Preliminary model of the Pre-Tertiary basement rocks beneath Yucca Flat, Nevada Test Site, Nevada, based on analysis of gravity and magnetic data

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ABSTRACT

Structures in the pre-Tertiary basement of Yucca Flat, Nevada Test Site, Nevada, are interpreted using the basement topography and basement gravity anomaly derived from an isostatic gravity inversion model. A new fault is proposed which eliminates some of the Paleozoic carbonate section just west of the Halfpint Range. Proposed faults that offset basement surface correlate closely with magnetic anomalies caused by the offset of Tertiary volcanic rocks.

INTRODUCTION

The Environmental Restoration Program of the U.S. Department of Energy, Nevada Operations Office, was developed to investigate the possible consequences to the environment of 40 years of nuclear testing on the Nevada Test Site. The majority of the tests were detonated underground, introducing contaminants into the ground-water system (Laczniak and others, 1996). An understanding of the ground-water flow paths is necessary to evaluate the extent of ground-water contamination. This report provides information specific to Yucca Flat on the Nevada Test Site.

Critical to understanding the ground-water flow beneath Yucca Flat is an understanding of the subsurface geology, particularly the structure and distribution of the pre-Tertiary rocks, which comprise both the major regional aquifer and aquitard sequences (Winograd and Thordarson, 1975; Laczniak and others, 1996). Because the pre-Tertiary rocks are not exposed at the surface of Yucca Flat their distribution must be determined through well logs and less direct geophysical methods such as potential field studies.

In previous studies (Phelps and others, 1999; Phelps and Mckee, 1999) developed a model of the basement surface of the Paleozoic rocks beneath Yucca Flat and a series of normal faults that create topographic relief on the basement surface.

In this study the basement rocks and structure of Yucca Flat are examined in more detail using the basement gravity anomaly derived from the isostatic gravity inversion model of Phelps and others (1999) and high-resolution magnetic data, as part of an effort to gain a better understanding of the Paleozoic rocks beneath Yucca Flat in support of groundwater modeling.

ACKNOWLEDGEMENTS

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DATA

The primary data for this report are the isostatic gravity of Yucca Flat processed and interpreted to form two derivative datasets: topographic surface of the pre-Tertiary basement rocks beneath Yucca Flat and the accompanying basement gravity anomaly (Phelps and others, 1999). The topographic surface of the basement (pre-Tertiary) rocks is derived by an iterative process that calculates the depth of the basin based on a density-depth relationship. Through this process the gravity contribution of the basement rocks to the gravity anomaly can be separated from the gravity contribution of the basin-filling rocks and unconsolidated deposits. The basin fill component, together with the density-depth relationship and constraints based on well logs, defines the depth of the basin at any point and therefore the shape of the topographic surface of the basement. The remaining gravity component is caused by density variations in the basement. The combination of the two components gives the shape and major density changes in the basement beneath Yucca Flat.

The magnetic data are from high-resolution surveys combined with regional surveys (McCafferty and Grauch, 1997). The data for Yucca Flat were filtered (computer algorithm

MFILT; Phillips and others, 1993) to separate the high frequency signals from lower frequency signals. Higher frequencies represent magnetic sources closer to the surface. A higher frequency anomaly was used to examine faulting in the basin-filling volcanic units. This magnetic anomaly represents the highest magnetic volcanic units, typically 350m below Yucca Flat, but also exposed at the surface around the margins.

MAGNETIC FIELD ANALYSIS

Tertiary extensional faulting defines the shape of the Yucca Flat basin (Cole, 1987) and cuts the basement rocks (Wahl and others, 1997; Cole and others, 1997). Tertiary faults appear to offset the basement units enough to alter the basement gravity (Healy, 1968; Cole and others, 1997; Phelps and others, 1999) and the resulting basement topographic surface derived from a constrained gravity inversion analysis (Phelps and others, 1999). A series of basement-cutting Tertiary faults are proposed based on offsets in the basement topography (Phelps and McKee, 1999). If these basement-cutting Tertiary faults also cut overlying magnetic volcanic units, the magnetic field ought to have a pattern reflecting them.

