SILVER PEAK/ALUM GEOTHERMAL AREAS

Esmeralda County, Nevada

Interpretation of Gravity Survey

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SUMMARY AND CONCLUSIONS – Depth-to-basement determinations from gravity data are the least accurate goals for data analysis. In complex geologic settings with highly variable rock types, computed depths can only be approximate. With limited hard data from drilling the contrasting bulk densities for the various geologic units required for accurate results are not available. Depths to basement for the Silver Peak and Alum geothermal areas are given as ranges of values based upon reasonably expected bulk density contrasts between major rock types.

In amagmatic geothermal systems, deep basins and high-angle fault-controlled permeability are fundamentally important factors. The interpretations presented in this report are consistent with the general geology but, primarily, with structural analysis of the area presented by Jeffrey B. Hulen in his July 2008 report "Geology and Conceptual Modeling of the Silver Peak Geothermal Prospect, Esmeralda County, Nevada". By logical extension of the structural model presented by Hulen for the Silver Peak area, interpreted high-angle fault geometry based upon the gravity results from the Alum area is also presented. All high-angle faults interpreted from linear features on the gravity map have strike directions within five degrees or less of those faults associated with a N40W "master" right-slip fault regime.

N15-20E normal faults, which are the products of maximum extensional stress in the area and associated with the best developed vertical permeability, are noted in both lease areas. Travertine deposits in the Silver Peak area are located at or near the intersections of these normal faults with a probable N25W strike-slip fault antithetic to a "master" right-slip fault regime that fits the observed high-angle fault geometry in the area. The most pronounced area of normal faulting in the two lease areas occurs in the Alum area. This faulting separates relatively shallow "basement" rocks from immediately adjacent 4000-6000 feet of valley fill and represents the primary target for geothermal exploration.

INTRODUCTION – A gravity survey of the Alum and Silver Peaks geothermal prospects was conducted in February 2008. Survey results have been reviewed and interpreted within the context of recognized limitations of the gravity method. This report discusses these limitations with respect to depth-to-basement determinations. It also discusses the utility of the gravity method with respect to detecting high-angle, basin-bounding faults, deriving systematic high-angle fault geometry and the appropriate use and limitations of the method with respect to extrapolating known geologic into covered areas of interest.

DISCUSSION OF GRAVITY METHODOLOGY – The gravity method measures the relative change in gravity associated with lateral variations in density of geologic materials. If no lateral density variations exist in the surveyed area, such as a horizontally layered region, the resultant gravity map will be featureless. Since lateral variations are quite common, most gravity maps display abundant anomalous features. Each gravimeter measurement records the change in gravity between a field station and some reference station. All gravity variations from sources other than lateral density variations can be accounted for using well known factors by Bouguer slab corrections, free-air corrections, terrain corrections and tidal correction. The resultant measured gravity represents the affect of an average of all density-differing volumes of rock within tens to hundreds to thousands of feet from the gravimeter depending upon geologic complexity in contrast with density affects on the reference station. If the geologic setting is three-dimensionally, totally-chaotic, then gravity results are un-interpretable. If, however, the survey area has large two and three dimensional contrasting volumes of rock, then a reasonable approximation can be made for the various sources of the observed gravity features. It is the goal of gravity interpretation to accurately determine the cause of these features.

The least achievable goal of a gravity survey is accurate determinations of depth-to-basement in a gravel- filled basin. The accuracy of using gravity for these determinations diminishes in direct proportion to the complexity of the basin's geology. Computed results are quite good if the basin is formed with a monolithic basement and in-filled by homogeneous, contrasting-density material. As geologic complexity increases both within the basement rocks and within the fill material, lack of control points is, typically, total or insufficient. Without **in situ, bulk-density** information associated with major geologic units within an area of interest, depth-to-basement computations are only as accurate as the **assumed** density contrasts between these units. Even if this information were available, interpretation of features defined by gravity must be made with context of the best available geology for the area. Without geologic controls, the number of possible explanations for a given gravity feature is essentially infinite. Laboratory determinations of density of various rock types from an area of interest do not represent the in situ bulk density contrasts that affect the gravity measurement. Secondary porosity associated with fractures, which can be significant, cannot be reproduced in the laboratory. Any attempt to determine depth-to-basement, must by necessity, make simplifying assumptions in lieu of hard information.

Of equal importance is correct determination of the regional gravity gradient. This regional gravity surface is too often determined by local gravity stations that are under the influence of local bulk density variations, such as basin margins. The gravitational effect of a large basin filled with low-density material can extend up to two miles or more onto the bedrock side of the basin margin. Gravity coverage of the Silver Peak/Alum survey appears sufficiently regional in extent to determine the gravity gradient for this region. Using complete Bouguer gravity values computed with an assumed density value of 2.67 gm/cc, the regional gradient is taken to be a horizontal surface with a value of -197.8 milligals. Essentially all other measured gravity values from the survey are more negative.

If the Silver Peak/Alum geologic settings conformed to the above described simple basin, then the negative gravity anomaly lying below the regional surface simply reflects variations in thickness of basin-infill material. Figure 1 is a view directly overhead of a shaded- relief map of the Silver Peak/Alum gravity surface. Figures 2 and 3 are low-angle views of this surface emphasizing the two areas of interest. To a reasonably good first approximation, the gravity surface of figures 2 and 3 is what the basement surface would look like if all infill material were removed. Buried fault scarps are essentially exposed in these figures. Given this simple setting and one depth-to-basement control point from drilling, the bulk-density contrast between basement and in-fill material can be determined and depths-to-basement throughout the basin can be accurately determined.

However this does not represent the case at hand. While an assumed uniform basement density might be generally applicable, a four to five milligals gravity low is observed over outcropping granitic "basement" west of Silver Peak. The density contract between granitic rock and their host rocks may be minimal, perhaps 0.05 gm/cc, but a vertically extensive, large volume of granitic material can produce the observed anomaly. A five milligals negative anomaly is associated with up to 1000 feet of valley fill, which it would be attributed to if a change in basement was not accounted for. Obviously five milligals is a significant anomaly resulting from variations in the bulk density of basement material, which demonstrates the problem with simplifying assumptions in a complex geologic environment. Significant variations in basement density can be expected elsewhere in the area.

Not only can density variations be expected in basement material, it is much more likely that density variations occur in the valley-fill material, which is quite evident from descriptions of the Esmeralda Formation, as one example. The simplifying assumption made with respect to highly variable valley fill is that an average bulk density will represent all valley fill. In the present case, all material of Tertiary age or younger is lumped into the valley fill category. Density contrasts between basement rocks at 2.67 gm/cc and valley fill ranging in density from 2.07 gm/cc up to 2.27 gm/cc range from 0.4 to 0.6 gm/cc. While a five milligals anomaly is produced by 1000 feet of valley fill at a density contrast of 0.4 gm/cc, it is produced by only 700 feet of fill at a density contrast of 0.6 gm/cc. In the absence of bulk density information about valley- fill material, only reasonable estimates of depth-to-basement can be made, but these estimates may vary by 50% from actual depths. It can be demonstrated that the depth-to-basement determination is the same whether multiple layers of densities assigned to various basin-fill material are used in the computation or an average density of all these layers.

Of greater value to geothermal exploration, the gravity method has the ability to map abrupt lateral changes in density commonly associated with high-angle faulting. Structurally-controlled basin margins are the most common settings for discovery of amagmatic geothermal resources. Hot springs occur where high-angle faulting has created fracture-related permeability allowing for and controlling the rapid vertical ascent of geothermal fluids. This does not preclude the existence of geothermal sources within the depths of gravel filled basins, but such occurrences are essentially undetectable.

