REPORT ON THE GRAVITY INTERPRETATION
OF THE LEACH HOT SPRINGS AREA
GRASS VALLEY, NEVADA

for

AMINOIL USA, INC.

WITH ADDENDUM

EXPLORATION DATA CONSULTANTS, INC.
DENVER, COLORADO
FEBRUARY, 1979

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I. INTRODUCTION

A combination of gravity, surface geology and photogeology was integrated to produce a structural interpretation of the Leach Hot Springs area, Grass Valley, Nevada.

The objectives of the interpretation were to 1) produce a Tertiary Isopach map with faults, 2) analyze surface geology, 3) incorporate the photogeological results and, 4) compile the various disciplines into a comprehensive picture for geothermal evaluation. Tertiary (actually post-Paleozoic) and Paleozoic densities were estimated. Evidence in many parts of Nevada and Utah suggests a sharp density contrast between the clastic Tertiary and the Paleozoic sediments.

Depth to basement and approximate fault configurations were determined by three-dimensional gravity modeling on the density contrast (base of Tertiary) horizon. The resulting structure map shows a series of north-north-westerly trending grabens bounded by dominant normal faults. Superimposed on the main graben pattern is a system of southwest to northeast trending secondary faults that form Paleozoic high saddles and terminate the extensions of the grabens.

The report discusses the interpretation methods, results, limitations and suggestions for future work. The interpretation results are discussed in terms of the accuracy of the structure map, regional geologic history, and the existence of geothermal prospects related to the interpreted structure of the area.

II. GRAVITY INTERPRETATION

A. BOUGUER GRAVITY

Gravity data were acquired by Exploration Data Consultants, Inc., and data on 504 stations were collected. Bouguer and terrain corrections were completed using a density of 2.67 gm/cm^3, which was selected to reflect the density of the mountainous terrain alongside the valley. Contoured Bouguer values and station locations are shown on the map included in this report.

A previous gravity survey over the area had been completed by the Lawrence Berkeley Laboratories. No data listing on this survey could be obtained, and only a contour map of the values at a large scale was available. The data sets from EDCON and LBL were integrated by photographically enlarging the LBL map to a scale of 1:62,500 and hand contouring the combined maps of both surveys. Differences between the two surveys exist and the integrated data set was not used in any interpretive or modeling routines, as preference was given to single data set with internal consistency.

The Bouguer gravity field contains the superimposed effects of sedimentary, structural, and stratigraphic features; basement lithology changes; and deep crustal features. This study is aimed at the gravity effects associated with the Tertiary-Paleozoic contact. Gravity effects from within the basement and deep in the crust are not of interest and are considered "regional".

Qualitative examination of the Bouguer gravity map is sufficient to locate sediment-filled grabens associated with gravity minima. The correlation of gravity lows and sediment-filled grabens exists throughout the Basin and Range province because low-density sediments fill the normal-faulted basement depressions. Determination of accurate base of Tertiary structure and of fault locations requires a more sensitive tool, three-dimensional gravity inversion. The gravity inversion and integration with surface geologic control are discussed below.

B. GENERAL PHILOSOPHY

Structure determination from gravity requires two major steps: 1) the broad gravity effect that is not of interest ("regional") must be subtracted from the Bouguer gravity field to produce the anomaly of interest ("residual") and 2) the "residual" anomaly must be fitted with a geologic model of proper formation densities that explains the residual anomaly. Both steps require application of geologic constraints. In this interpretation the geologic constraints were provided by surface geology available on published maps of the area.

C. DENSITY ANALYSIS

Available information on outcrop samples and approximately 50 porosity logs from Nevada Basin and Range wells, converted to density, demonstrate the extreme variability of the sediment density distribution. Quaternary valley-fill alluvium and playa deposits are very low in density, less than 2.0 gm/cm^3. Tertiary sediments in the Great Basin vary from low-density tuffs (2.1 gm/cm^3) to clastics (2.3 gm/cm^3) to conglomerates and carbonates (2.5-2.7 gm/cm^3). An average of 2.3 gm/cm^3 was used in the three-dimensional modeling. A density of 2.7 gm/cm^3 was selected to reflect the average density of the Mesozoic and Paleozoic basement in the area. The best overall density contrast between Tertiary sediments and high-density "basement" was considered to be -0.4 gm/cm^3.

D. REGIONAL/RESIDUAL SEPARATION

Grabens appear as relative minima on the Bouguer gravity map. In order to perform the proper gravity inversion to depth, the residual anomaly related to the sediment fill must be extracted from the Bouguer gravity. The residual anomaly is left after subtracting the regional gravity from the Bouguer gravity.

The regional gravity surface was constructed in a three-step manner. First of all, two-dimensional gravity models were calculated for grabens of known geometries and densities. Secondly, these models were compared to actual gravity profiles across the grabens with special attention paid to Paleozoic outcrops at the valley edges. Thirdly, the difference between the modeled and observed gravity for the east-west profiles was plotted and contoured.

Construction of the regional gravity must obey two simple principles: 1) the regional gravity should approach the Bouguer gravity along the high-density basement outcrops and 2) the regional gravity must be smooth since the geologic sources causing the regional (intrabasement density changes and crustal effects) are at great depth. Both criteria are satisfied by the chosen regional: 1) the regional gravity is only slightly higher than the Bouguer gravity at the basement outcrops and 2) the regional surface is a smooth plane. Some discrepancies in the regional determination were observed in the area of the Gold Bank Hills, and will be discussed in the interpretation section.

