continuous line in the second block of Figures 3 through 5. The calculated basin models are shown in the third block of Figures 3 through 5 with a suggested geologic interpretation shown in the lowest block. The cross sections have a five times vertical exaggeration so that gentle slopes appear steep.

The gravity survey of Garden Valley indicates a complex structural basin which was formed as a graben bounded by normal fault system (Figure 6). The shape of the basin appears to be markedly different between the Quinn Canyon and the Golden Gate Ranges (Profiles GC-1 and GC-2) than the shape between the Worthington Mountains and the Golden Gate Range (Profile GC-3).

Both profiles GC-1 and GC-2 (Figures 3 and 4) indicate a nearly symmetrical basin bounded on both sides by at least two normal fault systems. The maximum depth beneath profile GC-1 is calculated to be about 4700 feet. At profile GC-2, the basin is 3 or 4 miles (5 or 6 km) wider and about 700 feet (213 m) shallower. On profile GC-2, there is a small, relatively positive gravity anomaly which may be an indication of a small horst in the center of the basin. An alternative interpretation will be discussed below.

The basin cross-section beneath profile GC-3 appears to be strongly assymetrical and much narrower than at profiles GC-1 and GC-2. The depth beneath GC-3 is comparable to the depth at GC-1. This assymetry may be due to young tectonic uplift of the Worthington Range block which is bounded on both flanks by young, probably Quaternary faults (Fugro National, Inc., 1980).

4.4 DISCUSSION OF RESULTS

The differences in Basin shape indicated by the gravity interpretation as well as the topographic expression of the valley (see Figure 6) and surrounding mountains suggest that there may have been significant forces operating at large angles to those which are normally seen to have dominated formation of the basin and range structures. The axis of the valley trends NE-SW between profiles GC-1 and