The most accurate information from a gravity map is the location of the lateral contact between bodies of contrasting densities. If the contrast is sufficiently large and dimensions of the bodies are sufficiently large, then an interpretable feature is defined. The gravity anomaly created by a single vertical normal fault separating basement (bedrock) from valley fill is readily resolved into its causative elements. It is generally only the vertical component of movement on a fault that creates a change in gravity. Purely strike-slip faults that do not juxtapose rocks with contrasting densities do not produce gravity anomalies. While simple normal faults are common, many times basins boundaries are created by a series of step faults and less-than-vertical faults. In such cases, determination of individual steps or dip attitude is irresolvable. As the depth below surface to a given bedrock feature increases, the affect of the density-averaging-factor upon the gravimeter measurement makes the feature more and more difficult to uniquely resolve. The gravity anomaly of an actual series of step faults might be accurately produced by a single step fault. An actual steeply dipping basement surface may well be accounted for by a series of step faults. As gravity gradients become flatter, it is more likely that the gradient is associated with a slope caused by erosion rather than with a fault with normal movement.

Computer programs exist that mathematically determine the trace of maximum slope on gravity gradients and connect points of inflection along the flanks of anomalies. Theoretically, these traces delineate vertical boundaries between materials with contrasting densities. As many, and probably more, gravity anomalies are associated with sloping erosional surfaces than with actual fault-related vertical boundaries. Simply look at mountainous topography. Computer programs cannot determine actual causative features and their output must be used in context of known geology or at least with geologic reasoning. "Fault traces" derived from mathematical determination of all inflection points on a gravity surface simply delineate sinuous traces defined by connecting these points and bear little relationship to more reasonably-linear traces associated with actual faults. A near right angle intersection of two high-angle faults with components of vertical movement and separating rocks with contrasting densities is not an uncommon geological feature. Its expression on a gravity map is a rounded not angular anomaly as a result of averaging of all bulk densities proximal to the intersection.

The interpretation of gravity survey results must be controlled by as much geologic information about the survey area as is available. Since high-angle faults are most accurately defined by gravity survey results, it is most important to understand the high-angle fault geometry of the survey area. Hulen's report on the Silver Peak area provides the working context within which high-angle fault geometry as defined by gravity results are interpreted for both the Silver Peak and the Alum areas.

PRESENTATION OF RESULTS – Figure 4 shows the locations of high-angle faults as determined from linear features separating gravity highs from gravity lows, which are commonly associated with normal faulting, the up side associated with the more positive gravity values. Figure 12 is a template showing the geometry of folds and faults associated with a primary right-slip fault system and oriented to conform to faults mapped by Hulen in the Silver Peak area. Using the template as an overlay, it can be seen that all gravity linears can be associated with elements of this structural geometry. The template itself is taken from a paper by A.G. Sylvester, 1988, referred to in Hulen's 2008 Silver Peak paper. While the template is a common tool for structural analysis, its correct orientation for a given area is determined by the areas geology. Faults mapped by Hulen strike according to elements on the template. The N40W strike direction of the "master" right-slip fault(s) is presented by Hulen based upon Hulen's extensive literature search. The coincidence of mapped fault strike-directions and those interpreted from the gravity map with those predicted by the template is exceptional. It generates a high degree of confidence in the validity of the features related to high-angle faulting derived from the gravity map. The framework for making valid geophysical interpretations based upon the gravity data is supported by Hulen's mapping and research. The extrapolation of hard geologic information into covered areas by the use of geophysics is seldom better.

It should be mentioned that the fault geometries shown on the template represent the predictable results from stressing an homogenous plate of material according to the indicated compression and extension directions. It can be reasonably argued, that if these faults are a product of initial horizontal stress to an intact plate, then subsequent stress from the same or other orientations will not re-fracture the plate but merely reactivate the existing faults with motion attendant to the new stress directions. Broad clay-gouge and mylonitized fault zones attest to repeated movement on these initial faults.Figures 5 and 6 are more localized maps of the two geothermal prospects. Areas of travertine occurrence on the Silver Peak lease are shown on figure 5. These occurrences are located along a probable synthetic strike-slip as indicated by the template. More importantly, these deposits are proximal to intersections of this N25W synthetic fault with N20E normal (dilational) faults defined by the gravity data and expected from the predicted fault geometry. As pointed out by Hulen, N15-20E striking faults are the products of maximum extensional stress and represent the best structurally-controlled vertical permeability in the area. There appear to be no other areas in the Silver Peak prospect better defined for geothermal exploration than at these intersecting structures.

Figure 6 shows the Alum area's interpreted high-angle faults. A primary area for geothermal exploration is shown (red hachured area) that contains N20E normal faults with the greatest amount of vertical throw in the lease area intersected by major elements of the N40W "master" right-slip shear-fault zone. Extensive vertical permeability is expected to exist within this area and it lies immediately adjacent to a basin with 3000 to 5000 feet of fill.

Figures 7 through 11 show schematic interpretations of gravity profiles through the two lease areas. By necessity, depths-to-basement are shown as possible ranges rather than a single estimates. These interpreted profiles were created after numerous iterations for a reasonable range of feature dimensions using a three-dimensional computer modeling routine. Faults are the most accurately located features on these sections as explained above. Computer modeling is used to create the gravity anomaly assumed to be associated with a given feature on the gravity map. Results from successive iterations using varying dimensions of the computer model, which finally approximate the observed data determine the models final dimensions. The inflection point on an observed gravity profile and its strike direction taken from the gravity map defines the location of a probable step fault. Its location is not varied in the model. Computed anomaly amplitudes vary with dimensions of and depth to the various density elements of the model. A range of model dimensions using a reasonable range of density contrasts is determined that best fit the observed profile. Hard information on bulk densities of the various rock types in the surveyed area helps to minimize the range of model dimensions, e.g., depth-to-basement.