E. COMPUTER GRAVITY MODELING SOFTWARE

EDCON's computer software system, GF-2/3, utilizes a method of successive approximation to calculate the structure of the high-density basement that best satisfies the residual gravity field. GF-2/3 is a prism-oriented calculation system that performs basically two types of calculations. The first is a direct calculation of the gravity field for a given mass, where the anomalous mass is completely defined by specification of its upper and lower surfaces as well as its density-depth function. The second type of calculation is gravity inversion where the gravity anomaly, density-depth relation, and either the upper or lower surface of a body are given and the program iteratively solves for the unknown surface.

F. GRAVITY MODELING

GF-2 was used in the forward-modeling mode with a 4000-ft grid interval to calculate the two-dimensional graben models. For example, a four-mile-wide graben 10,000 ft deep with a -0.4 gm/cm^3 density contrast produces a -30 mgal anomaly.

The datum-adjusted, tied and smoothed Bouguer gravity map was digitized on a X-Y-Z digitizer. A computer gridding program then sampled the digitized surface on a 4000-ft grid.

A computer plane generation program was used to produce a 4000-ft grid of the regional gravity. A simple subtraction yielded the desired residual gravity grid in preparation for three-dimensional gravity inversion.

Two approaches to the density-depth function seemed desirable before the initial testing stages of the study: 1) individual valleys should be inverted using the best density-depth curve from the available wells and 2) the density contrast should be larger (more negative) at the top of the section than near the bottom. Approach (1) was not possible due to the lack of consistency of density vs depth in the Basin and Range grabens and no logs were available in the Leach Hot Springs area. Approach (2) was rejected because no geological constraints could be inposed on the possible presence of low-density, near-surface layers. Results of two-dimensional modeling tests led to the conclusion that the best density contrast to use was a constant density. Therefore, gravity inversion was performed with a constant density contrast of -0.4 gm/cm^3 throughout the final stages of the interpretation.

G. MODELING RESULTS

1. Profile analysis

Ten profiles, A-A' through J-J', were investigated and two-dimensional modeling completed. The profile positions are indicated on the Bouguer gravity map. In addition, the results of the three-dimensional modeling routines, GF-3, are shown on the profiles.

Differences between the two-dimensional and three-dimensional modeling results are observed. These are primarily the result of the fact that many of the gravity anomalies interpreted are not two-dimensional in nature, and are not amenable to this interpretation. Additionally, small wavelength anomalies (noise, near-surface density anomalies) are amplified much more severely by the two-dimensional than the three-dimensional routines.

2. Three-Dimensional modeling

The results of the three-dimensional modeling routine, GF-3, are indicated on the accompanying Tertiary Isopach map. In addition, inferred structural elements are shown.

The map shows a series of NNW-trending grabens separated by Paleozoic (?) high saddles. Dashed contour lines in the northern part of the map show areas of insufficient gravity control, and the northernmost valley (except for its easternmost edge) is very approximate in shape. A small embayment (T32N, R38E, Sec 1) is indicated along the eastern graben edge. An area of very thin valley fill (possible pediment) is interpreted to the southeast of this embayment, with a suggested extension, or saddle, forming the southern boundary of the northernmost valley.

A complex structural pattern, with dominant SW-NE trending lineaments, is indicated in the area to the west and northwest of Leach Hot Springs (T32N, R38E, Sec 36). An area in which the high-density basement is close to surface is shown at, and east of, the Leach Hot Springs occurrence.

A small, narrow, and deep valley (inferred depth 6,500 feet) is interpreted in the central part of the area (T31N, R38E, Sec 12). A pronounced pediment (?) (Sec 14 and 23) is present on the eastern side of the valley.

The southernmost of this series of valleys is characterized by a strongly developed SW-NE grain on both sides of the deep (7500 feet) graben structure. These structures may be related to similar gravity trends in the Gold Bank Hills area to the southwest.

A good correlation exists between a simple planar regional gravity field and the observed pre-Tertiary "Basement" outcrops in most parts of the map. Two exceptions are evident, i.e. firstly, in T32N, R39E, Sec 21 and southwards, where the "Basement" outcrop is not confirmed by the modeled gravity results. The outcrop is anomalous in this respect and may represent a possible thrust remnant or gravity slide, as indicated on the map. Secondly, the Gold Bank Hills area is characterized by much lower regional field values than anywhere else in the study area. This anomalous regional field could not be delineated sufficiently well, due to the lack of gravity control along the western side of Gold Bank Hills, and the modeled results were therefore forced by hand to conform to the mapped outcrop positions. This negative gravity feature may be partly due to the presence of low-density material (intrusive?) in depth and may be related to the known mineralization of the Gold Bank Hills area.

III. CONCLUSIONS

A. PHOTOGEOLOGY/GRAVITY CORRELATION

A vast amount of detail is presented on the photogeological interpretation presented as part of the study of the Leach Hot Springs Geothermal area. The same amount of detail is not reflected in the interpreted gravity results, probably as a result of the station spacing (i.e. sampling interval) of the gravity field, but also because many of the indicated photolineaments may probably just be small scale surface expressions.