The magnetic anomaly pattern shown in figure 5 exhibits linear features that correspond closely with the proposed basement faults. It shows a distinct north-south pattern and aligns well with the interpreted basement faults, indicating the north-south fault structures seen on the basement topography as modeled by gravity are also seen in the Tertiary volcanic section. This supports the hypothesis that large offsets in the basement surface are faults and indicates these faults cut the overlying volcanics. The basement faults extend into the Tertiary section, cutting volcanic units, and are therefore younger than the youngest magnetic volcanic rocks. The pattern shown by the magnetic anomaly would be displaced somewhat from the pattern of the basement faults because the magnetic anomaly represents rocks above the basement rocks, and the faults would be displaced up-dip from their location at the basement. The magnetic anomaly reflects the top of the shallowest magnetic volcanic rocks, on average 350m below the surface of Yucca Flat, and the basement model topographic surface represents the basement beneath Yucca Flat, typically 1 km, but as much as 2.5 km deep.

BASEMENT GRAVITY MODELING

The basement gravity anomaly was compared with the mapped geology in the surrounding region (rock units) (fig. 1) and with the modeled basement topography (fig. 2). Figure 2 is a composite figure, merging local topography from 30m DEMs outside Yucca Flat with the basement topography inside Yucca Flat, as modeled by Phelps and others (1999), to create the shading, and colored with the basement gravity anomaly shown in figure 1. This allows one to see how the basement gravity changes in relation to the topography of the basement surface beneath Yucca Flat. No clear relationship can be seen between the basement topography and the associated basement gravity.

If we are to use gravity to model the rock units which comprise the basement, then we must categorize the basement rock units such that differences will be visible using the basement gravity anomaly, which is sensitive to vertical to sub-vertical changes in density. For the purpose of this study the most meaningful subdivision of the stratigraphy that highlights density changes is the hydrostratigraphic classification used by Lazcniak and others (1996). They separated the Paleozoic rocks into four categories: 1) the upper carbonate aquifer, which is comprised of Permian and Pennsylvanian Tippipah Limestone, 2) the Eleana confining unit, comprised of Mississippian and Devonian Eleana and Chainman Formations, 3) the lower carbonate aquifer, comprised of Devonian through Cambrian carbonate rocks, and 4) the siliceous rock confining unit, consisting of lower Paleozoic and pre-Cambrian argillite, siltstone, sandstone, and shale. This hydrostratigraphy is a useful breakdown for gravity modeling because there is a density contrast between the siliceous rocks, Eleana confining unit and siliceous confining unit, and the carbonate rocks, upper carbonate aquifer and lower carbonate aquifer. The carbonate rocks are typically denser and yield a higher gravity anomaly value.

To model the basement rocks beneath Yucca Flat, a geologic cross-section (section G-5b, fig.1) was constructed through central Yucca Flat using available surface and subsurface geologic data. A gravity profile was derived by sampling basement gravity and basement topography at 200m intervals along the line of section. This profile formed the data for the 2-dimensional (2D) model.

The modeling procedure involved inserting blocks to the 2D model and changing their shape and density until they created a gravity anomaly that matched the derived anomaly. The solutions are non-unique; we chose to model bodies that geometrically resemble the geologic cross-section interpretation, simplifying by using the hydrostratigraphic units described above. For the density of the siliceous rocks we used the average crustal value of 2.67g/cc. For the carbonate rocks we chose a value of 2.78g/cc, which is intermediate between calcite (2.71g/cc) and dolomite (2.85g/cc). For the highest density rocks we chose 2.83g/cc, a value slightly lower than pure dolomite. The degree to which we were able to match the model gravity anomaly to the sampled anomaly served as an initial test of the validity of the geologic cross-section. Modifications were made to the geologic cross-section so as to better fit the gravity model. These modifications consisted primarily of adding a large down-to-the-east fault to the eastern end of the section, as discussed below.

DISCUSSION

The major features in the basement gravity (fig. 1) include:

(1) the general increase in gravity from east to west,
(2) the abrupt drop in gravity along the western edge of the Halfpint range (anomaly A of figure 1),
(3) the linear low on the western central side of Yucca Flat (anomaly B of figure 1), and
(4) the high anomaly in the southern part of Yucca Flat (anomaly C of figure 1).