Figure 1

Silver Peak/Alum Geothermal Areas
Complete Bouguer GravitySurface Map

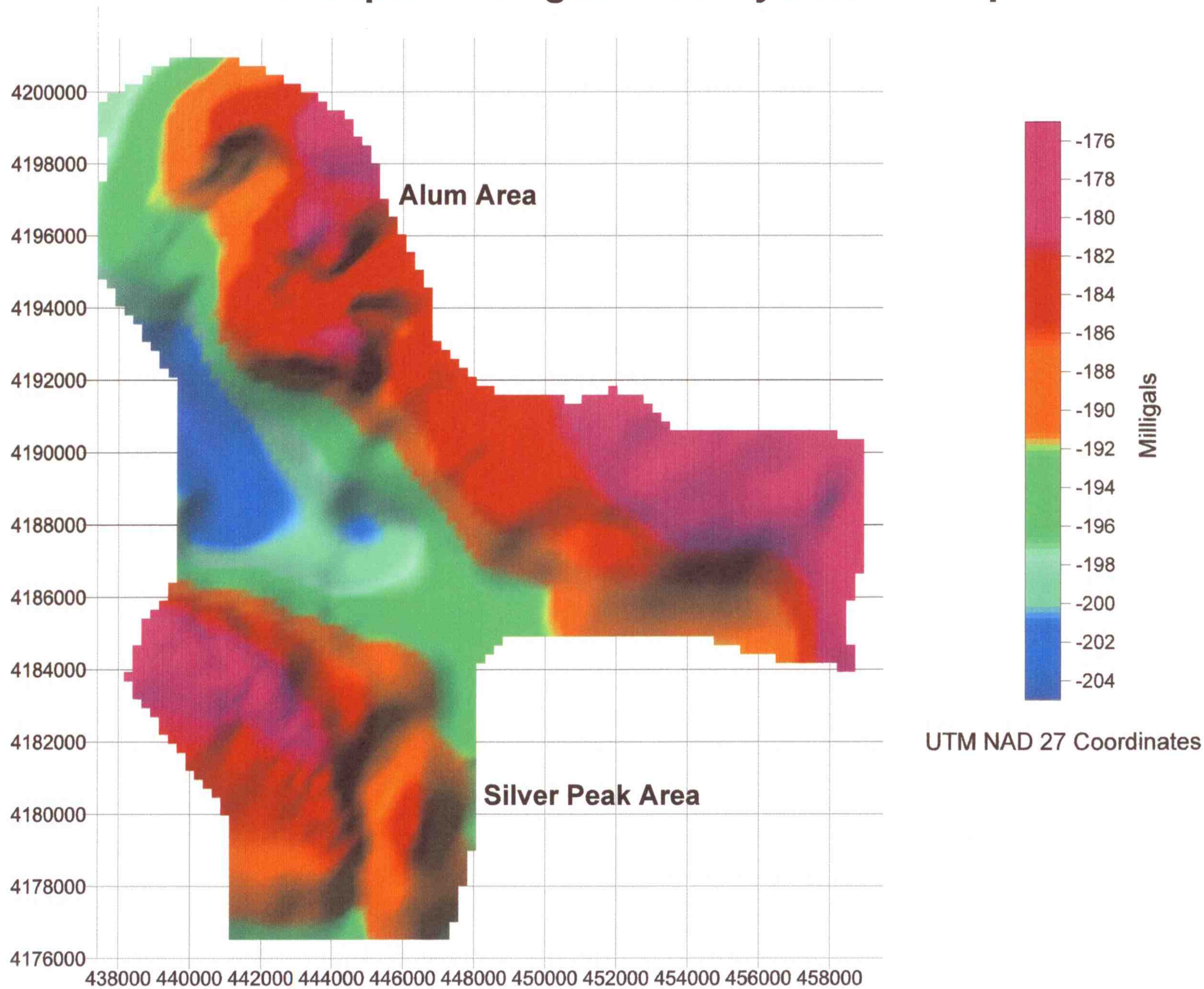
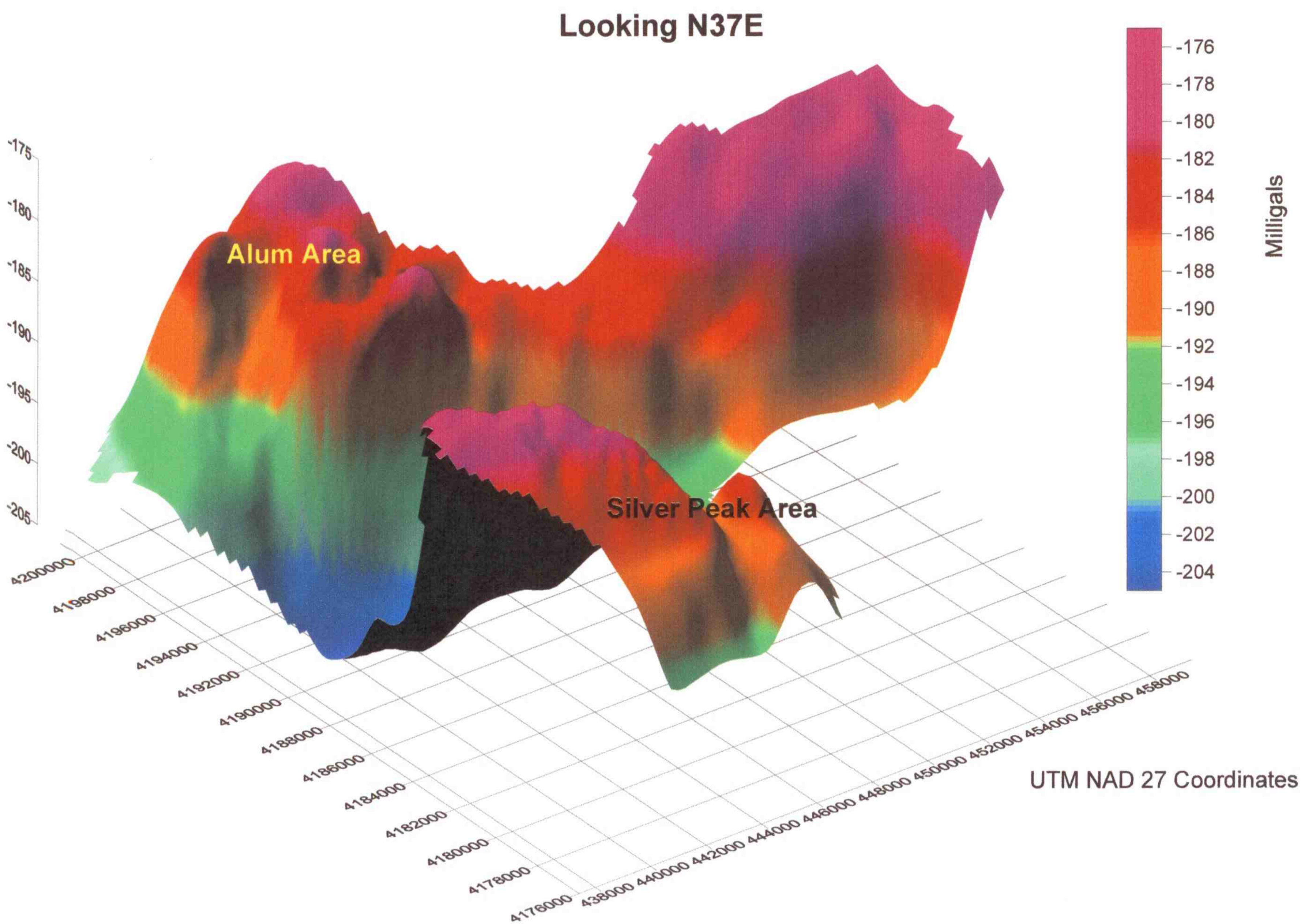