A noteworthy point of agreement in the two approaches is the well-developed SW-NE grain in the Gold Bank Hills area and the eastern side of the deep graben. Little positional agreement exists between the photogeological and gravity expression of the main graben-forming normal faults, except in a few localities. This is probably due to the fact that secondary faults, or displacements, related to the main normal faults at depth, are observed on the surface.

The main Leach Hot Springs fault, as mapped by photogeology, does not have a corresponding gravity expression except on the opposite side of the valley. This may be due to a possible silicification process in the Hot Springs area, which may have obliterated all density contrasts related to the existing fault structures.

B. GEOTHERMAL PROSPECTS

One of the most important results which seems to present itself in this survey, is the presence of anomalous high-density "basement" (or pediment?) close to the surface in a few localities in the area, such as at the Leach Hot Springs location, as well as at T31N, R39E, Sec 17 and 18; T31N, R38E, Sec 14 and 23; T31N, R39E, Sec 34 and 27, and a few other possible occurrences along the sides of the southernmost deep valley (T31N and T30N, R39E).

The anomalous areas may be related to existing, or dormant, areas of silicification as a result of geothermal activity. The relationship of these anomalies to any existing heat-flow anomalies, and their correlation with the available structural information, may be of significant importance in the delineation of geothermal targets.

C. DISCUSSION OF RESULTS

Mapping the base of the Tertiary structure with gravity data is a very cost-effective method of determining basin depths, fault locations, and geologic history.

Perhaps one of the prime benefits of this study will be the ability to better plan seismic reflection programs by narrowing in on the more prospective depression within the valley and on the better structural features within the depression. In the Leach Hot Springs area basement highs (?) and other prospective features have been delineated for possible detailed seismic coverage and/or drilling. The gravity interpretation can be used to interpolate between individual seismic profiles at a later date and to better correlate faults and structural information.

D. LIMITATIONS

Gravity interpretations have certain non-uniqueness limitations in any geologic province. Some of these limitations are more acute in the Basin and Range province than in other areas. Fortunately, however, the addition of geologic constraints from surface geology has helped to overcome some of the problems. The major limitations are listed below:

1. In performing our structural determination from gravity, we assumed that the material above the Paleozoic unconformity (Tertiary and Quaternary) had an average density of 0.4 gm/cm^3 below the Paleozoic "basement" density. Analysis of available data in Nevada suggested this average, but also indicated a large variability.

   Quaternary sediments have a 1.9 to 2.0 gm/cm^3 density and variable thickness. Tertiary sediments and volcanics vary in density from 2.1 gm/cm^3 for tuff to 2.6 gm/cm^3 for carbonates and conglomerates. The structural map, without adequate control from drilling, may be in error. The most likely sources of error are anticipated from Quaternary playa deposits of unknown thickness and lower density Tertiary conglomerates and lacustrine carbonates. These two anomalous density features will also affect the seismic statics and velocities. Without more knowledge of the Tertiary and Quaternary densities, the structure map is probably best utilized as a shape map.

2. Gravity inversion at the edges of the valley suffers from edge effect problems. Therefore, the base of the Tertiary structure in the immediate vicinity of the graben-forming, normal faults is less accurate than in the center of the valley. Depth of sediments between the valley edges and the graben-forming faults and over the Paleozoic saddles may be shallower than mapped if the material is predominately low-density Quaternary fill.

3. The variability of Tertiary and Quaternary densities discovered in the gravity interpretation may be an indication of possible velocity problems for seismic processors and interpreters alike. Although sophisticated statics programs are available to sharpen up seismic profiles, long period, or low frequency, statics (velocity pushdowns) may

be distorting the structural picture.

E. RECOMMENDATIONS

Detailed structural interpretations from gravity are good representations of the actual thickness and shape of Tertiary fill in individual grabens. The next exploration stage should involve seismic reflection data over the better prospects within the valley. Care should be taken to avoid velocity pitfalls in the areas of known anomalous densities.

One additional geophysical technique has proven useful in the Basin and Range province. Electrical induced-polarization and resistivity surveying have proven useful in determining thickness of alluvial cover in Basin and Range grabens. The alluvial cover is desirable to aid the gravity and seismic processing.

EXPLORATION DATA CONSULTANTS, INC.

Eduard de Ridder

IV. ADDENDUM

Detailed Structural Modeling - Leach Hot Springs and Panther Canyon area

At the request of Aminoil USA, Inc. some detailed three-dimensional modeling, using the restraints developed in the general interpretation of the area, was completed over the Leach Hot Springs and Panther Canyon areas. These maps are presented separately to the report as computer-plotted contour maps with a contour interval of 50 feet and a scale of 1" = 1000 ft. It must be realized that the modeling routines used in the production of these maps were taken to the limits of resolution, and some of the finer detail presented may not be reflective of the real causative structures, but may rather be related to short wavelength noise in the observed (and interpolated) gravity field.

The results primarily seem to indicate the possible presence of a dual structure on the Leach Hot Springs pediment (?) with an inferred saddle, or lowering of near-surface densities to the east. This effect may be real, however, and related to the Leach Hot Springs fault as observed on surface.

The Panther Canyon detailed structure map reveals a more pro-ounced, but still small, SW-trending ridge (Sec 27), with a utherly extension (Sec 34) in the area of possible geothermal erest.