The Pre-Cambrian and Paleozoic stratigraphic section in the Halfpint Range forms a shallow, west dipping homocline (Cole and others, 1997). The exposed section extends from the late Proterozoic Johnnie Formation through the Ordovician Pogonip Group before it is buried by the alluvium in Yucca Flat (Wahl and others, 1997). The basement gravity reflects this homocline, producing lower data values in the pre-Cambrian and Cambrian silicic rocks (Johnnie Formation through the middle part of the Carrara Formation) in the eastern Halfpint Range and increasing over the denser carbonate rocks in the western part of the range. The basement gravity continues to increase in a westerly direction, as the carbonate section thickens progressively through the Silurian and Devonian part of the section beneath Yucca Flat. The basement gravity decreases at the western edge of the Halfpint Range, however, indicating a density change along the western edge of the range (anomaly A of figure 1). The basement gravity then continues to increase again to the west, repeating the Halfpint Range pattern. This pattern may be produced by repeating the stratigraphic section on a down-to-the-east fault which brings less dense siliceous confining unit closer to the surface, accompanied by the removal of some of the overlying, more dense carbonate rocks (fig. 4). This can be accomplished by a down-to-the-east fault, a structure with the opposite sense of motion to modern topography. This would indicate displacement along the fault is a pre-Tertiary structure that does not displace the basin-filling rock units in Yucca Flat. The geologic cross-section includes the CP thrust, a thrust fault exposed at the surface in the CP Hills to the south (Cole and Cashman, 1999) and inferred to be present from drill hole data (Cole and others, 1997). Though such a horizontal structure would not be seen in the basement gravity, we have included the CP thrust in our cross-section to conform to the drill hole data.

Modeling the basement gravity along the profile line G-5b, the basement gravity low west of the Halfpint Range can be accommodated by approximately 3,000m of offset. The overall increase westward can be accommodated by a gradual thickening of the carbonate rocks as they dip to the west. A sharp peak in the basement gravity just to the east of anomaly A is modeled as a local body of dense dolomitic rock. This is consistent with the continuation of the basement gravity peak approximately one mile to the south, where there is a local basement gravity peak over an exposure of limestone of the Ordovician Pogonip group. An alternate explanation for the local basement gravity peak is a local body of high-density intrusive rock, such as the basaltic intrusives that outcrop approximately two miles to the southeast (Byers and Barnes, 1967). The intrusive would have to be similar in shape (that is, more akin to a dike) and density (2.83 g/cc) to the modeled dolomitic body.

The NE basement gravity low, labeled anomaly B (fig. 1), continues the trend of the syncline in Syncline Ridge. The basement gravity indicates this feature extends NE below the basin fill of Yucca Flat, bending north. This is in agreement with field observations that show the beds of Syncline Ridge trending from north-northeast to north (Cole and Cashman, 1999).

The syncline of Syncline Ridge can be modeled as a core of Tippipah Limestone and Eleana Formation extending to roughly 1,000m below sea level and a thickness of lower Paleozoic carbonate rocks extending to a depth of about 4,000m below sea level. The syncline is overturned to the west, the lower limb thicker and gently to moderately dipping eastward.

The large gravity high at the southern end of the basin, labeled anomaly C (fig. 1), could be a thick accumulation of carbonate rocks. A thick accumulation of carbonate rocks in this area would be consistent with our model, and with rocks found in drill hole UE-1h, the bottom of which penetrated Paleozoic dolomite (Cole and others, 1997). A dense intrusive body, such as a gabbro, is also possible, but lack of an associated magnetic anomaly would require it to be, at most, weakly magnetic. However, no large bodies of dense intrusives are observed at the surface in the Nevada Test Site area, so the authors believe a dense accumulation of dolomitic rocks is more plausible.

CONCLUSION

Large structures can be seen in the basement gravity anomaly beneath Yucca Flat. These include:

1) a large fault just west of the Halfpint Range,
2) the syncline of Syncline Ridge extending north under the Yucca Flat basin, and
3) a large gravity high in the southern part of the Yucca Flat basin, possibly a thick section of carbonate rocks.