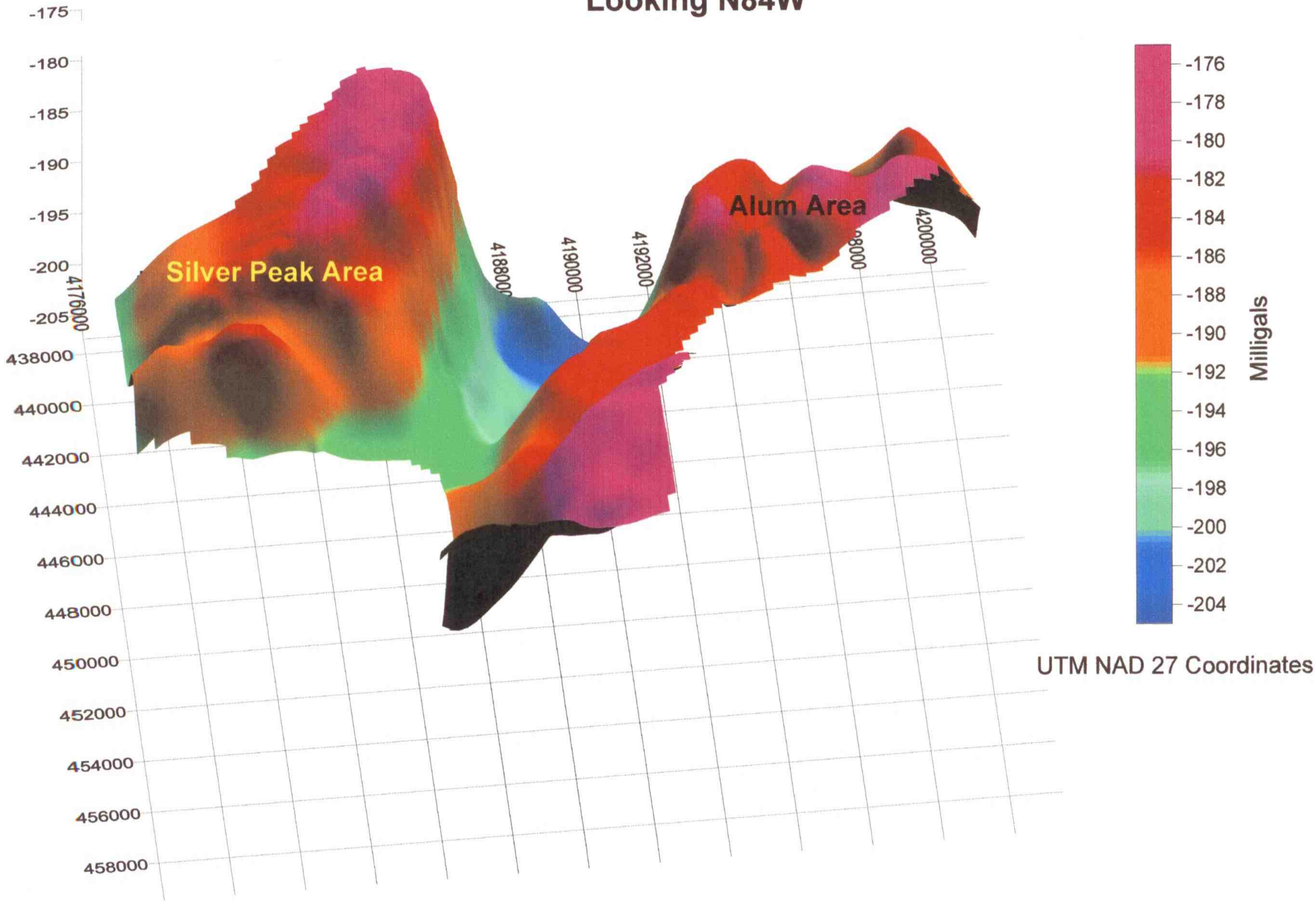
Figure 2

Silver Peak/Alum Geothermal Areas
Complete Bouguer Gravity Surface Map



Silver Peak/Alum Geothermal Areas
Complete Bouguer Gravity Surface Map

Looking N84W

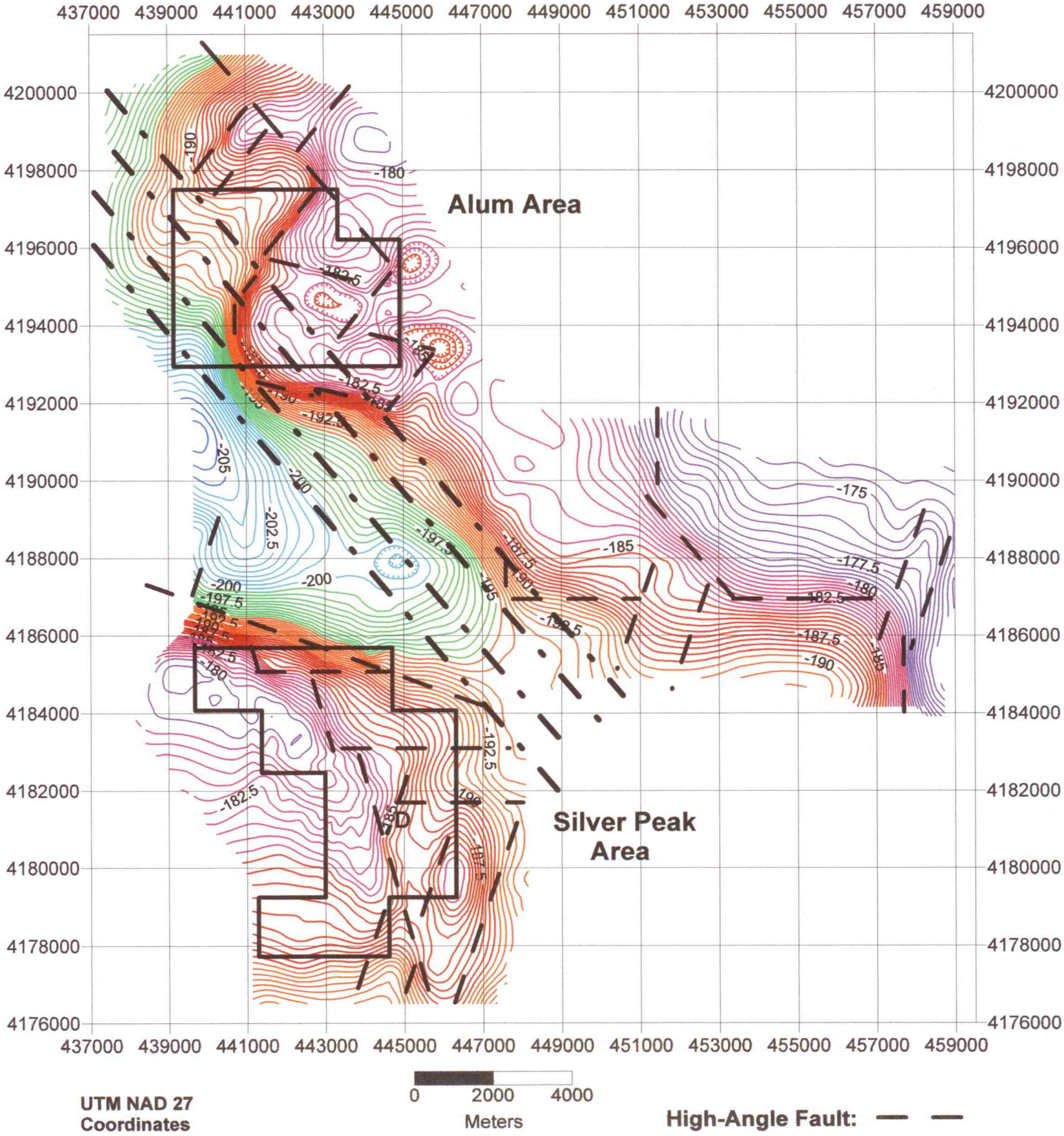


Silver Springs/Alum Geothermal Areas

Figure 4

Complete Bouguer Gravity Map

Showing High-Angle Faults Intepreted from Gravity

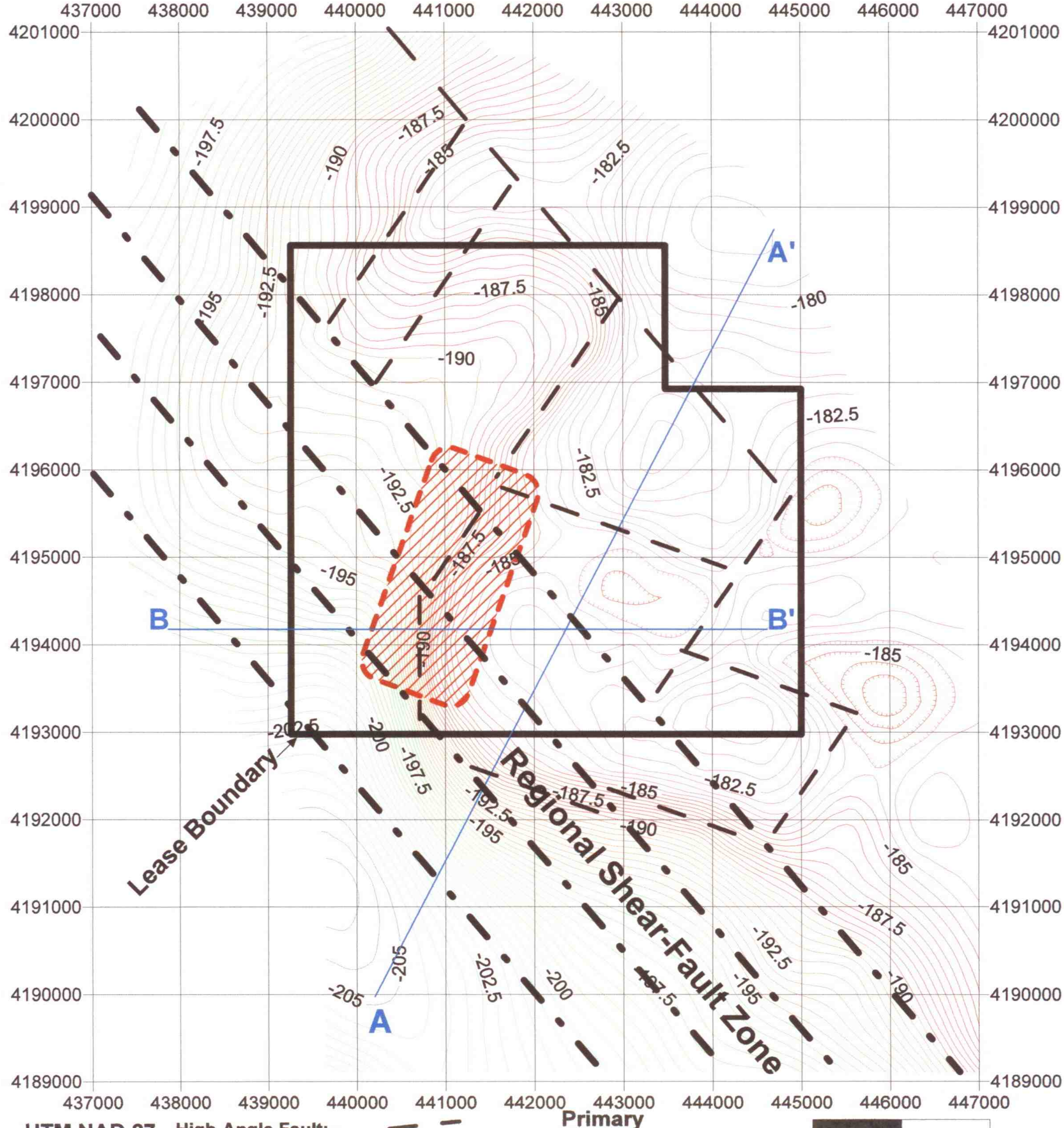


Alum Area

Figure 5

Complete Bouguer Gravity Map

Showing High-Angle Faults Interpreted from Gravity



UTM NAD 27 Coordinates

High-Angle Fault:

Interpreted Gravity Profile: A A'

Primary Geothermal Target Area:

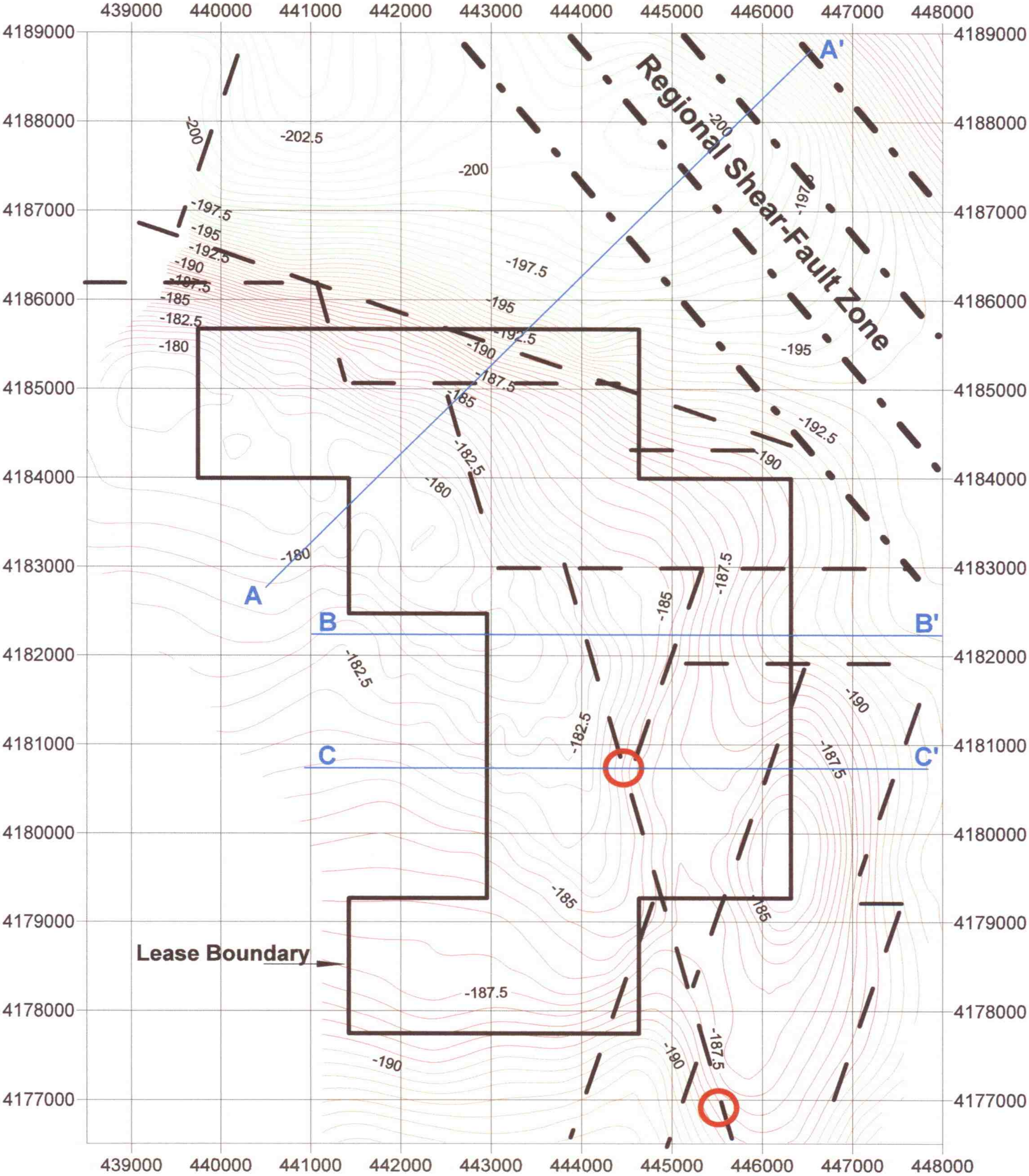
0 1000 2000 Meters

Silver Peak Area

Figure 6

Complete Bouguer Gravity Map

Showing High-Angle Faults Interpreted from Gravity



UTM NAD 27 Coordinates

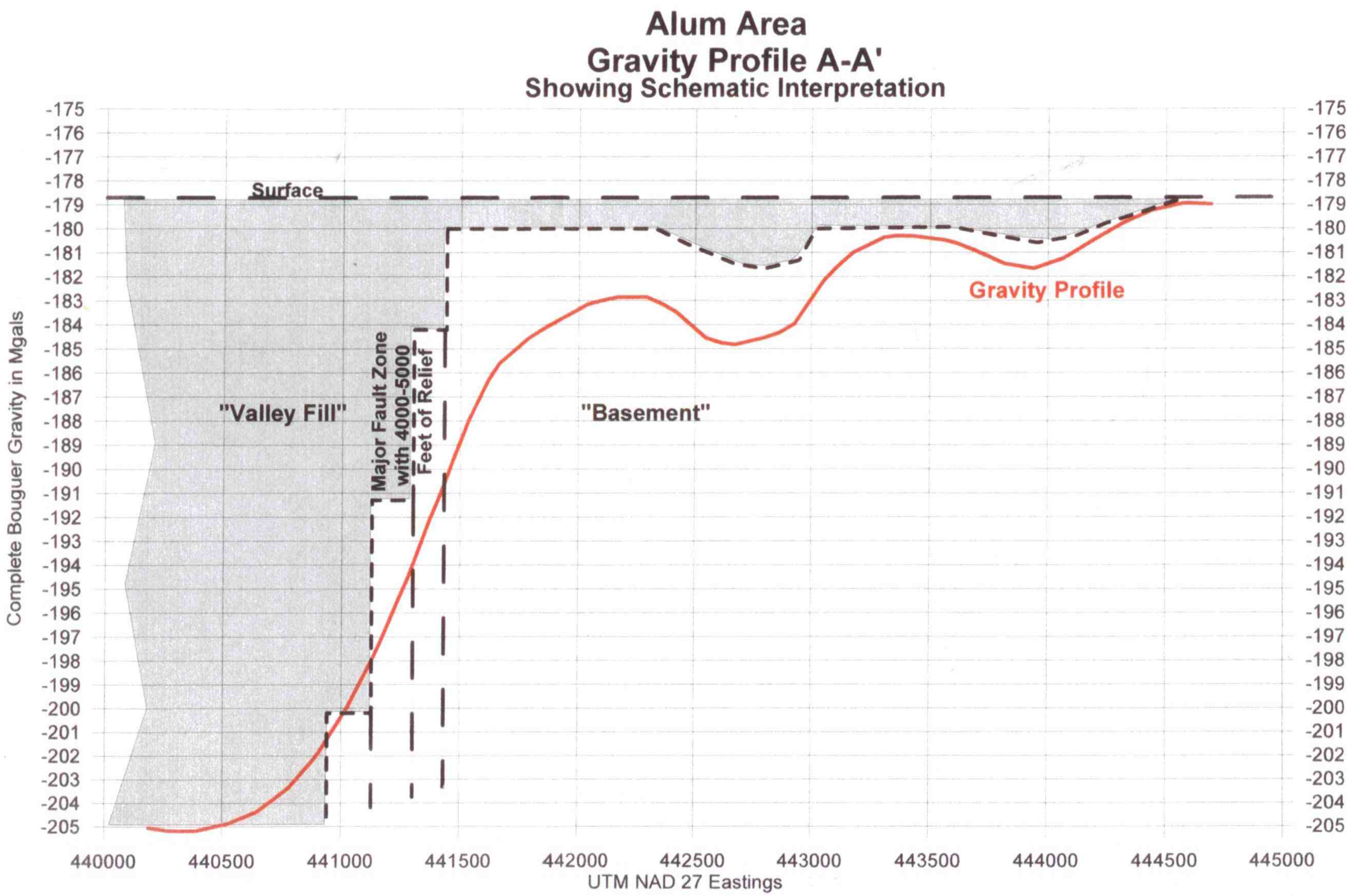
High-Angle Fault:

Travertine:

Interpreted Gravity Profile: A A'

0 1000 2000 Meters

Figure 7



Alum Area
Gravity Profile A-A'
Showing Schematic Interpretation
Complete Bouguer Gravity in Mgals
UTM NAD 27 Eastings
Surface
"Valley Fill"
Major Fault Zone
with 4000-5000
Feet of Relief
"Basement"
Gravity Profile
-175
-176
-177
-178
-179
-180
-181
-182
-183
-184
-185
-186
-187
-188
-189
-190
-191
-192
-193
-194
-195
-196
-197
-198
-199
-200
-201
-202
-203
-204
-205
440000
440500
441000
441500
442000
442500
443000
443500
444000
444500
445000