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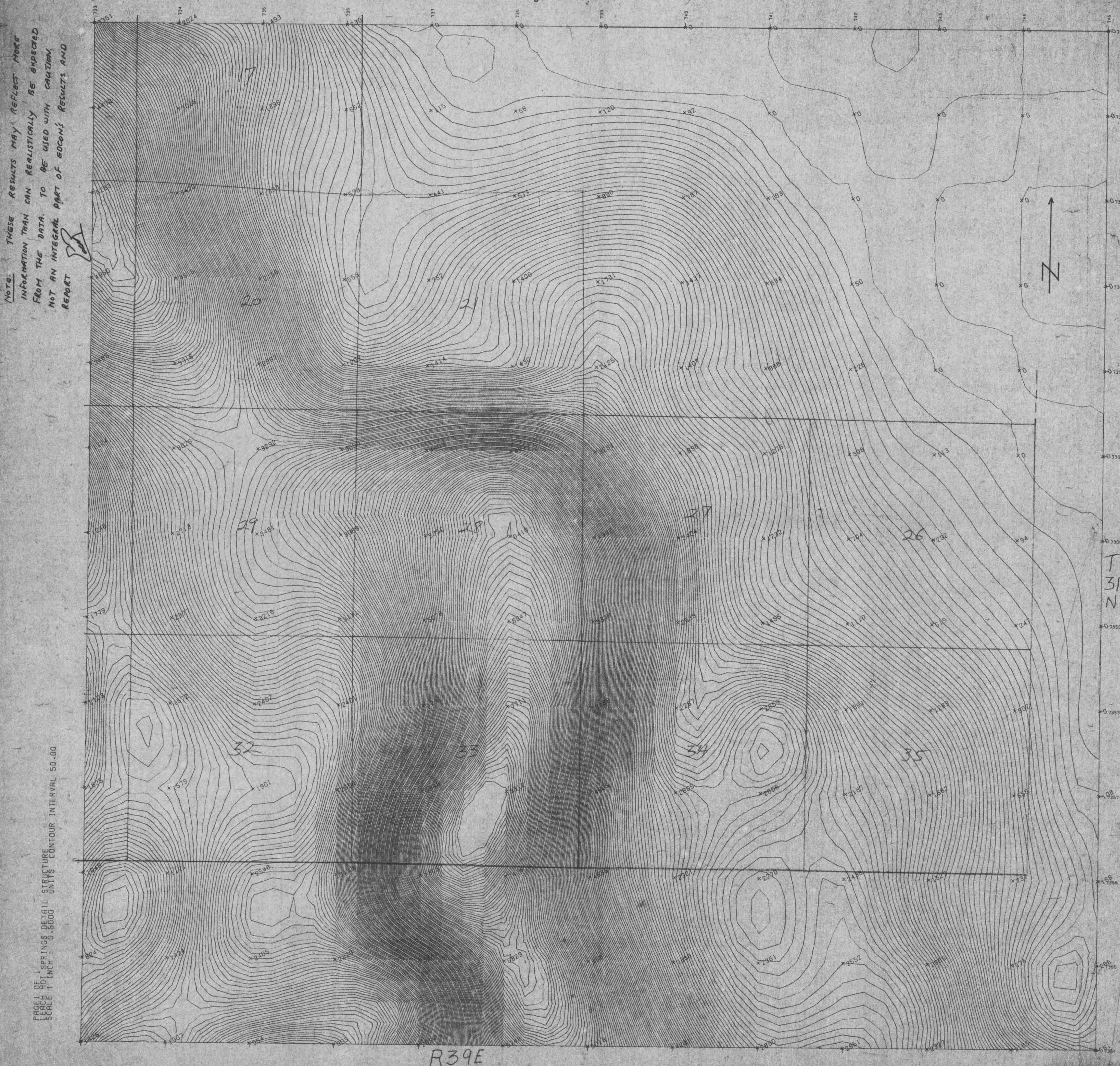
PAGEO OF 1
78AO LEACH HOT SPRG.'S 1 : 62,500 C.I. 100 FE
SCALE 1 INCH = 1.3021 UNITS CONTOUR INTERVAL 1000.00