GC-2, but it is essentially N-S at GC-3. Similar distortions occur in the adjacent mountains, being particularly noticeable between the Worthington mountains and the Quinn Canyon ranges and in the Golden Gate Range near the east end of profile GC-1. An E-W trending fault has been mapped in the Golden Gate Range at this latter location. If this fault were projected into the valley, it would cross profile GC-2 where the previously mentioned, small, relatively positive gravity anomaly occurs. Cross-valley faulting in this vicinity could account for the surficial distortions, this small gravity anomaly and the changes in basin shape. It could be the reason that the maximum valley width occurs near profile GC-2.

5.0 CONCLUSION

There is a large, well defined, negative gravity anomaly associated with Garden Valley. An average density contrast of 0.50 g/cm^3 between the alluvium and bedrock was used to calculate the thickness of the valley fill material.

The gravity interpretation indicates there are major range bounding normal faults on both sides of the valley. The basin is approximately 4800 feet (1463 m) deep on the north and south end. The central part of the basin shallows to a depth of 4000 feet (1219 m). The calculated bedrock depths are only approximations because litle is known about the actual density distribution in and around the valley. Future studies that acquire better density data or measure actual depths to bedrock in deep parts of the valley can be used to refine the gravity interpretation.

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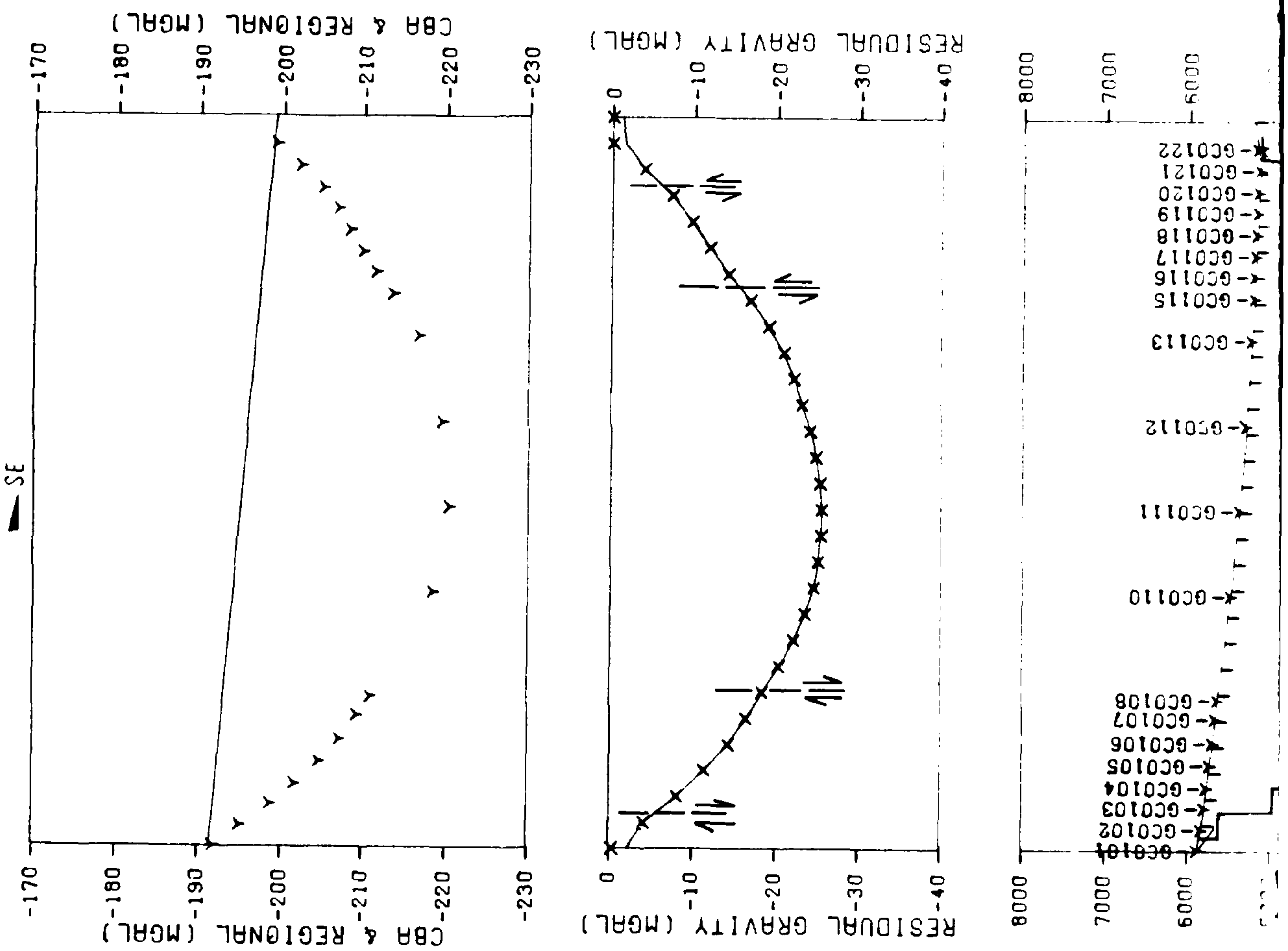
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-40
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6000
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GC0102
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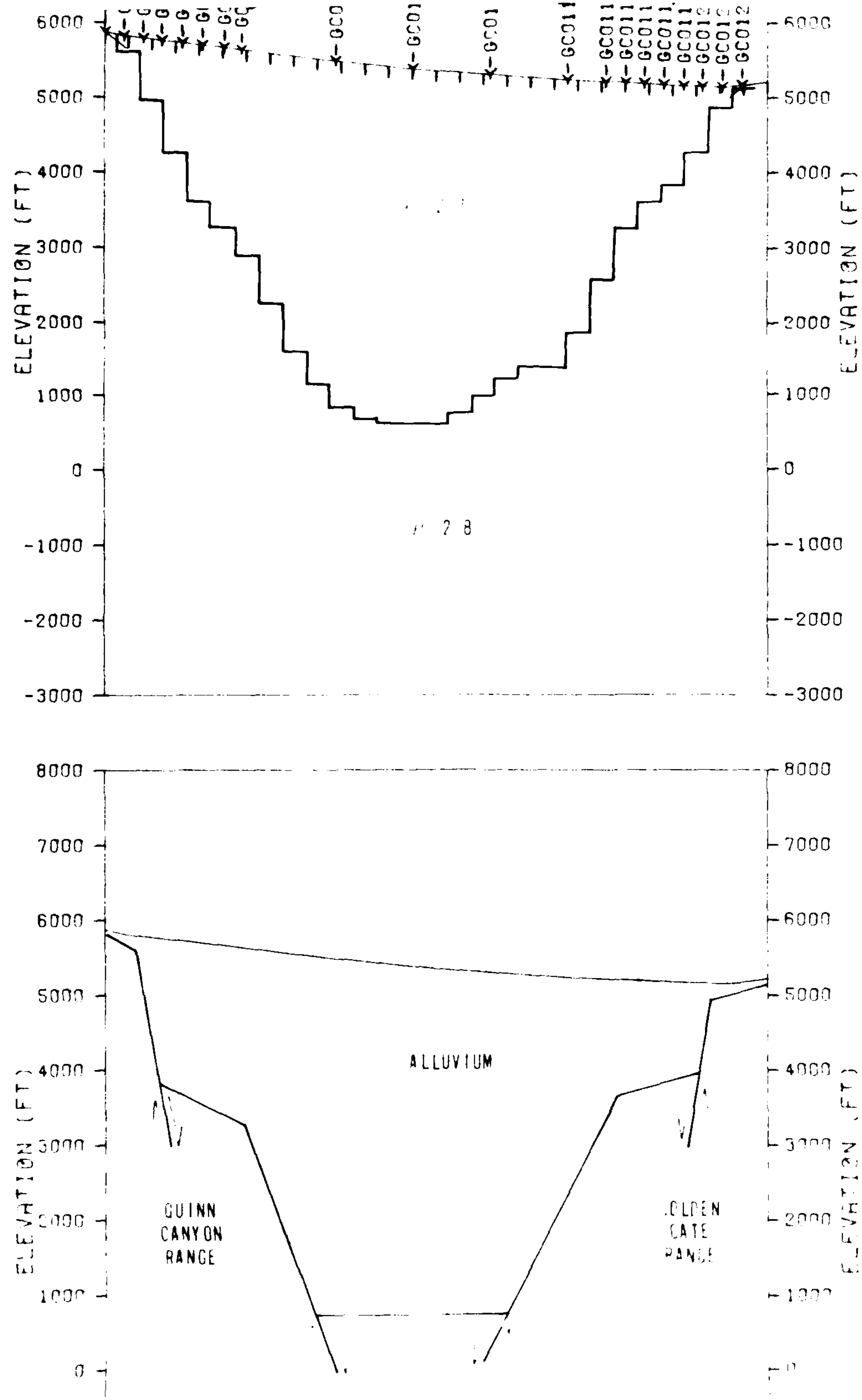
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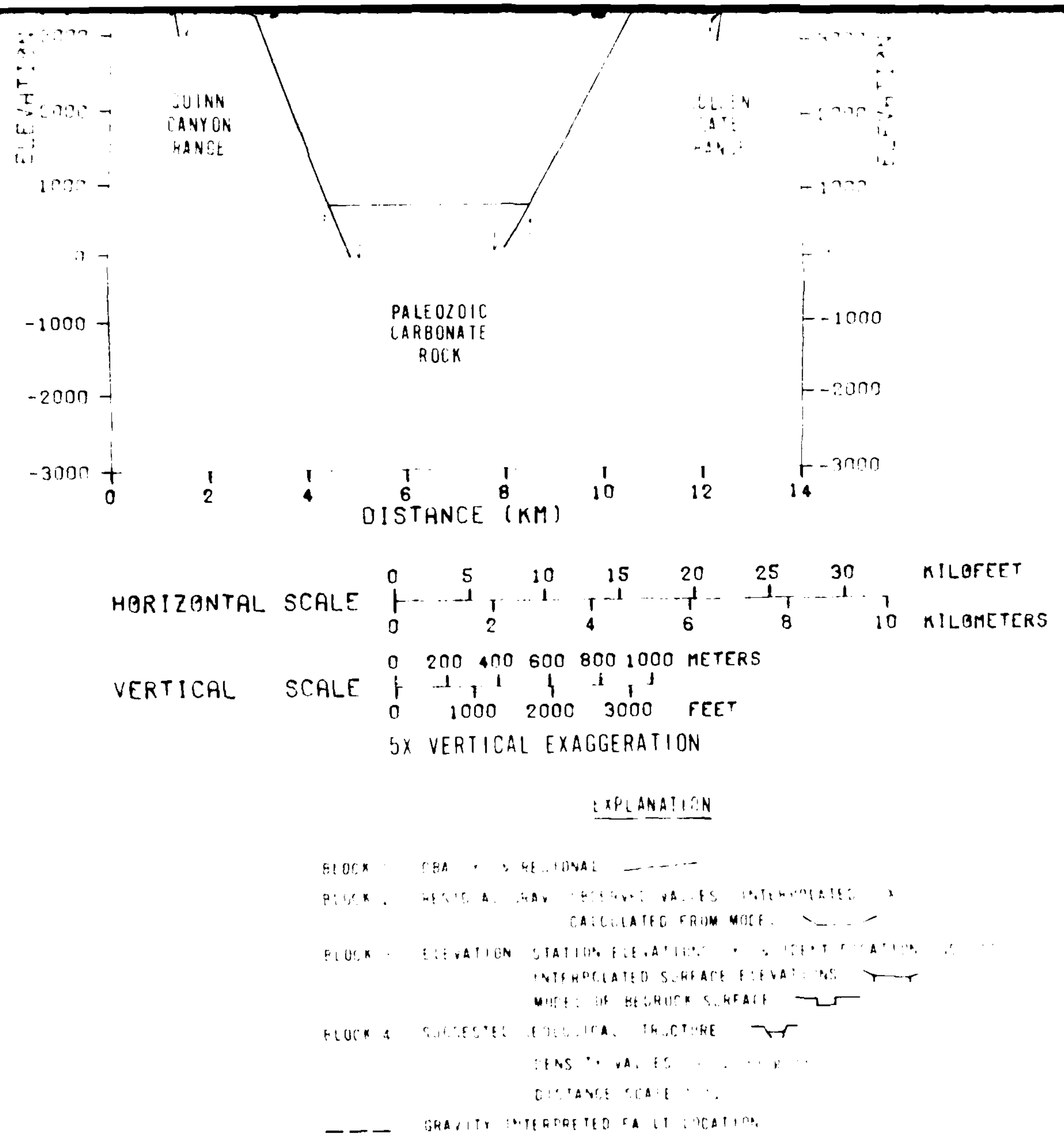