Figure 8

Alum Area
Gravity Profile B-B'
Showing Schematic Interpretation

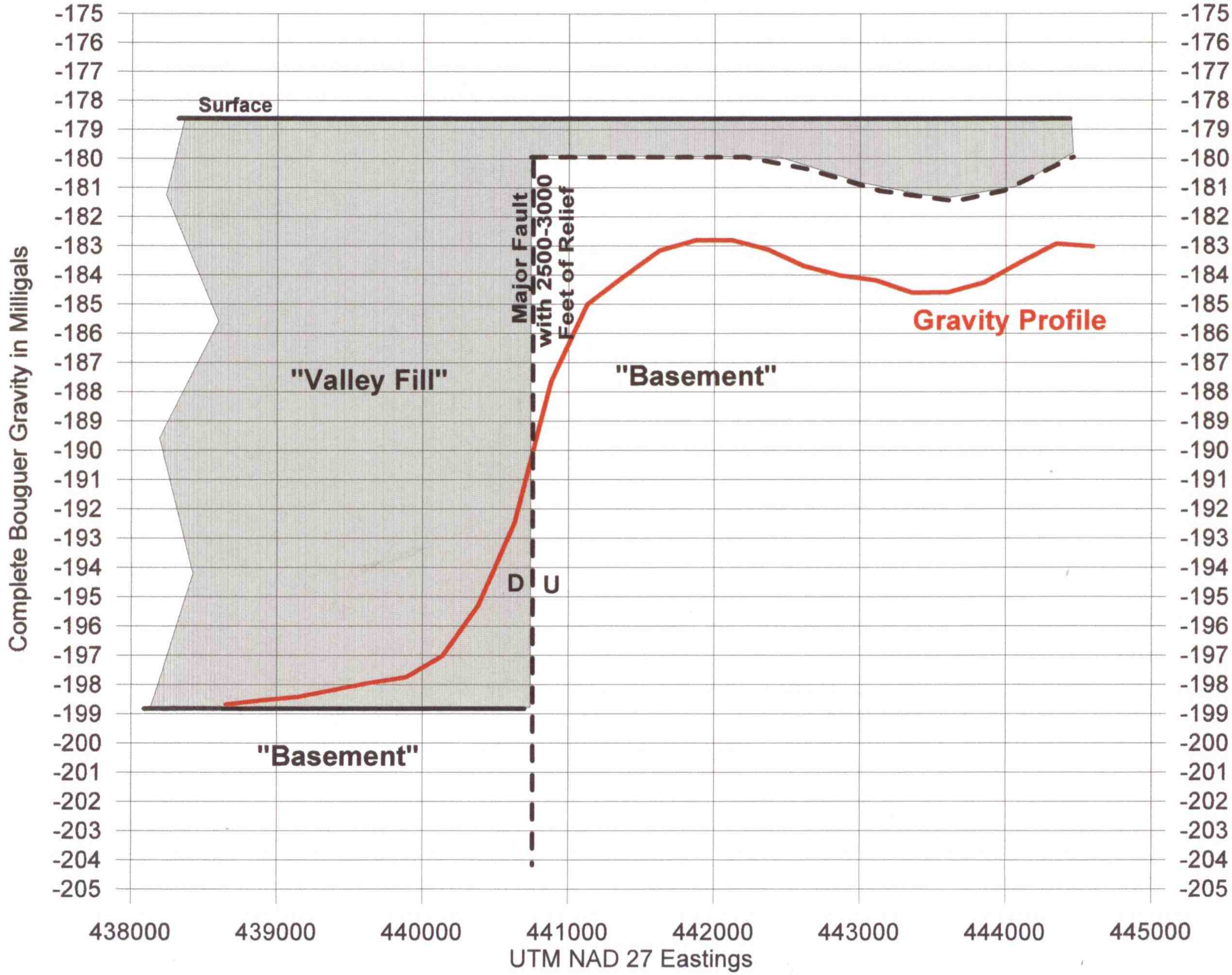


Figure 9

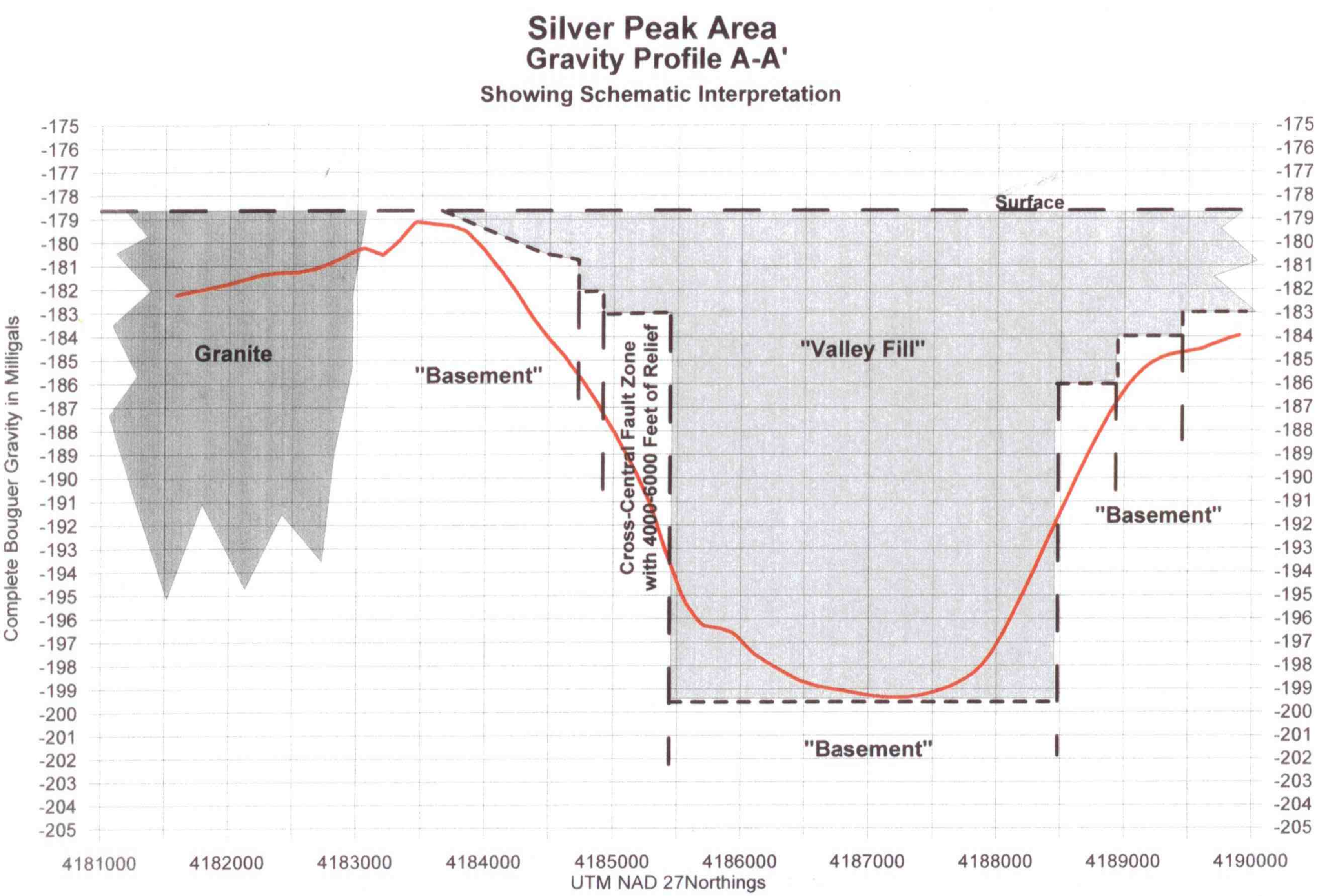

Silver Peak Area
Gravity Profile A-A'
Showing Schematic Interpretation
Complete Bouguer Gravity in Milligals
-175
-176
-177
-178
-179
-180
-181
-182
-183
-184
-185
-186
-187
-188
-189
-190
-191
-192
-193
-194
-195
-196
-197
-198
-199
-200