TOPOGRAPHY

LEACH HOT SPRINGS
TOPOGRAPHY C.I.=10
SCALE 1:62,500
EDCON OCT 1978

PANTHER CANYON AREA

Detailed modeling Results. Scale 1" = 1000 FT

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HIGH-DENSITY BASEMENT VERY CLOSE TO SURFACE
HIGH-DENSITY BASEMENT CLOSE TO SURFACE
ANOMALOUS OUTCROP POSITION GRAVITY SLIDE (?) THRUST REMNANT?
AREA OF CONFLICTING RESULTS GRAVITY MODELING vs KNOWN and INFERRED GEOLOGY
BURIED PEDIMENT (?) SHOWING MINOR STRUCTURES
ANOMALOUS LOW DENSITY AREA
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AXIS OF POSITIVE GRAVITY STRUCTURE
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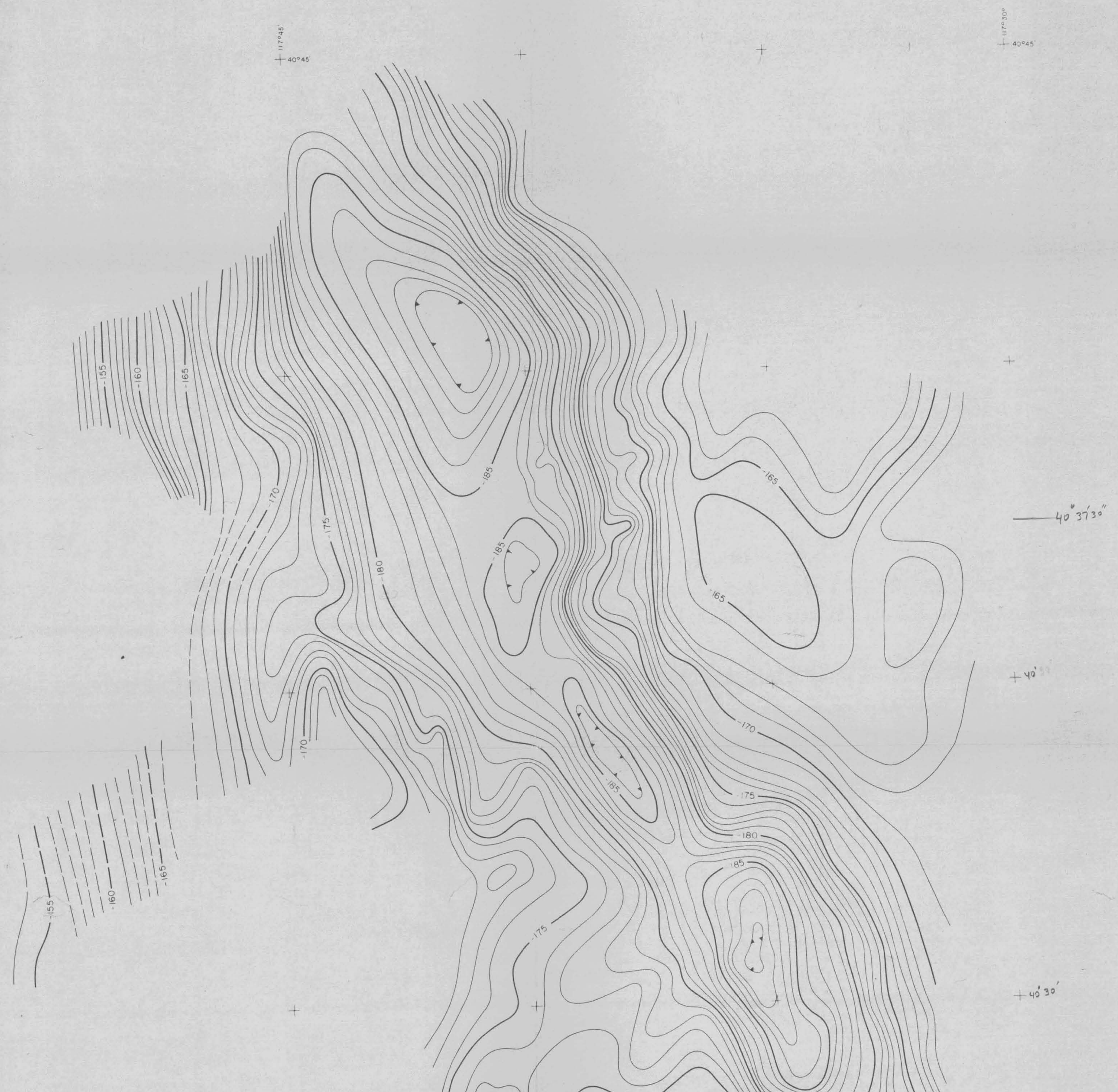
EDCON
GRASS VALLEY
NEVADA
VALLEY FILL ISOPACH MAP
DENSITY CONTRAST Δρ = -0.4 gm/cm³
SCALE: 1" = 4000'
C.I. = 500 Feet
NOVEMBER, 1978
EXPLORATION DATA CONSULTANTS, INC.
DENVER, COLORADO

NV/LCH/AMN-2



LEACH HOT SPRINGS AREA

EDCON

GRASS VALLEY
NEVADA

INTEGRATED BOUGUER GRAVITY SURVEYS

(L.B.L. and EDCON DATA SETS)

SCALE: 1/62,500	C.I. = 1 Mgal	NOVEMBER, 1978

EXPLORATION DATA CONSULTANTS, INC.
DENVER, COLORADO

Leach Hot Springs
Scale 1:62,500
Station Location Map
by EDCON Oct 1978

PAGE0 OF 1
7880 LEACH HOT SPRG.'S 1 : 62,500 2.67 GM/CC
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Station Location Map