INTERPRETED GRAVITY PROFILE GC-1
GARDEN VALLEY, NEVADA

FIGURE 3

BMO

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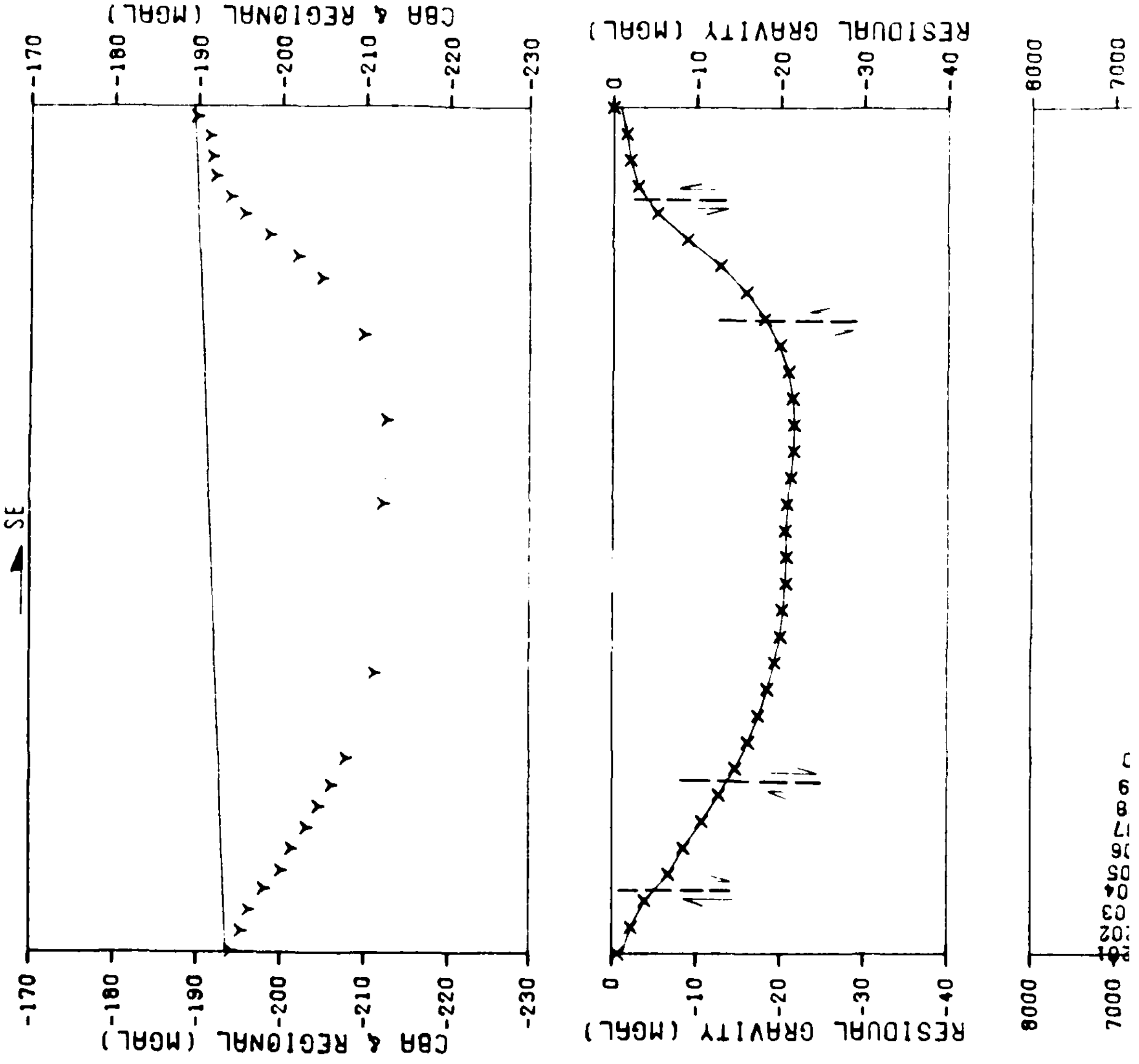
3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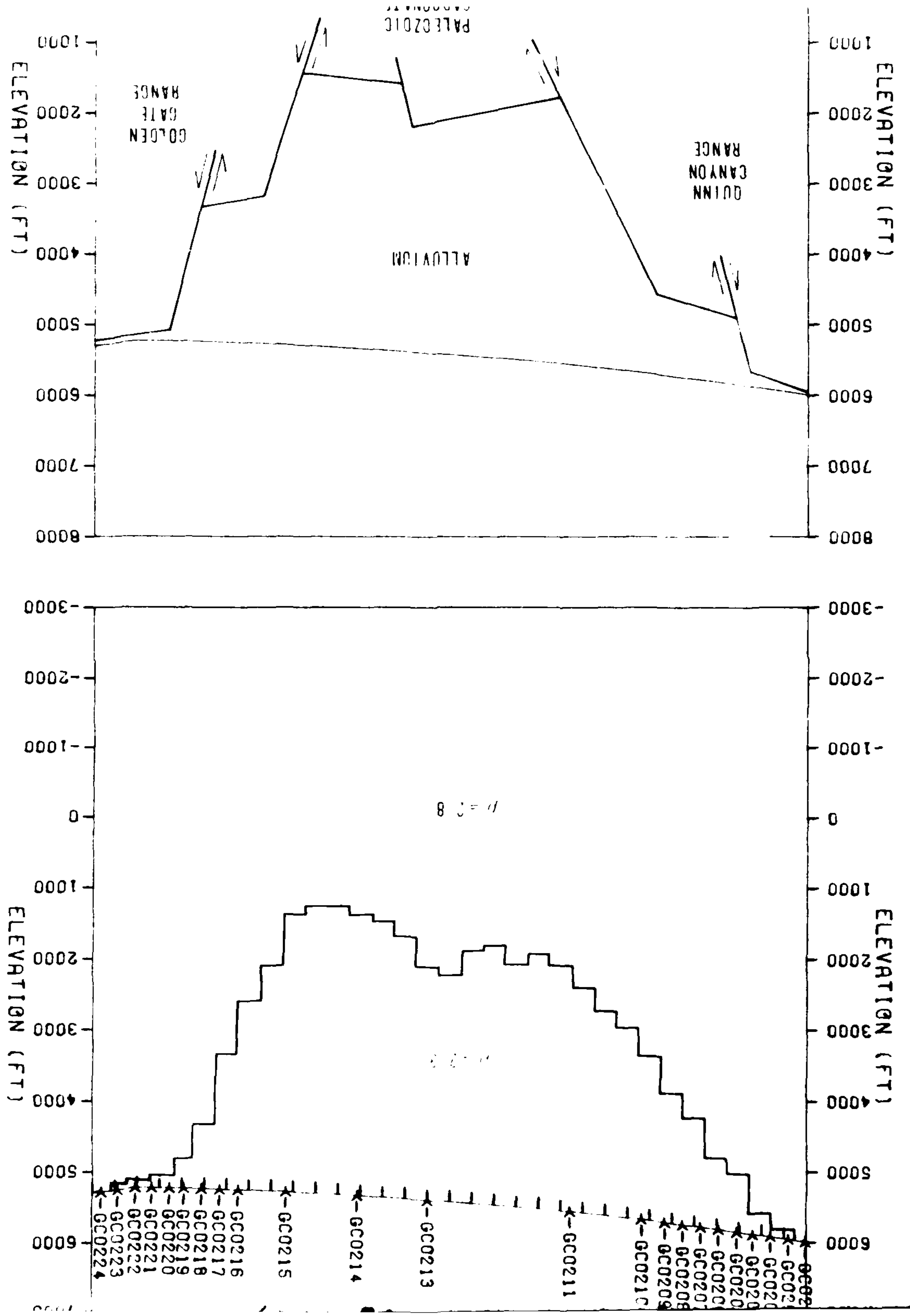
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PALEOZOIC
ALLUVIUM
QUINN CANYON RANGE
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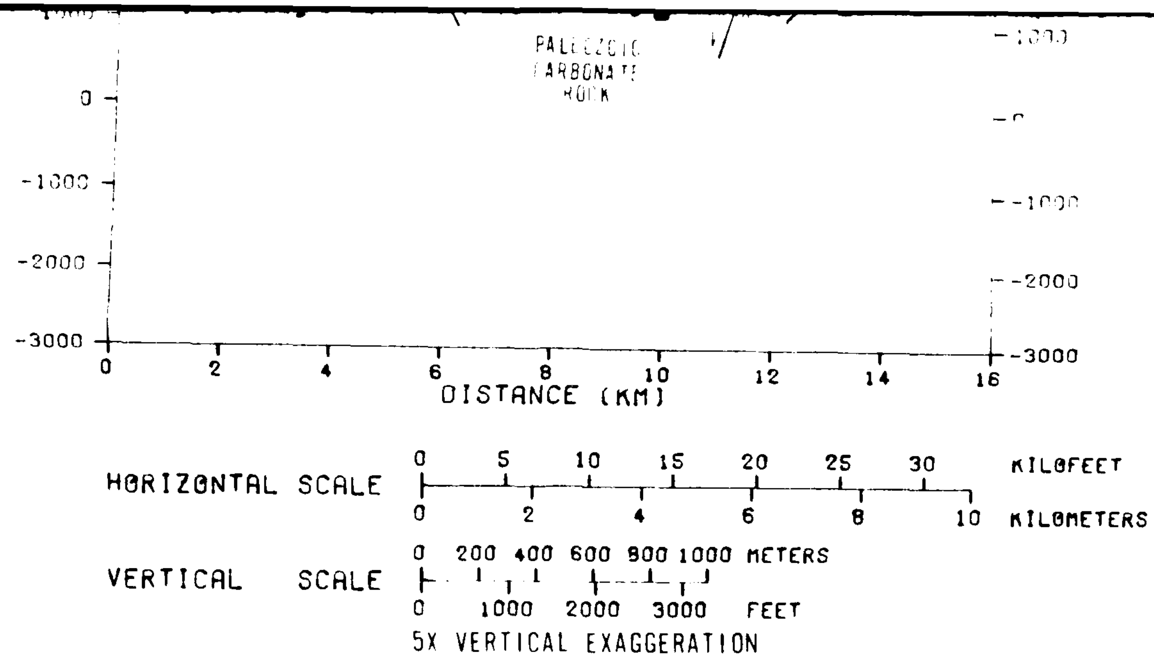
GC0213
GC0211



EXPLANATION

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INTERPOLATED SURFACE ELEVATIONS
MODEL OF BEDROCK SURFACE [illegible]

BLOCK 4 SUGGESTED GEOLOGICAL STRUCTURE
DENSITY VALUES [illegible]
DISTANCE SCALE [illegible]

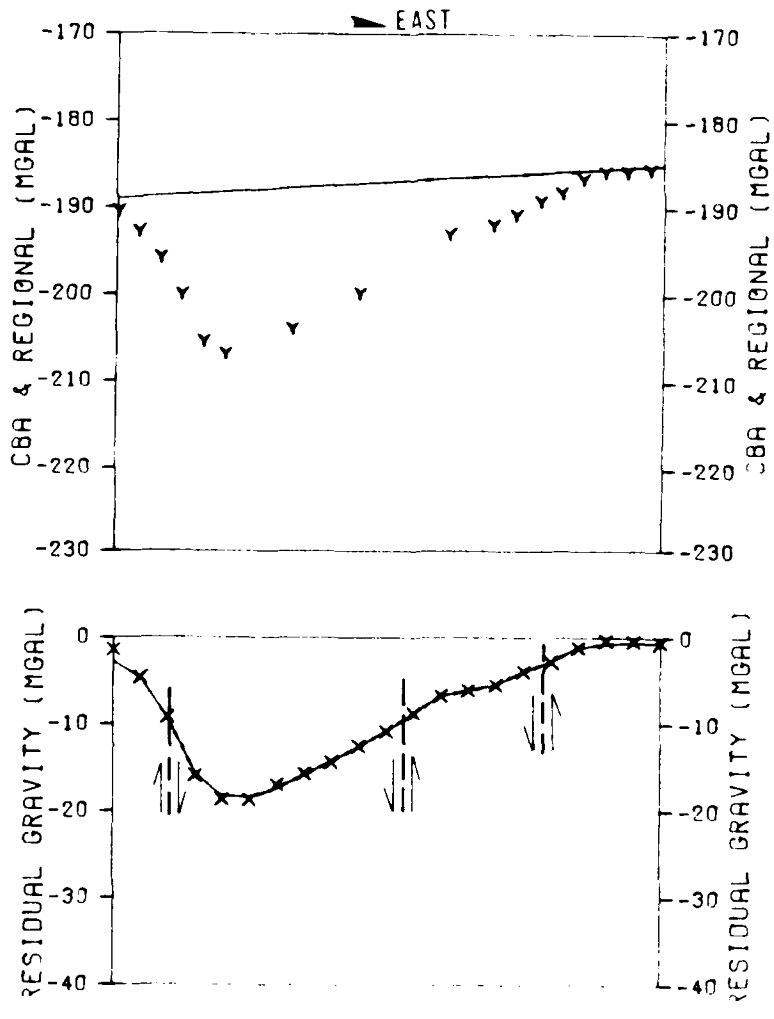
— — — GRAVITY INTERPRETED FAULT LOCATION