Analysis of high-resolution magnetic data reinforces the interpretation of the location of faulting in the basement topography caused by Miocene extension

FUTURE WORK

Preliminary work examining the structure of basement rocks beneath Yucca Flat has shown that significant structures exist in the basement section, and that the basement surface in deformed by faults that cut overlying Tertiary volcanic units. A more detailed examination of the magnetic data would improve our understanding of the location and extent of the Tertiary faults beneath Yucca Flat. Models based on gravity analyses would benefit from the development of procedures to describe error and sensitivity to changes in model parameters.

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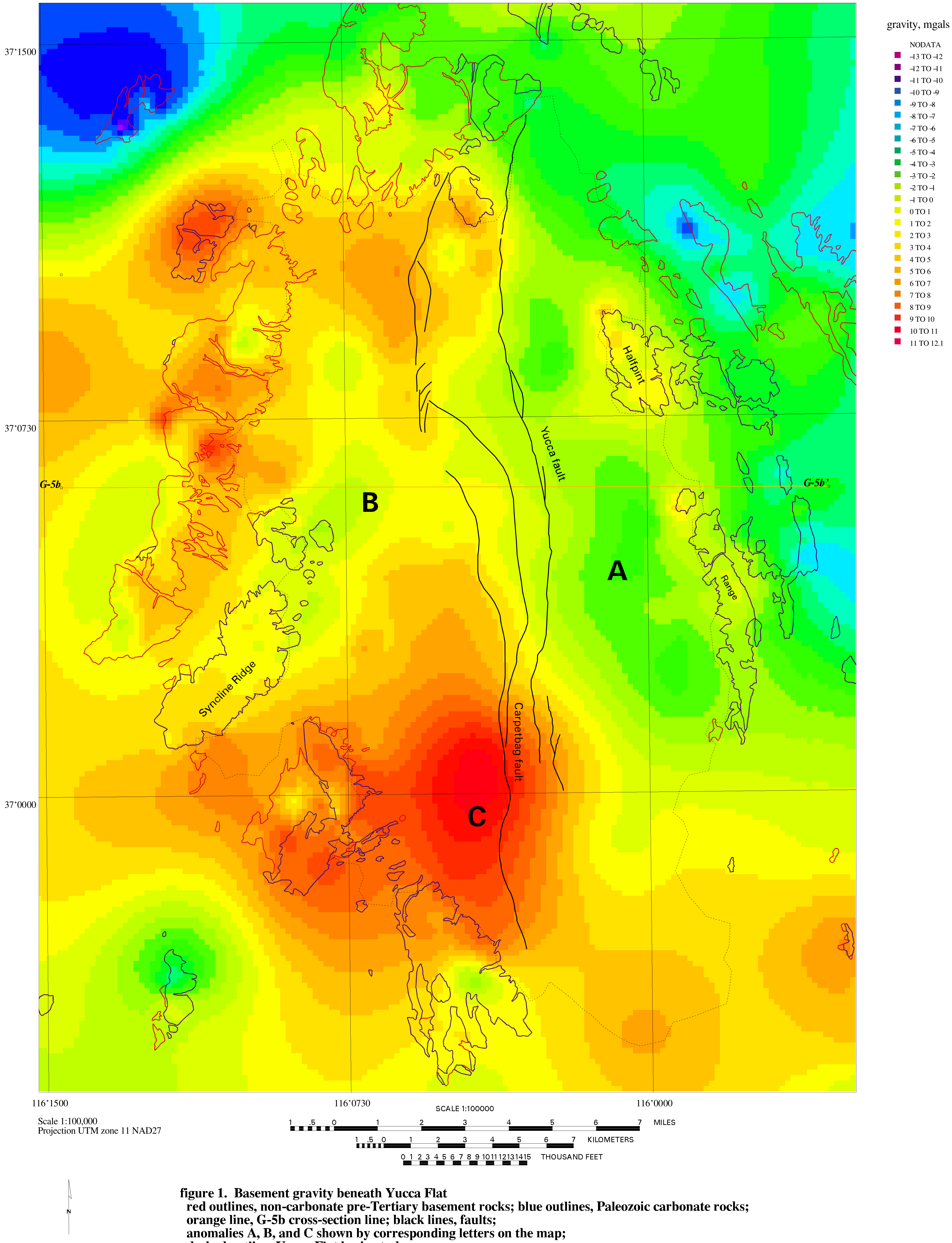