PAGE0 OF 1
78A0 LEACH HOT SPRG.'S 1 : 62,500 2.67 GM/CC
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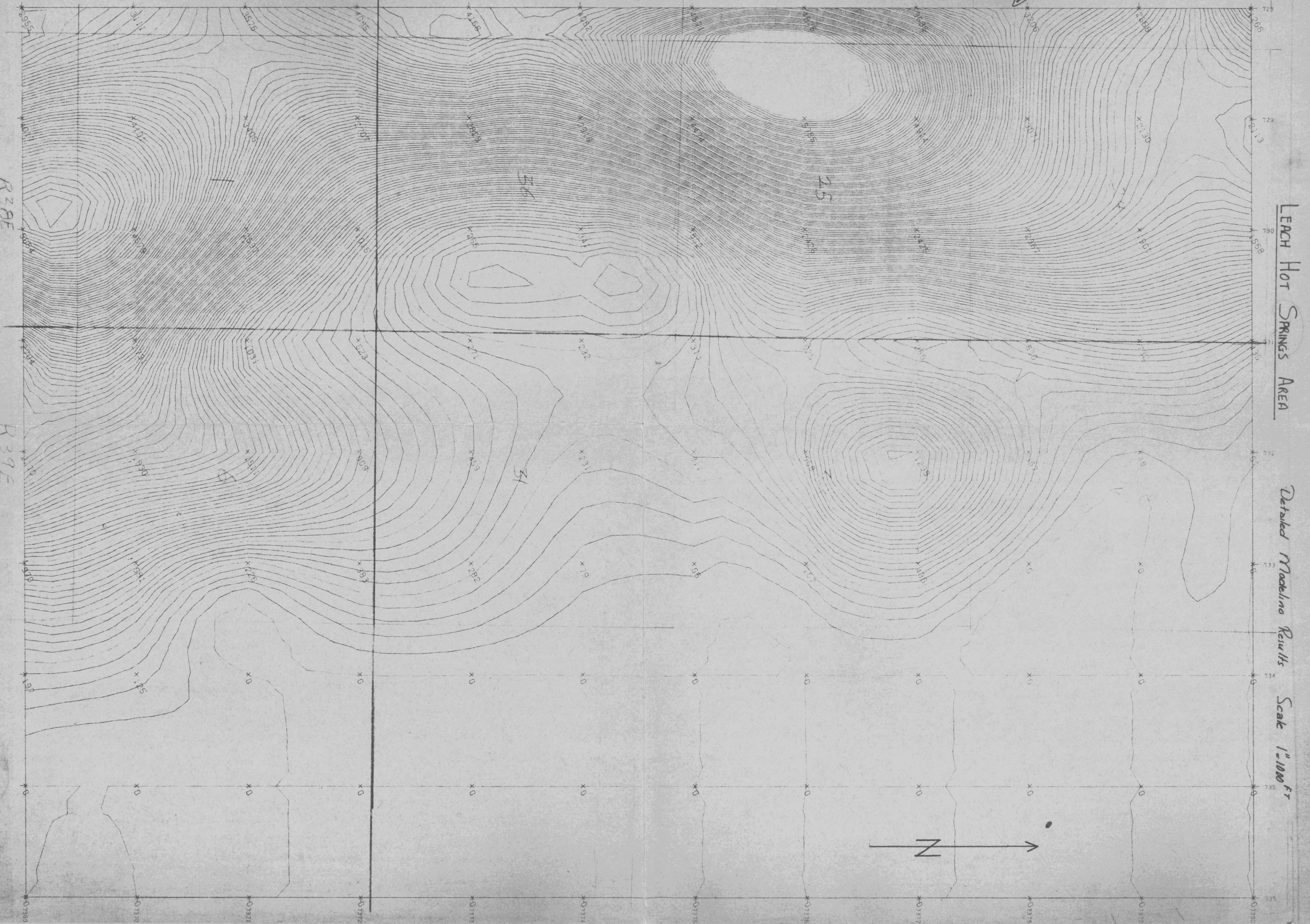
BOUGUER ANOMALY

2.67 BOUGUER ANOMALY
SCALE 1:62,500
EDCON OCT. 1978

PAGE1 OF 1
LEACH HOT SPRINGS DETAIL STRUCTURE
SCALE 1 INCH = 0.5000 UNITS CONTOUR INTERVAL 50.00

NOTE: THESE RESULTS MAY REFLECT MORE INFORMATION THAN CAN REALISTICALLY BE EXPECTED FROM THE DATA. TO BE USED WITH CAUTION. NOT AN INTEGRAL PART OF EDCON'S REPORT AND RESULT.