-201
-202
-203
-204
-205
Surface
Granite
"Basement"
Cross-Central Fault Zone
with 4000-6000 Feet of Relief
"Valley Fill"
"Basement"
"Basement"
4181000
4182000
4183000
4184000
4185000
4186000
4187000
4188000
4189000
4190000
UTM NAD 27Northings

Figure 10

Silver Peak Area

Gravity Profile B-B'

Showing Schematic Interpretation

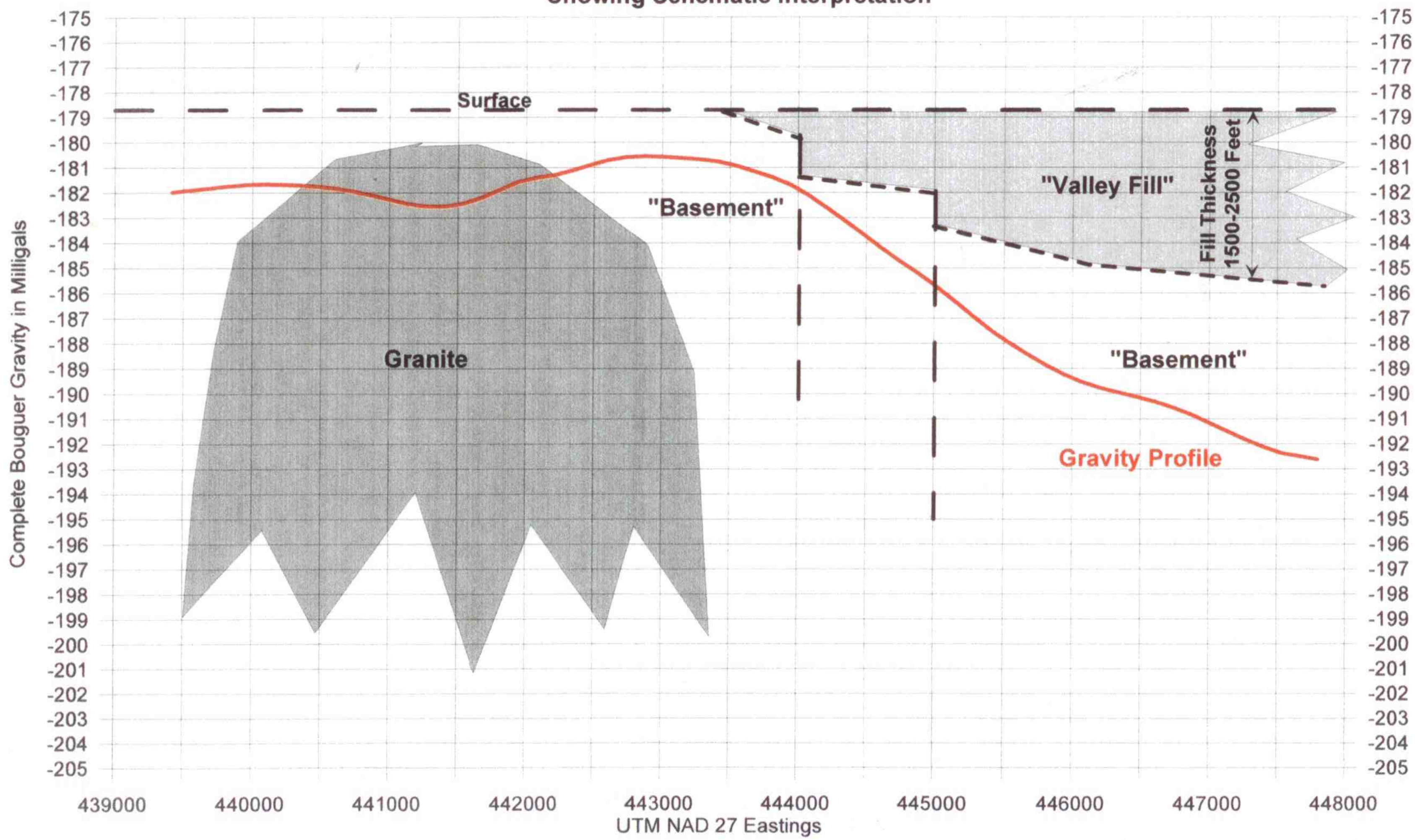
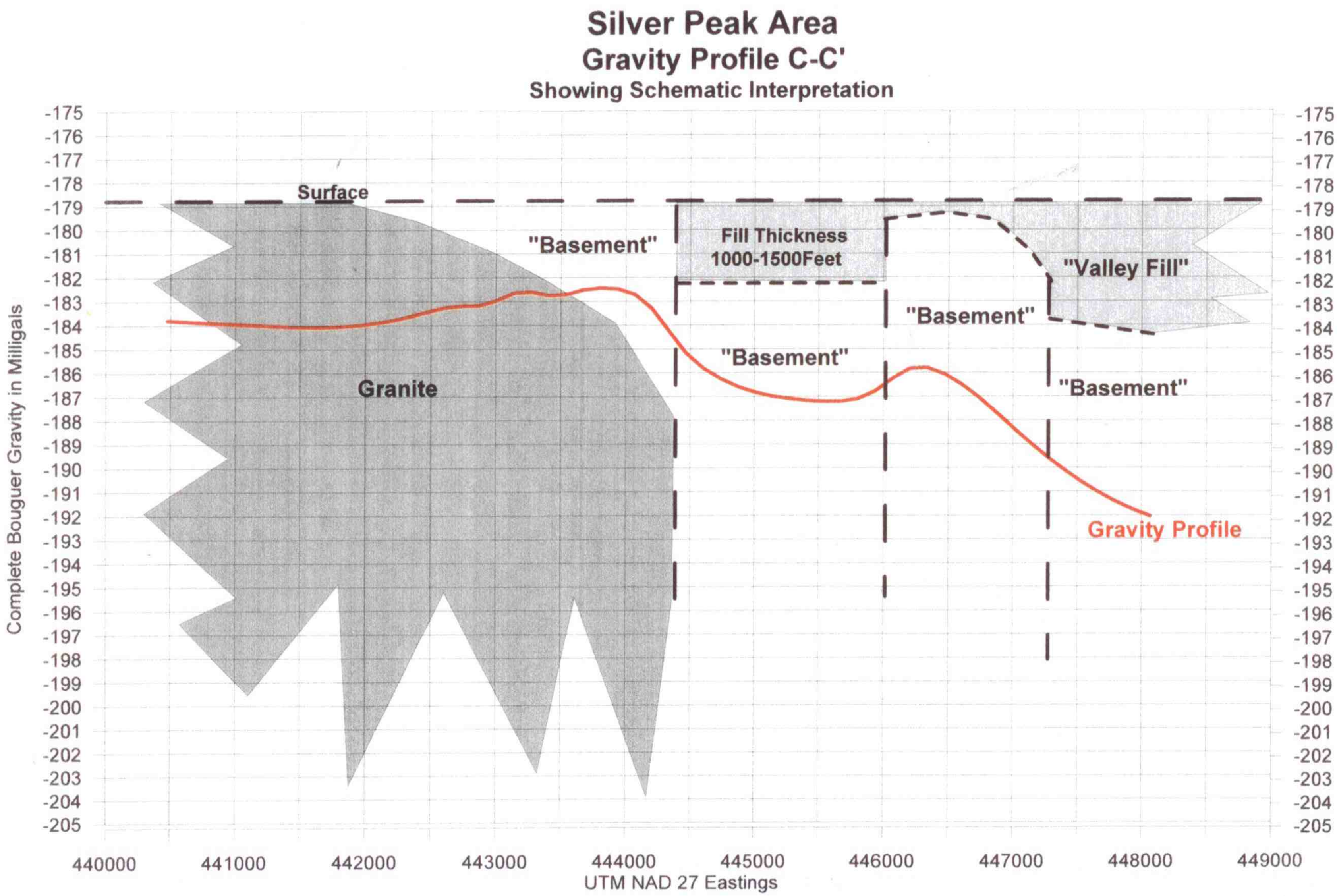