figure 1. Basement gravity beneath Yucca Flat
red outlines, non-carbonate pre-Tertiary basement rocks; blue outlines, Paleozoic carbonate rocks;
orange line, G-5b cross-section line; black lines, faults;
anomalies A, B, and C shown by corresponding letters on the map;
dashed outline, Yucca Flat basin study area

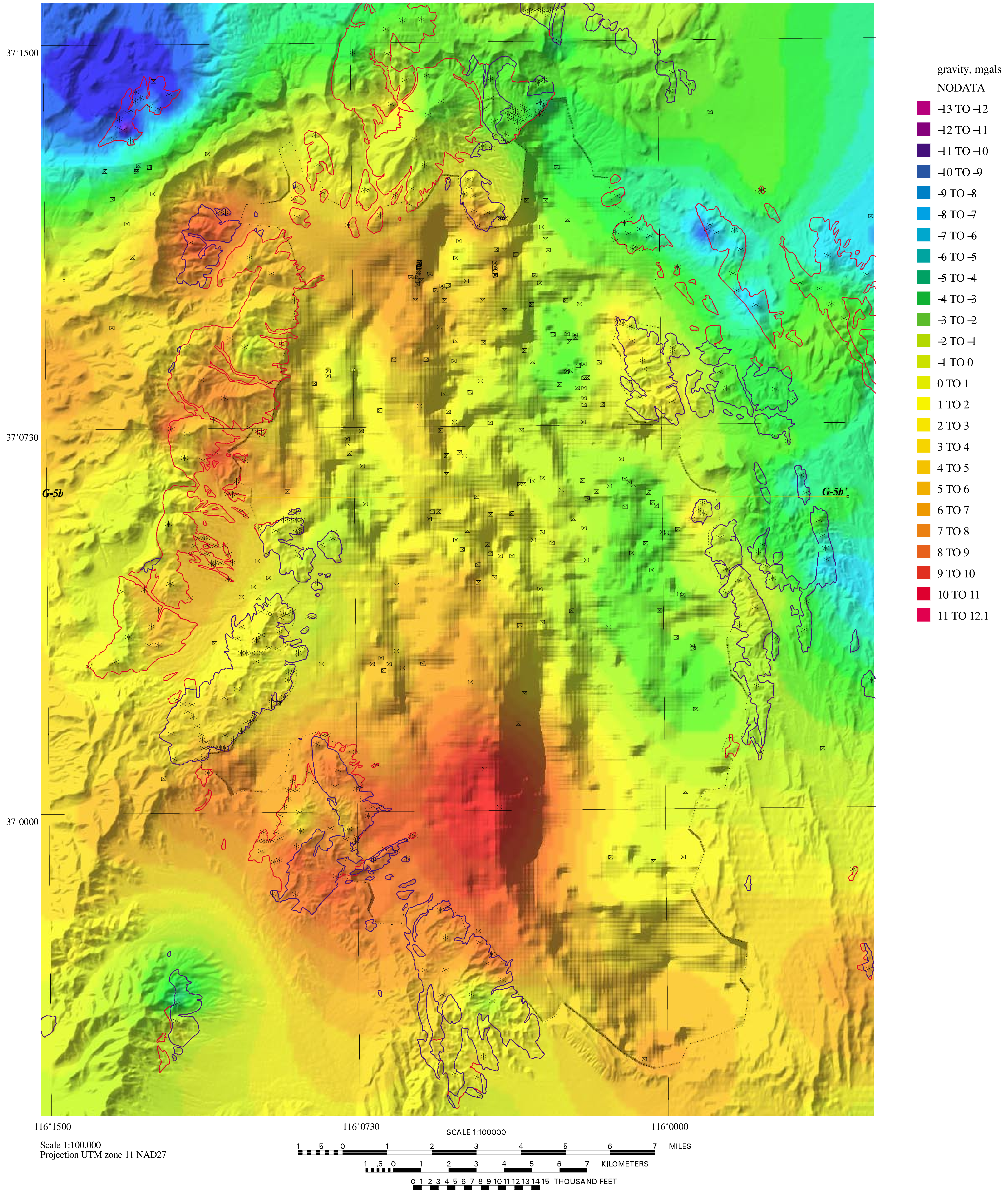

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figure 2. Basement gravity beneath Yucca Flat merged with basement topography
red outlines, non-carbonate pre-Tertiary basement rocks;
blue outlines, Paleozoic carbonates; orange line, G-5b cross-section line;
black boxes, wells reaching basement (depth control for model);
asterisks, gravity stations on exposed basement rock;
dashed outline, Yucca Flat basin study area.