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AMINOIL U.S.A.
EDCON
LEACH HOT SPRINGS AREA
NEVADA
BOUGUER GRAVITY
BOUGUER DENSITY = 2.67 gm/cm³
SCALE: 1" = 4000'
C.I. = 1 MGAL
OCTOBER 30, 1978
EXPLORATION DATA CONSULTANTS, INC.
DENVER, COLORADO
LEGEND
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LEACH HOT SPRINGS AREA
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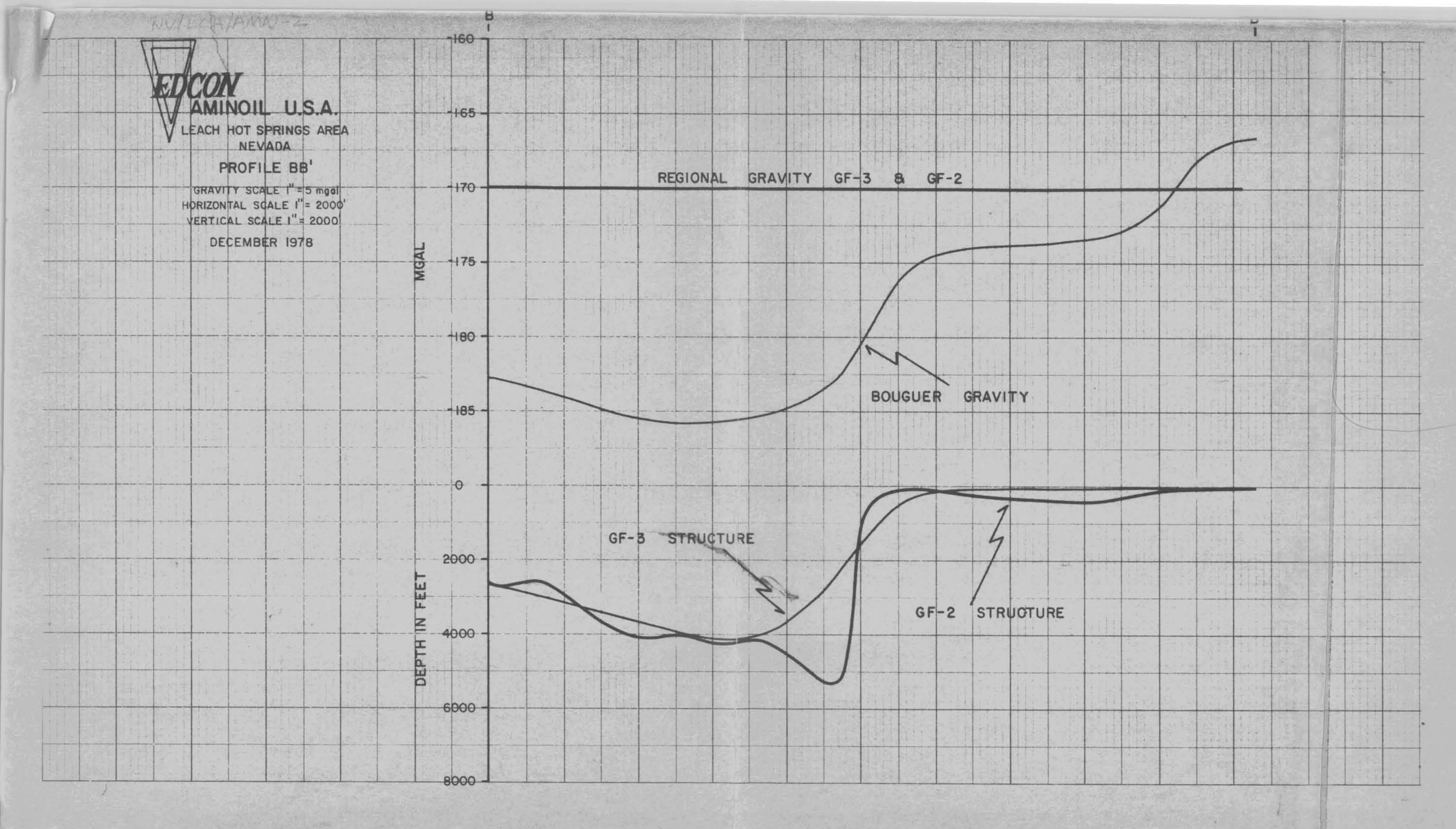

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AMINOIL U.S.A.
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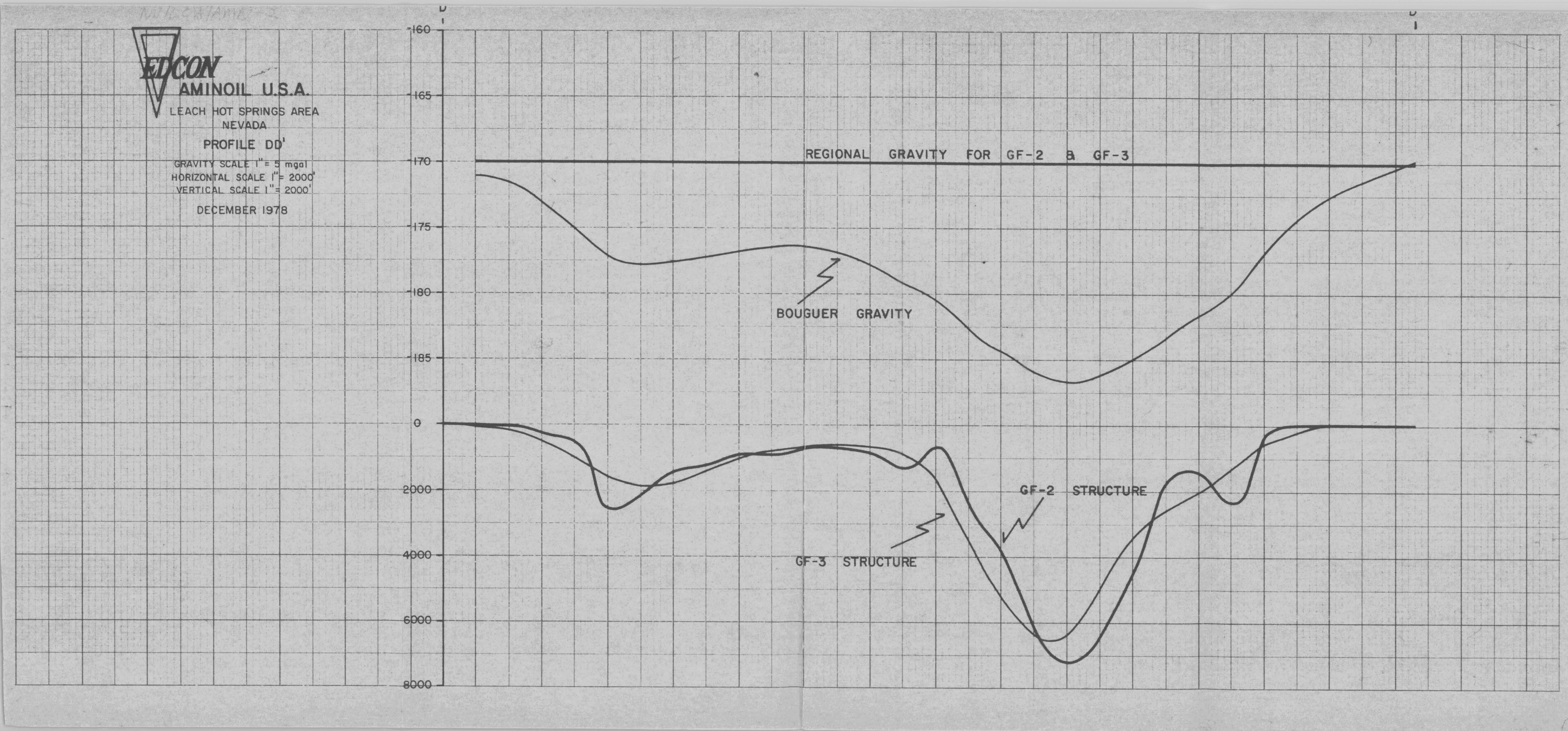
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AMINOIL U.S.A.