INTERPRETED GRAVITY PROFILE CC-[illegible]
GARDEN VALLEY, NEVADA

MX [illegible] INVESTIGATION
DEPARTMENT OF THE AIR FORCE BMO

FIGURE 4

FUGRO NATIONAL, INC.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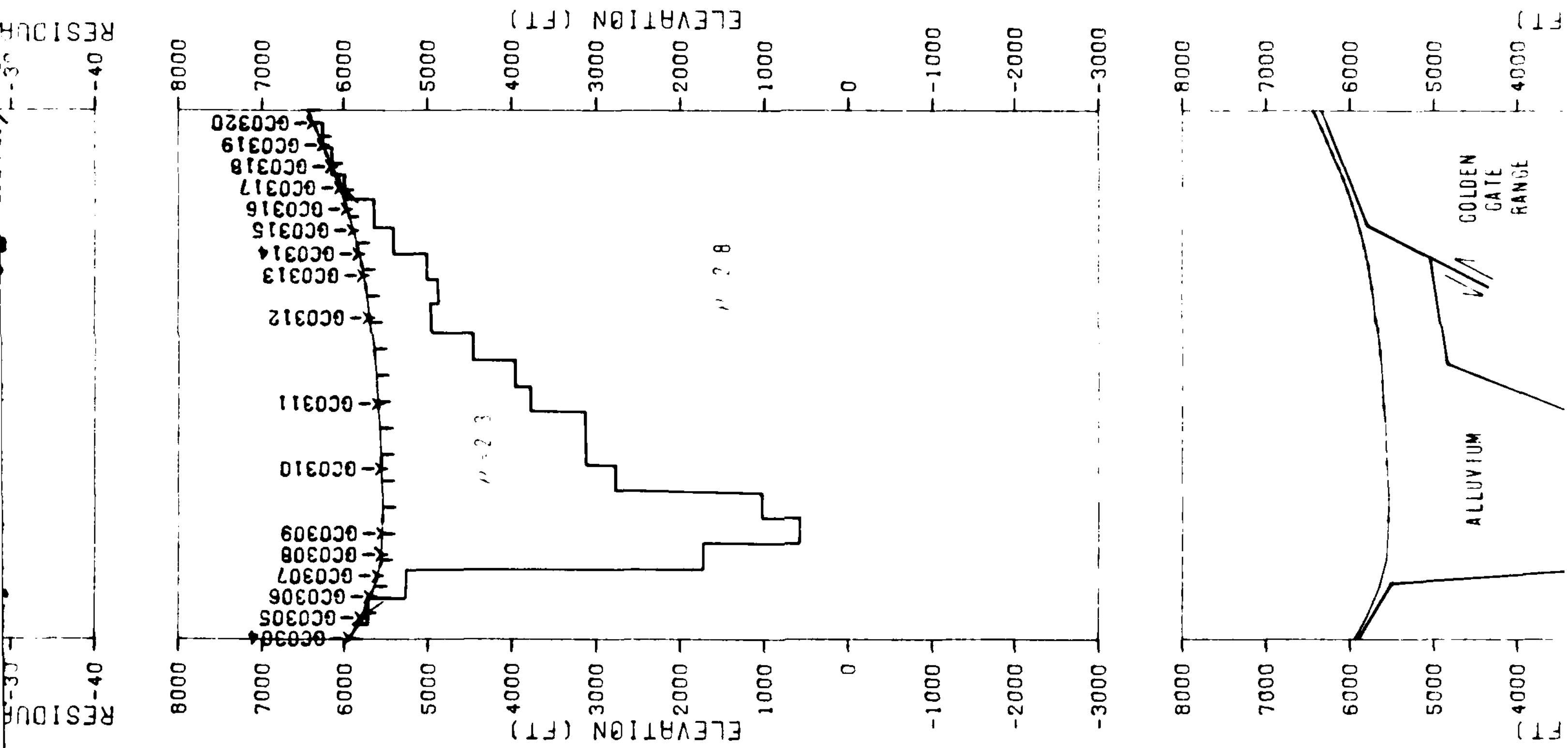
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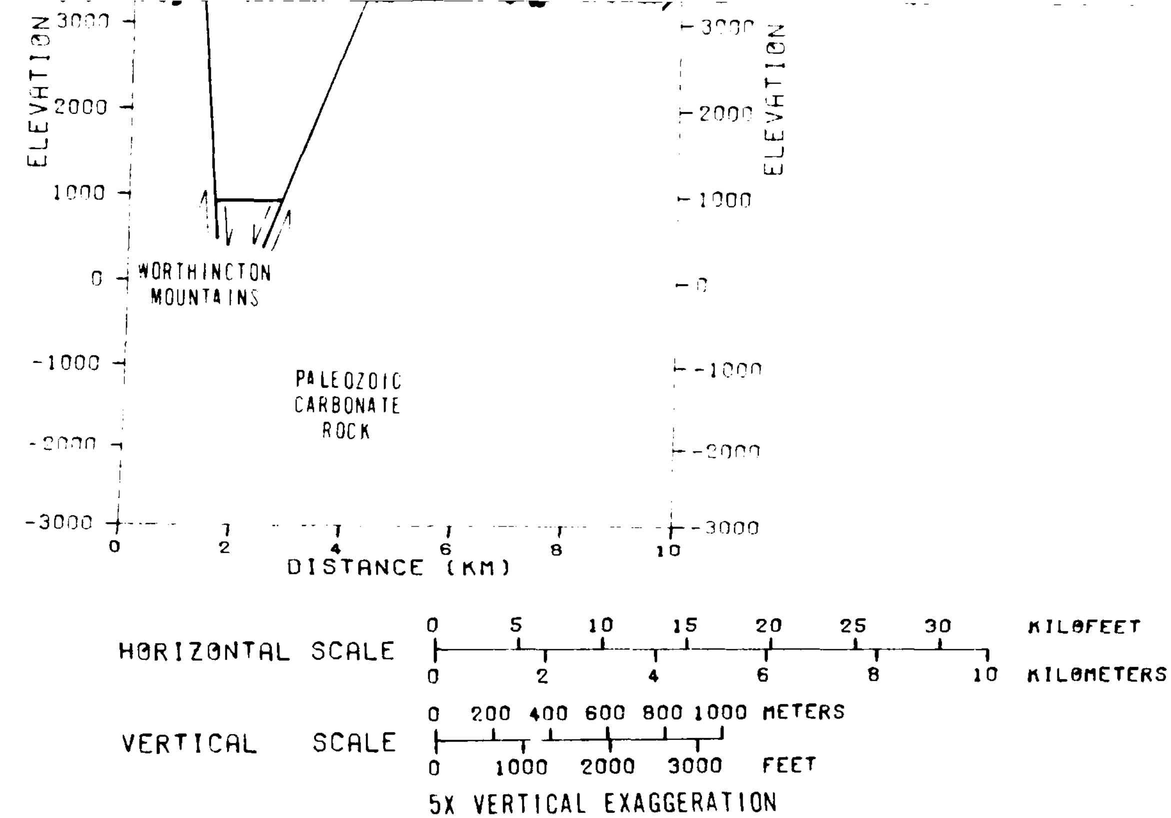
GOLDEN GATE RANGE
ALLUVIUM

2



EXPLANATION

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CALCULATED FROM MODEL

BLOCK [illegible] ELEVATION STATION ELEVATIONS [illegible] Y [illegible] IDENTIFICATION [illegible]
INTERPOLATED SURFACE ELEVATIONS [illegible]
MODEL OF BEDROCK SURFACE

BLOCK 4 SUGGESTED GEOLOGICAL STRUCTURE [illegible]
DENSITY VALUES [illegible]
DISTANCE SCALE [illegible]

GRAVITY INTERPRETED FAULT LOCATION

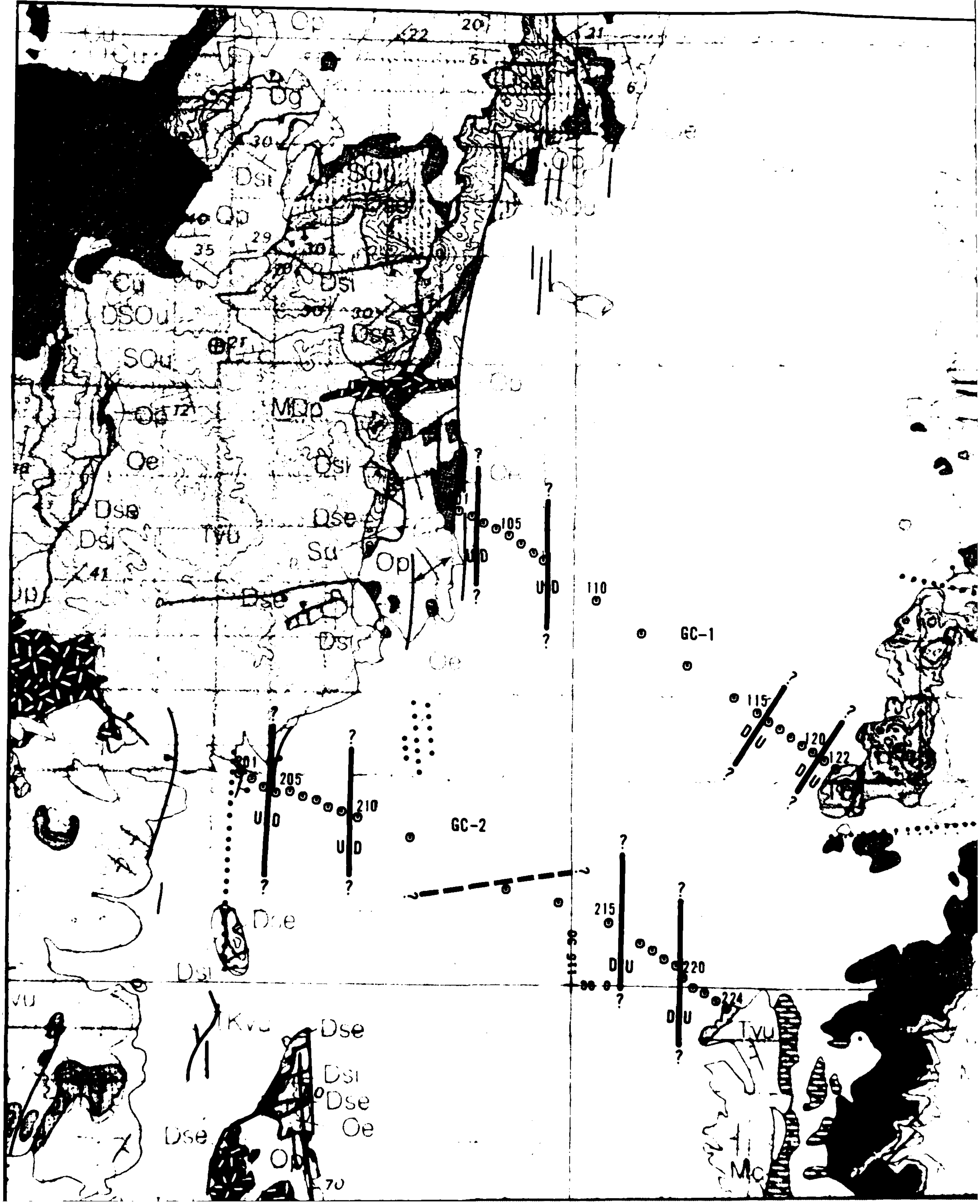
INTERPRETED GRAVITY PROFILE GC-3
GARDEN VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE BMO