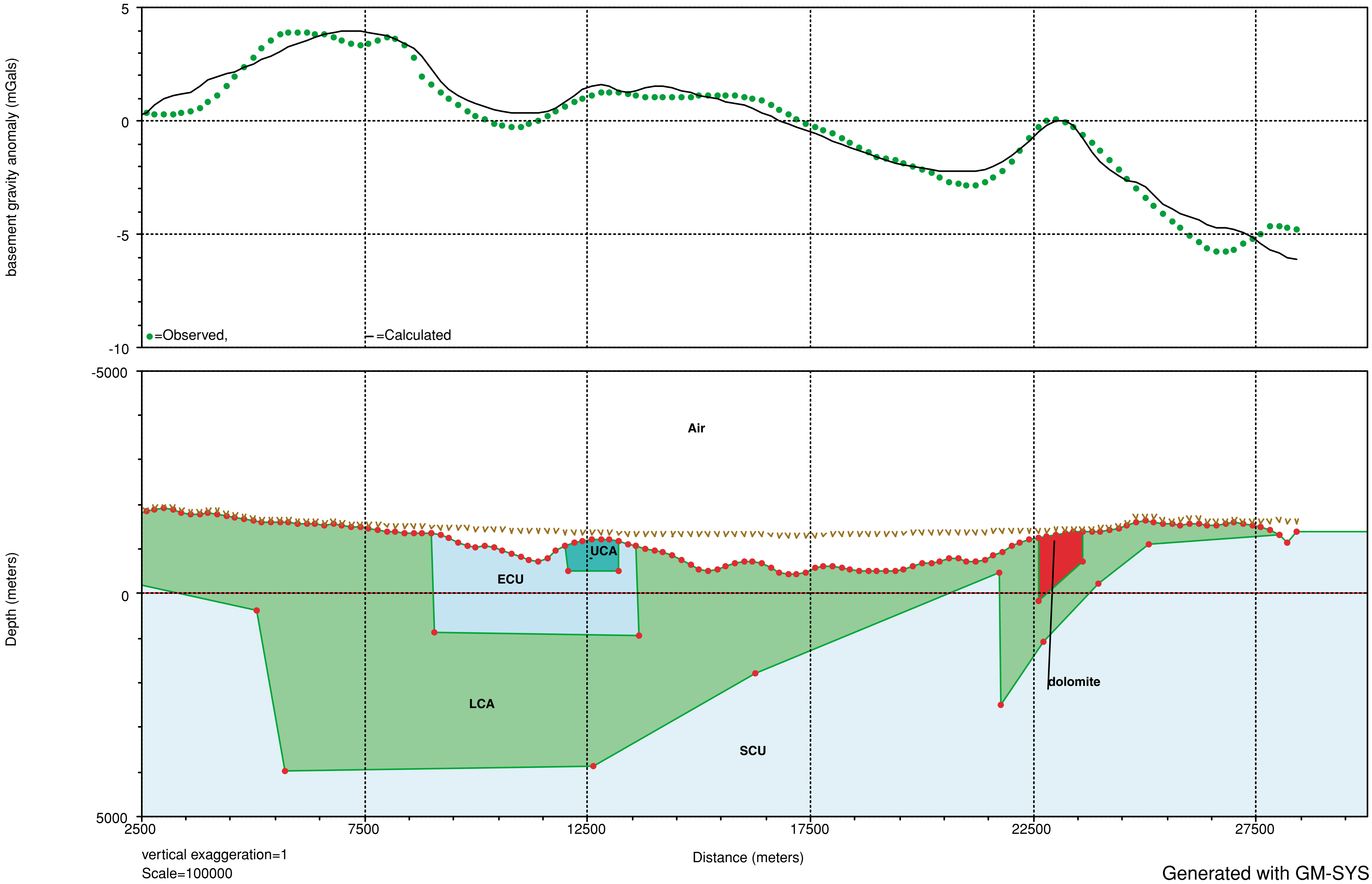

figure3. Model of basement rocks across profile line G5b, based on basement gravity. Abbreviations are as follows: UCA, upper carbonate aquifer, ECU, Eleana confining unit, LCA, lower carbonate aquifer, SCU, siliceous confining unit. Red dots on the surface profile represent elevation