LEACH HOT SPRINGS AREA
NEVADA

PROFILE HH'

GRAVITY SCALE 1" = 5 mgal
HORIZONTAL SCALE 1" = 2000'
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FEBRUARY, 1979

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LEACH HOT SPRINGS AREA
NEVADA

PROFILE 11'

GRAVITY SCALE 1" = 5 mgal
HORIZONTAL SCALE 1" = 2000'
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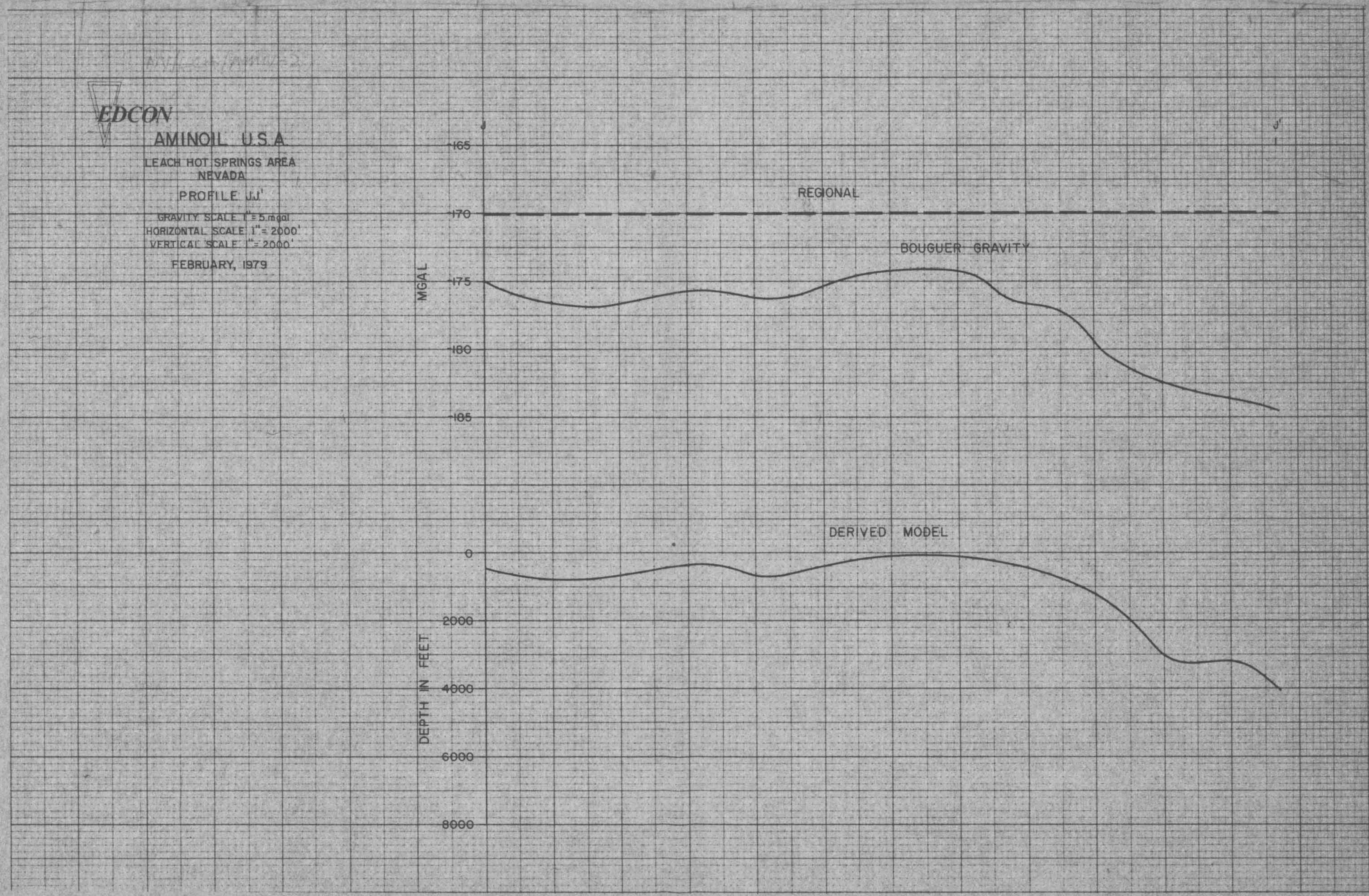
FEBRUARY, 1979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