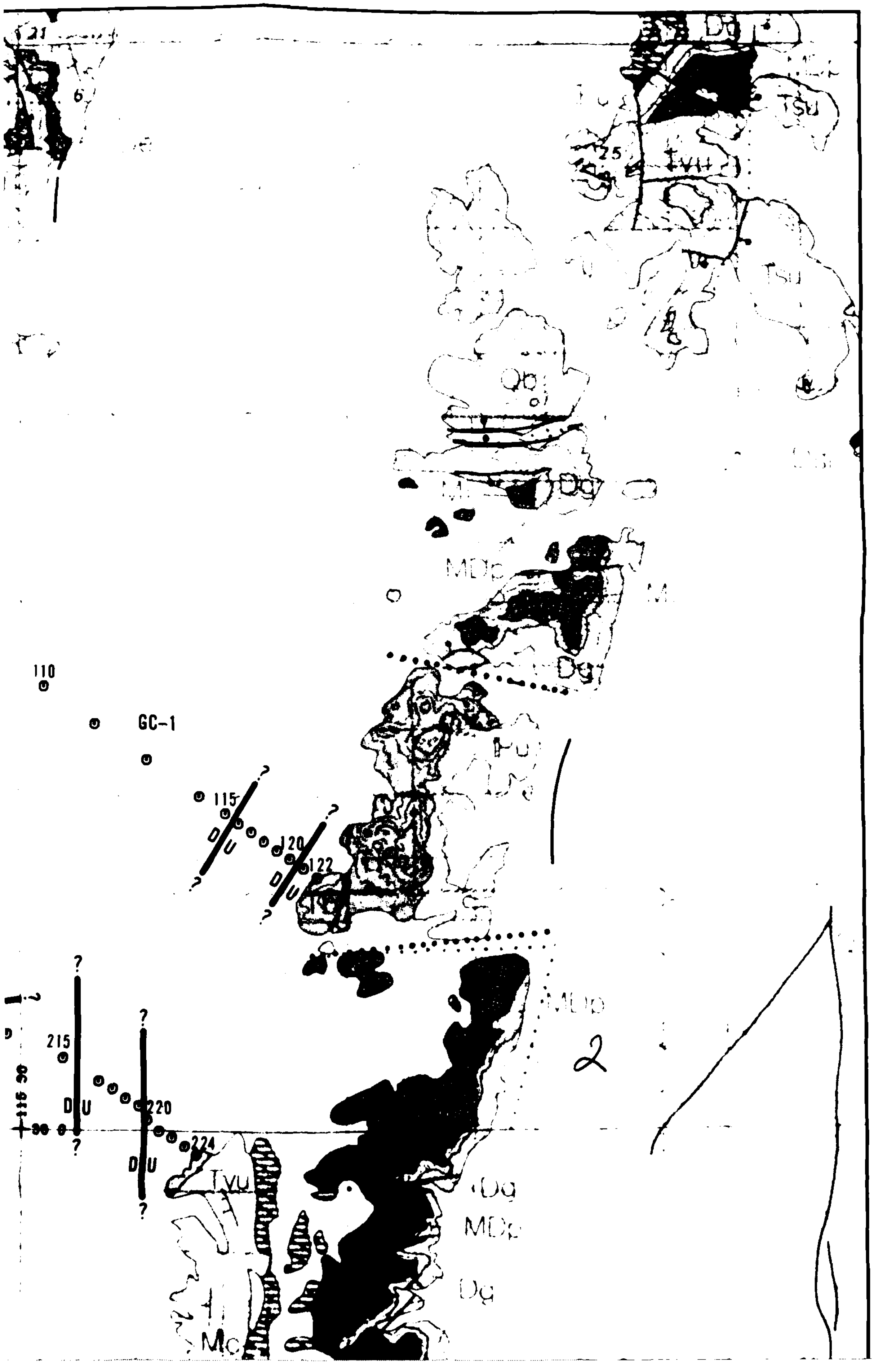
FIGURE 5

FUGRO NATIONAL, INC.

FN-TR-33-GN



Op
Dg
Dsi
SOu
Cu
DSOu
MDp
Oe
Dse
Tvu
Su
UD
105
110
GC-1
115
120
122
DU
201
205
210
GC-2
215
220
224
Kvu
Mc
70



Dg
Tsu
Tvu
Qb
MDp
Mc
GC-1
110
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D
U
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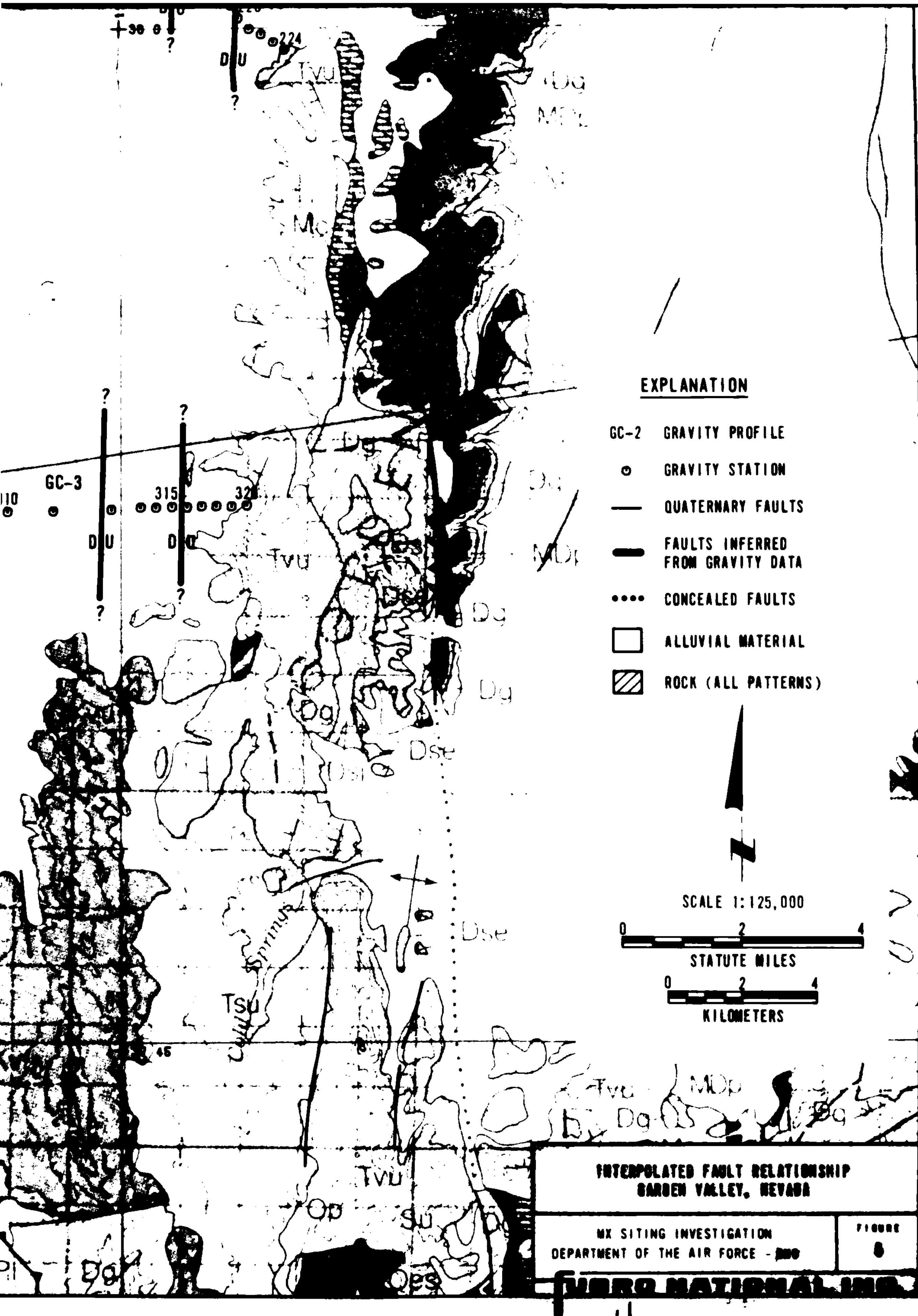
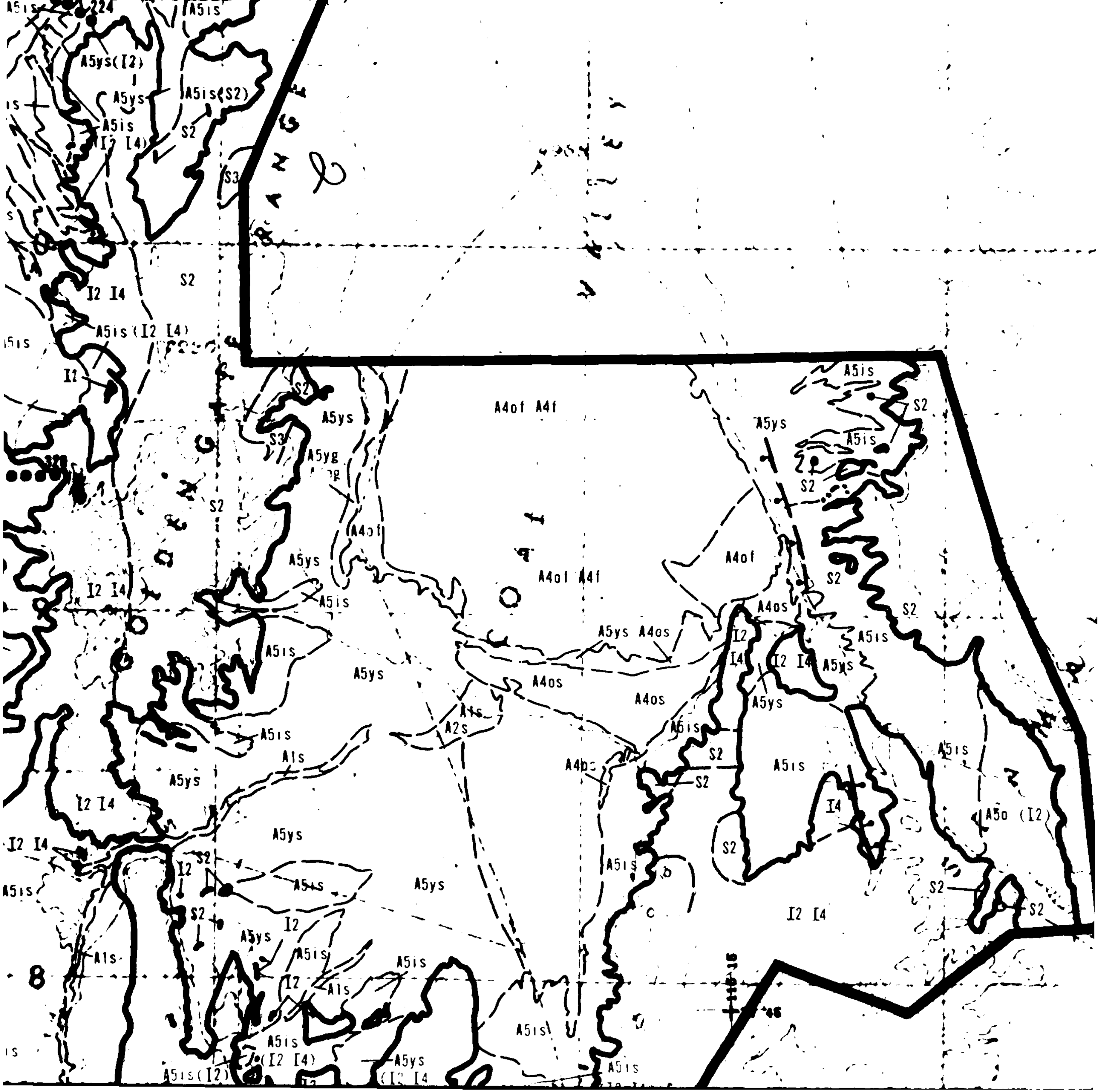
D U
220
224
D U
Tvu
Dse
Op
70
Des
20
Oe
31
Su
Mc
I
304
310
GC-3
315
U D
D U
D U
Tvu
Dg
Su
Op
Dg
MDp
MDp
Tsu
46
Tvu
Op
Su
PlPl
Dg
Des
30 MAY 80