points on the basement surface, red dots within the model represent vertices in the model blocks, and v's represent elevation points on the topographic surface.

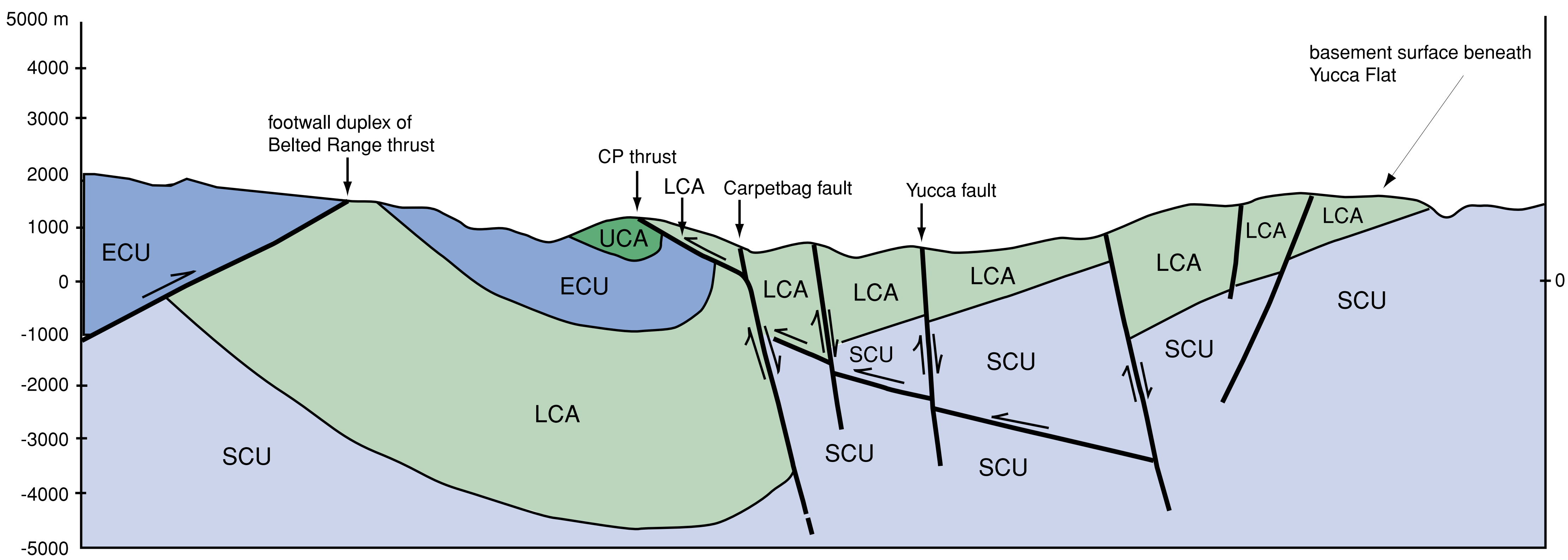

figure 4. Geologic cross-section interpretation of basement gravity model. Abbreviations are the same as those used in figure 3.