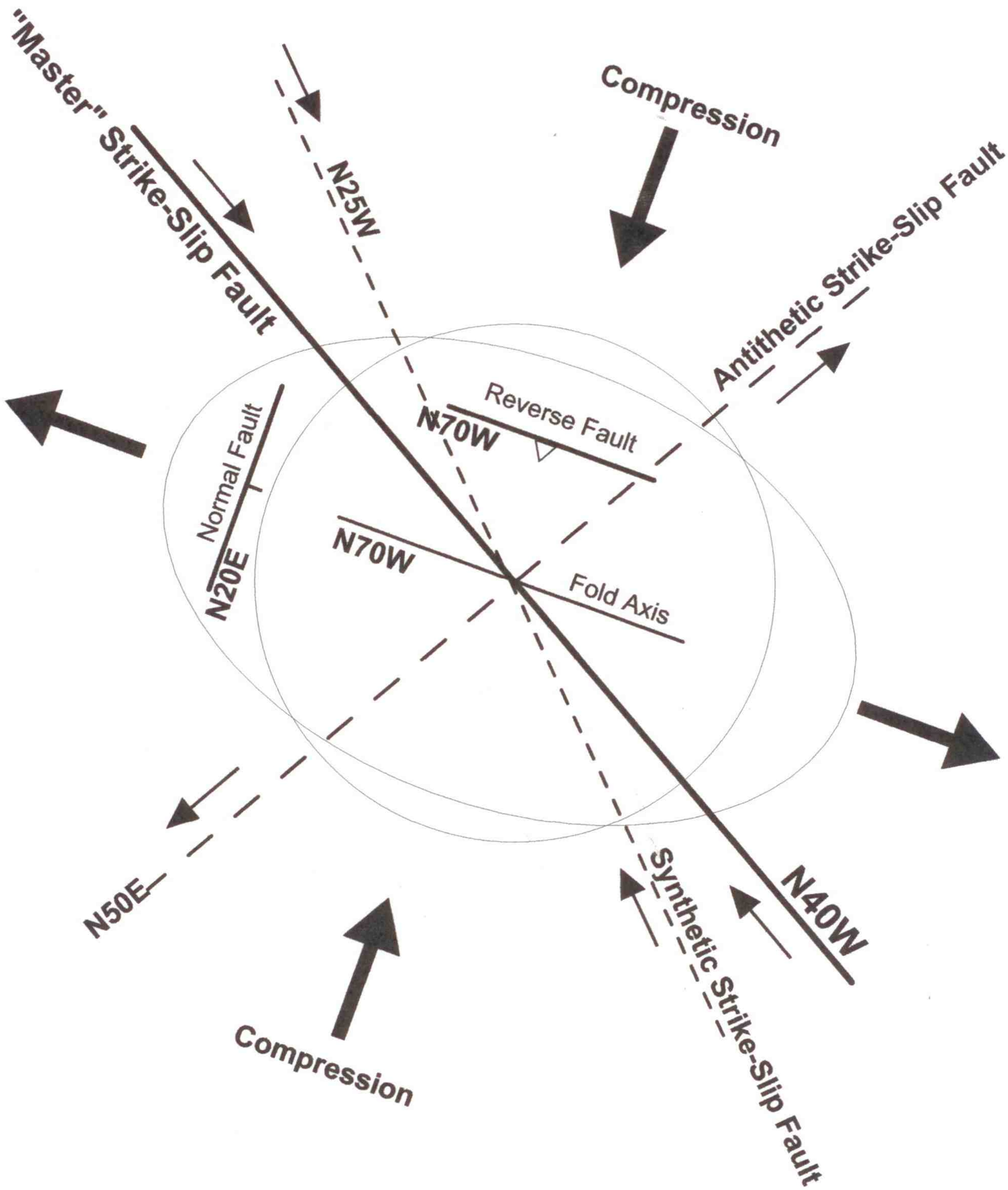
Figure 11



Silver Peak Area
Gravity Profile C-C'
Showing Schematic Interpretation
Complete Bouguer Gravity in Milligals
UTM NAD 27 Eastings
Surface
"Basement"
Fill Thickness
1000-1500Feet
"Valley Fill"
"Basement"
"Basement"
"Basement"
Granite
Gravity Profile
-175
-180
-185
-190
-195
-200
-205
440000
441000
442000
443000
444000
445000
446000
447000
448000
449000

Silver Peak/Alum Geothermal Areas

Geometry of Folds and Faults Relative to "Master" Left-Slip Fault



Overlay for Figures 4, 5 and 6