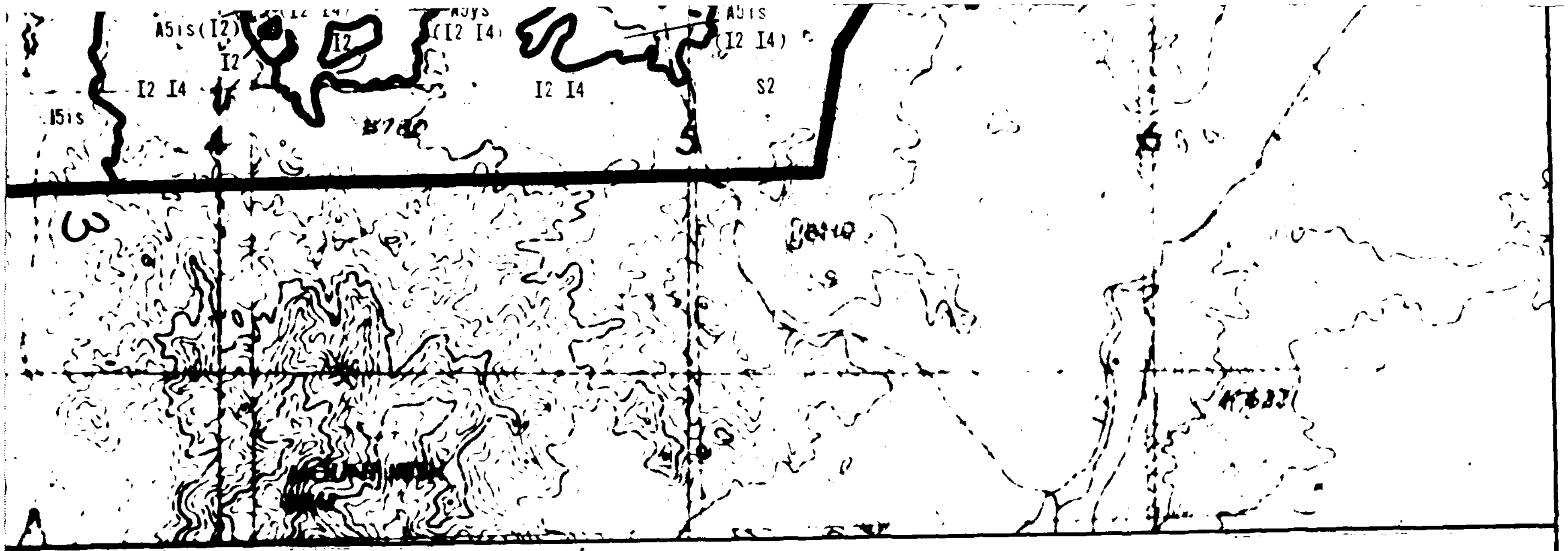
3


GC-3
D U
Tvu
Tsu
Dg
Dse
Op
Su
EXPLANATION
GC-2 GRAVITY PROFILE
GRAVITY STATION
QUATERNARY FAULTS
FAULTS INFERRED FROM GRAVITY DATA
CONCEALED FAULTS
ALLUVIAL MATERIAL
ROCK (ALL PATTERNS)
SCALE 1:125,000
0 2 4
STATUTE MILES
0 2 4
KILOMETERS
INTERPOLATED FAULT RELATIONSHIP
GARDEN VALLEY, NEVADA
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE
FIGURE

R-33-6N
A1s
A5ys
A1f
A4of
I2 I3
A5ys (I2 I3)
S2
A5ig
I4
I2 I4
115
I2
A5yf
A5is



A5ys(I2)
A5is(S2)
A5is (I2 I4)
A4of A4f
A5ys
A5yg
A4of
A5is
S2
S3
I2 I4
A5ys A4os
A4os
A4bs
A2s
A1s
A5o (I2)
I4
I2
8



EXPLANATION

SURFICIAL BASIN-FILL UNITS

Modern stream channel and floodplain deposits of: A1f, clay (CL) and sandy
and (SM).

der stream channel and floodplain deposits in terraces composed of silty sand (SM).

tive playa deposits of sandy silt (ML)

Deposits - Inactive playa, older lake bed, and abandoned shoreline deposits of:
s, sand and gravelly sand (SP); and A4og, sandy gravel (GP)

ts - Active, younger alluvial fan deposits of: A5yf, sandy silt (ML);
y sand and gravelly sand (SM); and A5yg, weakly cemented sandy gravel (GM).

eposits - Inactive, intermediate age alluvial fan deposits of:
silty sand and gravelly sand (SM); and A5ig, sandy gravel (GM)

- Older, highly eroded alluvial fan deposits of moderately cemented
than 30 percent boulders and cobbles

vial Fan Deposits - Inactive, intermediate-age alluvial fan deposits of:
cemented silty sand and gravelly sand (SM); and A5ig, sandy gravel (GM)

n Deposits - Older, highly eroded alluvial fan deposits of moderately cemented
th greater than 30 percent boulders and cobbles

ROCK UNITS

latite, dacite, and andesite

sediment, and ignimbrite

omite, locally cherty, with interbedded shale and sandstone

bedded limestone and sandstone

ologic unit symbols indicates a *mixture* of either *surficial basin-fill* or *rock units*
ap scale

underlies surface unit at shallow depth.