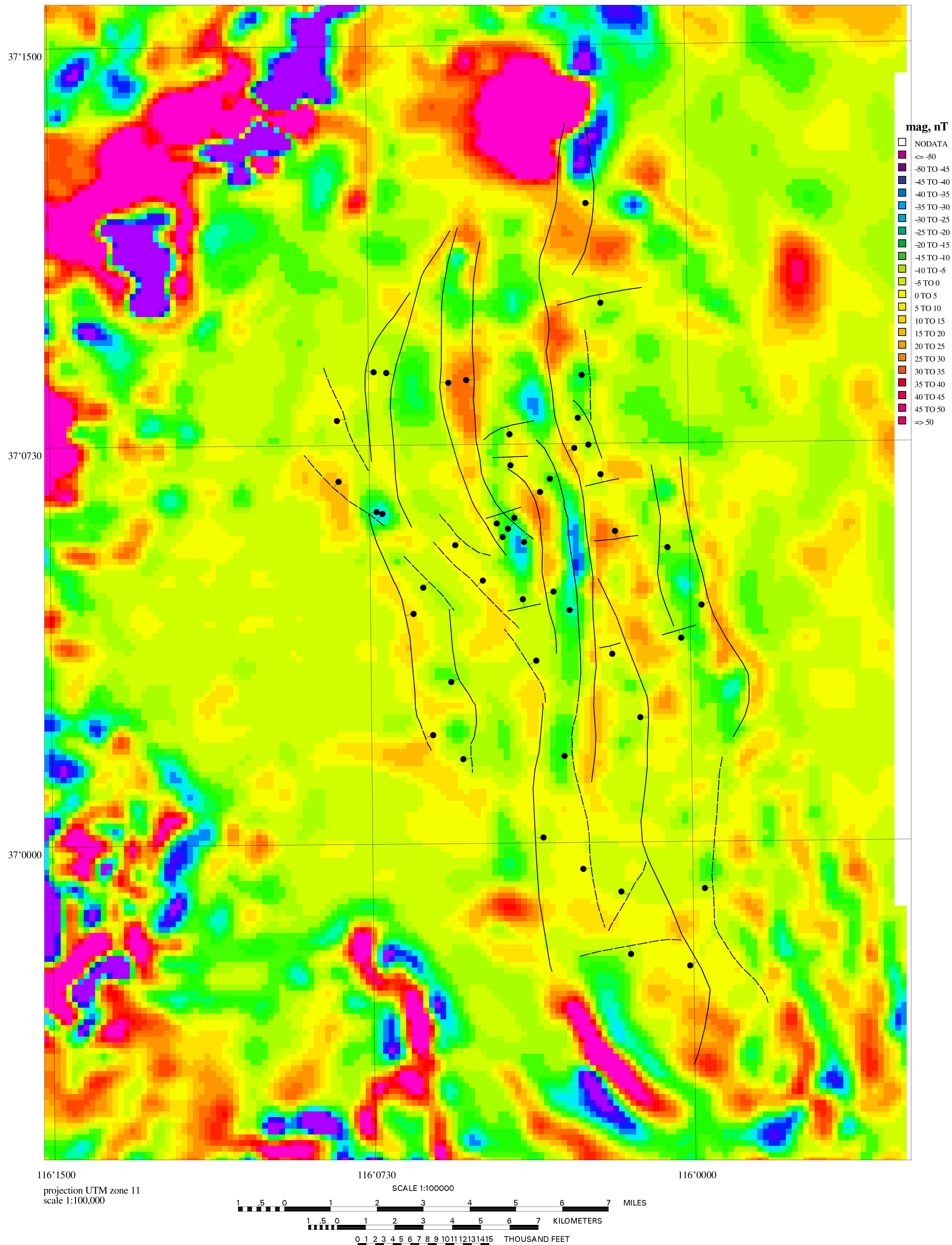

figure 5. Tertiary high-angle faults beneath Yucca Flat shown on magnetic anomaly surface
Black lines, faults (dashed where less certain) with bar & ball on downthrown side