SYMBOLS

ock and *surficial* basin-fill units

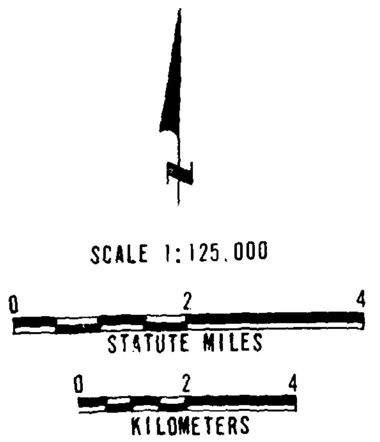
surficial basin-fill or rock units

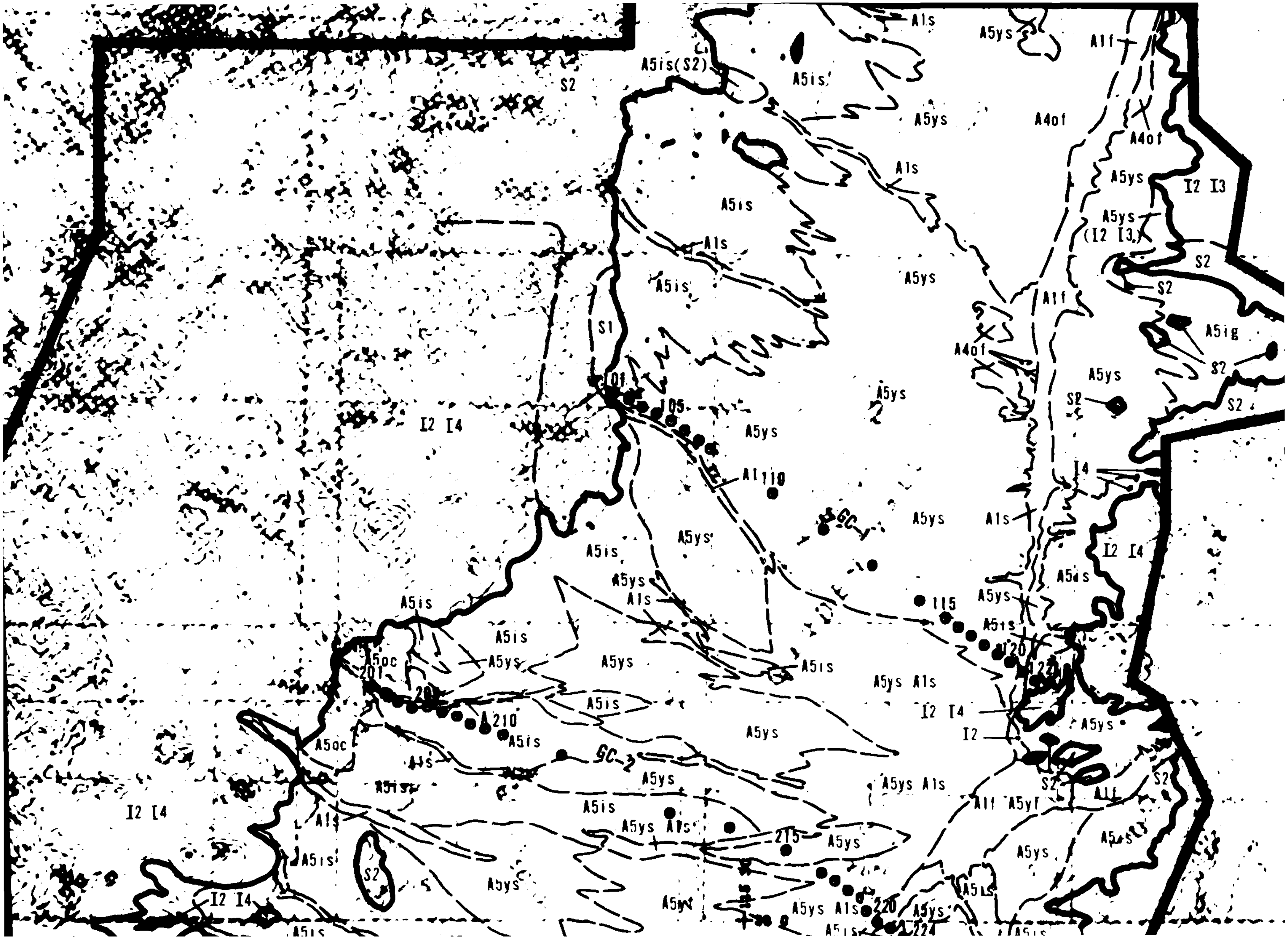
surface rupture of faults offsetting surfic·· basin-fill deposits, ball on downthrown side

ll units pertain only to the upper several feet of soil. Due to variability of surficial deposits
resentation unit descriptions refer to the predominant soil types. Varying amounts of other soil
ted within each geologic unit

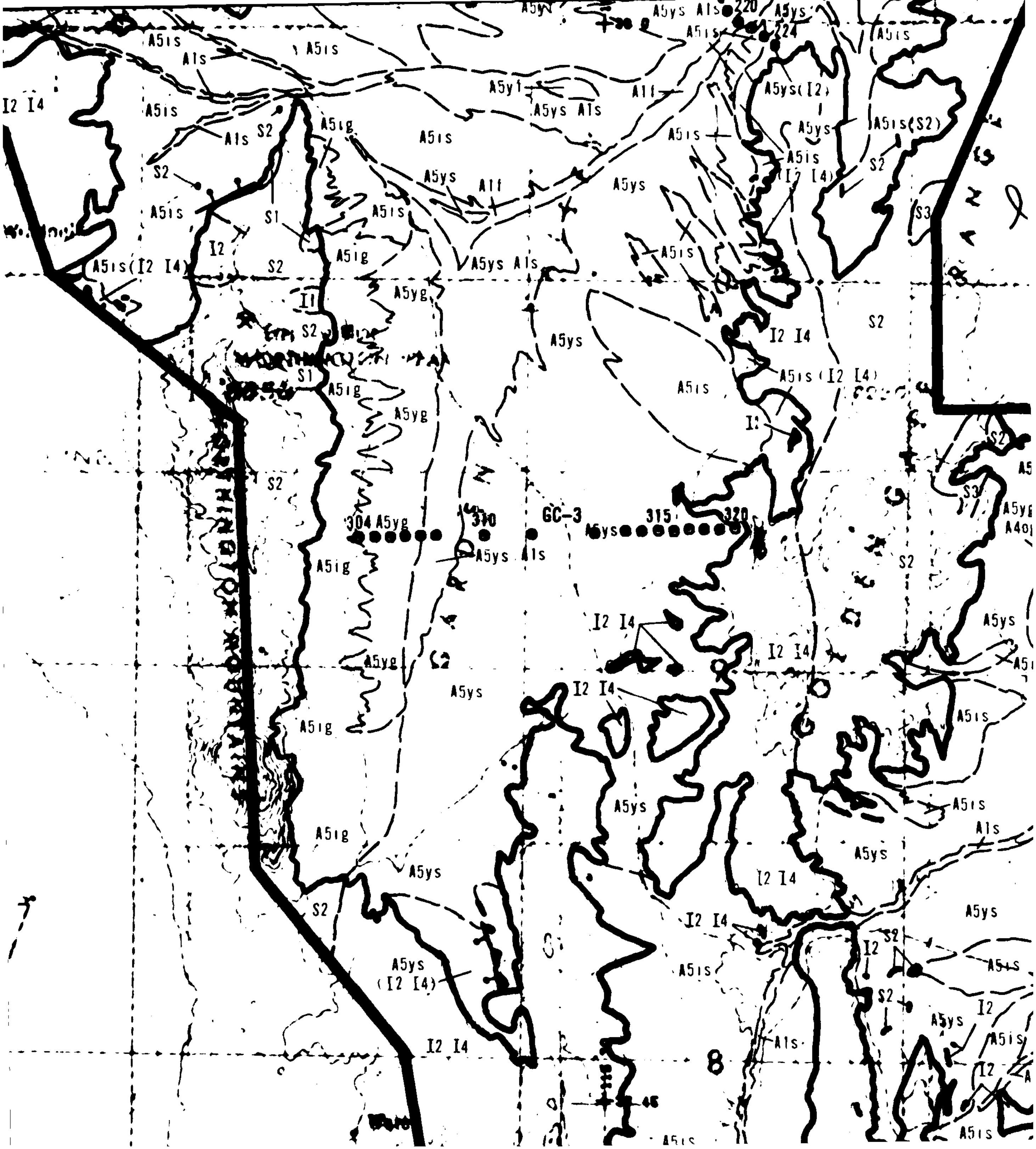
of geologic data stations is presented in Volume VI, Drawing 1. A tabulation of all station data
scription of all geologic units is included in Volume VI, Section 1.0

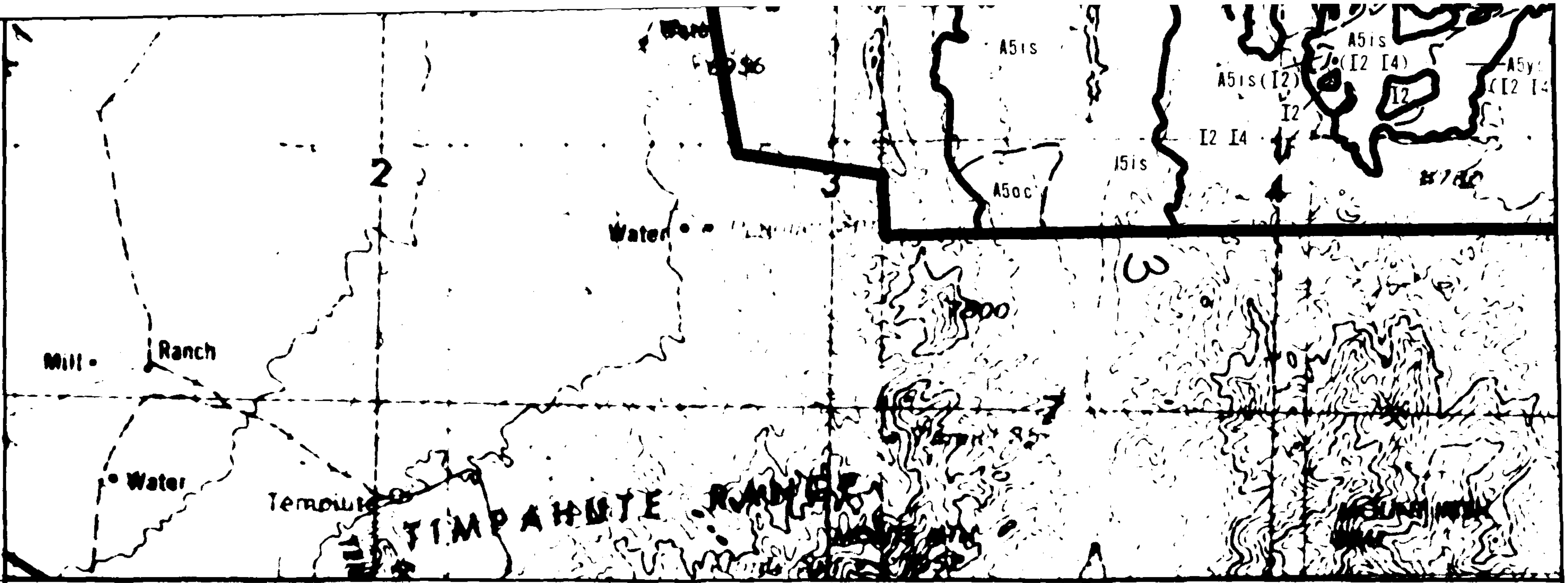
of exposed rock from: Kleinhampl and Ziony (1967), Tschanz and Pampeyan (1970)





A5is(S2)
A5is
A5ys
A4of
A1s
A1f
I2 I3
A5ys (I2 I3)
S2
S1
A5ig
I2 I4
I4
101
105
A1 110
GC-1
115
120
122
I2
A5oc
201
205
A 210
GC-2
215
220
224
A5yf


GC-3
304 A5yg
310
315
320
220
224
A5is
A5ys
A5ig
A5yg
A1s
A1f
A5y1
S1
S2
S3
I1
I2
I2 I4
A5is (I2 I4)
A5ys (I2 I4)
A5is(S2)
A5ys(I2)



EXPLANATION

SURFICIAL BASIN-FILL UNITS

A1f A1s	Younger Alluvial Deposits - Modern stream channel and floodplain deposits of: silt (ML) and A1s, silty sand (SM).
A2s	Older Fluvial Deposits - Older stream channel and floodplain deposits in terra
A4f	Younger Playa Deposits - Activeplaya deposits of sandy silt (ML)
A4of A4os A4og	Older Playa and Lacustrine Deposits - Inactive playa, older lake bed, and aban A4of, sandy silt (ML): A4os, sand and gravelly sand (SP); and A4og, sandy gr
A5yf A5ys A5yg	Younger Alluvial Fan Deposits - Active, younger alluvial fan deposits of: A5y A5ys, weakly cemented silty sand and gravelly sand (SM); and A5yg, weakly cem
A5is A5ig	Intermediate Alluvial Fan Deposits - Inactive, intermediate age alluvial fan d A5is, moderately cemented silty sand and gravelly sand (SM); and A5ig, sandy

A5is / A5ig	Intermediate Alluvial Fan Deposits - Inactive, intermediate age alluvial fan de… A5is, moderately cemented silty sand and gravelly sand (SM); and A5ig, sandy g…
A5oc	Older Alluvial Fan Deposits - Older, highly eroded alluvial fan deposits of mod… gravelly sand with greater than 0 percent boulders and cobbles

ROCK UNITS

Igneous (I)

I1	Granite
I2	Rhyolite, quartz latite, dacite, and andesite
I3	Basalt
I4	Tuff, tuffaceous sediment, and ignimbrite

Sedimentary (S)

S1	Orthoquartzite
S2	Limestone and dolomite, locally cherty, with interbedded shale and sandstone
S3	Shale, with interbedded limestone and sandstone

A5ys/A5is *Combination of geologic unit symbols indicates a mixture of either surficial bas…* inseparable at map scale

A5is(I2) Parenthetic unit underlies surface unit at shallow depth.

SYMBOLS

Contact between rock and surficial basin-fill units

Contact between surficial basin-fill or rock units

Fault, trace of surface rupture of faults offsetting surficial basin-fill deposi…

Gravity Station

NOTES

1. Surficial basin-fill units pertain only to the upper several feet of soil. Due to vari… and scale of map presentation, unit descriptions refer to the predominant soil types … types can be expected within each geologic unit.
2. The distribution of geologic data stations is presented in Volume II, *Drawing 1*. A tab… and generalized description of all geologic units is included in Volume II, Section 1.0…
3. Geology in areas of exposed rock from: Kleinhampl and Ziony (1967), Tschanz and Pampey…

GRAVITY STATION LOCATION MAP
GARDEN VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - BMO

DRAWING 1

FUGRO NATIONAL, INC.

8

APPENDIX A1.0

GENERAL PRINCIPLES OF THE GRAVITY EXPLORATION METHOD

A1.0 GENERAL PRINCIPLES OF THE GRAVITY EXPLORATION METHOD

A1.1 GENERAL

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

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

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

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

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

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

A1.2 INSTRUMENTS

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

A1.3 FIELD PROCEDURES

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

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

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

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

A1.4 DATA REDUCTION

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

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

a. 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. Latitude Effect: Points at different latitudes will have different "gravities" for two reasons. The earth (and the geoid) is spheroidal, or flattened at the poles. Since points at higher latitudes are closer to the center of the earth than points near the equator, the gravity at the higher latitudes is larger. As the earth spins, the centrifugal acceleration causes a slight decrease in gravity. At the higher latitudes where the earth's radii 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

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

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

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

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

APPENDIX A2.0

GARDEN VALLEY, NEVADA

GRAVITY DATA

FN-TR-33-GN

GARDEN VALLEY GRAVITY DATA

PROFILE GC-1

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
GC0101	38	747	115323858704T	0	329422043	62800145549200302	197	80204
GC0102	38	738	115321258140T	0	264422027	62839145617200289	47	80481
GC0103	38	727	115318857838T	0	230422007	62874145456200273	-383	80120
GC0104	38	718	115316357549T	0	208421991	62911145340200259	-756	79823
GC0105	38	708	115313657178T	0	192421973	62950145267200245	-1164	79526
GC0106	38	695	115311256886T	0	178421950	62986145189200226	-1500	79276
GC0107	38	681	115308656571T	0	165421924	63024145148200205	-1816	79154
GC0108	38	669	115306656273T	0	159421903	63054145146200188	-2080	78886
GC0110	38	607	115295454757T	0	130421791	63219145252200098	-3313	78141
GC0111	38	556	115286353714T	0	114421699	63354145610200023	-3853	77941
GC0112	38	507	115277152949T	0	103421610	63490146098199951	-4023	78021
GC0113	38	457	115267852270T	0	98421520	63627146733199878	-3954	78316
GC0115	38	433	115263252034T	0	94421477	63695147161199843	-3713	78630
GC0116	38	420	115260951909T	0	94421453	63729147414199823	-3557	78632
GC0117	38	408	115258651801T	0	93421432	63763147624199806	-3432	78993
GC0118	38	395	115256351693T	0	95421408	63797147825199787	-3314	79150
GC0119	38	382	115254051594T	0	96421385	63832148016199768	-3194	79304
GC0120	38	371	115251751512T	0	101421365	63865148242199752	-3031	79500
GC0121	38	358	115249451430T	0	105421341	63900148546199733	-2737	79777
GC0122	38	345	115247151650T	0	107421318	63934148683199714	-2423	80068

END OF LIST

GARDEN VALLEY GRAVITY DATA

PROFILE GC-2

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
GC0201	38	328	1153669	5986B	0	203421258	62182144147199689	797	80583
GC0202	38	320	1153643	5947B	0	189421244	62228144262199677	555	80461
GC0203	38	307	1153620	5912B	0	184421221	62254144366199659	351	80370
GC0204	38	299	1153595	5877B	0	176421206	62291144390199647	53	80185
GC0205	38	301	1153567	5841B	0	174421211	62332144411199649	-269	79984
GC0206	38	293	1153541	5804B	0	164421197	62370144505199638	-510	79859
GC0207	38	288	1153514	5770B	0	160421188	62410144528199630	-602	79680
GC0208	38	277	1153490	5740B	0	152421168	62445144550199615	-1037	79536
GC0209	38	270	1153464	5708B	0	147421156	62484144587199604	-1296	79383
GC0210	38	261	1153431	5666B	0	140421140	62532144666199591	-1598	79216
GC0211	38	231	1153327	5552B	0	124421087	62685144978199547	-2315	78872
GC0213	38	150	1153134	5395B	0	106420941	62970145734199429	-2924	78782
GC0214	38	130	1153027	5327B	0	102420907	63127146060199399	-3192	78739
GC0215	38	98	1152926	5272B	0	99420850	6327614663319935[illegible]	-3104	79014
GC0216	38	67	1152863	5247B	0	94420794	63369147247199307	-2683	79516
GC0217	38	56	1152838	5238B	0	93420775	63406147574199291	-2421	79807
GC0218	38	43	1152815	5229B	0	93420751	63440147943199273	-2119	80139
GC0219	38	33	1152791	5222B	0	92420733	63475148267199258	-1847	80435
GC0220	38	14	1152777	5222B	0	92420698	63496148413199230	-1670	80610
GC0221	375998		1152757	5218B	0	96420669	63526148590199206	-1512	80788
GC0222	375990		1152734	5220B	0	97420655	63560148603199195	-1468	80826
GC0223	375978		1152711	5256B	0	96420633	63594148390199177	-1310	80858
GC0224	375966		1152690	5278B	0	96420612	63625148408199159	-1077	81016

END OF LIST

GARDEN VALLEY GRAVITY DATA

PROFILE GC-3

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
GC0304	375285	1153432	59328	0	328419335	62558143190198165	858	80953
GC0305	375286	1153404	58008	0	259419337	62599143817198166	233	80722
GC0306	375286	1153377	56858	0	242419338	62639144234198166	-427	80425
GC0307	375287	1153350	55968	0	242419340	62678144340198167	-1155	79999
GC0308	375288	1153323	55458	0	221419343	62718144137198169	-1848	79461
GC0309	375288	1153296	55448	0	199419344	62758144022198169	-1970	79320
GC0310	375288	1153211	55518	0	160419345	62882144313198169	-1625	79605
GC0311	375289	1153127	55968	0	162419349	63005144445198170	-1656	80019
GC0312	375290	1153017	56898	0	158419354	63167144575198172	-56	80699
GC0313	375293	1152963	57578	0	165419361	63246144276198177	280	80610
GC0314	375293	1152934	58168	0	172419361	63288144028198177	587	80923
GC0315	375294	1152905	58818	0	192419364	63331143775198177	949	81082
GC0316	375294	1152877	59588	0	203419364	63372143401198177	1298	81180
GC0317	375295	1152850	60448	0	229419367	63411143018198179	1727	81340
GC0318	375295	1152823	61418	0	276419368	63451142477198179	2692	81424
GC0319	375295	1152795	62488	0	288419368	63492141820198179	2445	81423
GC0320	375296	1152767	63698	0	363419371	63533141050198180	2814	81454

END OF LIST

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