High-angle faults in the basement of Yucca Flat, Nevada Test Site, Nevada, based on analysis of a constrained gravity inversion surface

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ABSTRACT

Using a model of the topographic subsurface derived from drill hole and gravity inversion analysis of the basement rocks in Yucca Flat, Nevada Test Site (NTS), Nevada, a fault map and digital fault dataset were constructed based on offsets of the basement surface. Because these faults are, in large part, not present at the surface, they are interpreted to be inactive faults, older than the alluvial basin fill.

INTRODUCTION

The Environmental Restoration Program of the Department of Energy was developed to investigate the possible consequences to the environment of nearly 40 years of nuclear testing on the NTS. 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 NTS.

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, samples, and less direct geophysical methods such as potential field studies.

In a previous study, Phelps and others (1999) developed an elevation model of the basement surface of the Paleozoic rocks beneath Yucca Flat (hereafter referred to as the Pz surface), based on gravity and well hole information. Offsets of this surface which form topographic relief are presumed to be caused by high-angle faults displacing the Paleozoic rocks. By examining the basement surface slope, faults are inferred in areas of steep linear topographic features. The faults are included in a spatial dataset that accompanies this report (see Appendix). This interim report establishes faults that offset the Pz surface beneath Yucca Flat as part of a study to define the Paleozoic framework of Yucca Flat.

ACKNOWLEDGEMENTS

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METHOD

All topographic features showing significant vertical offset on the Pz surface were interpreted as faults. The interpretation forms the basis for this report, and it takes advantage of the fact that a gravity analysis is sensitive to vertical changes in density. As the angle of the contact of the density contrast between two rock bodies decreases the resulting gravity signal becomes broader and more shallow, and less definable. Moderate and shallowly dipping contacts of rocks of differing densities are essentially “invisible” to gravity analyses, and would not produce significant features in the Pz surface. Topographic offsets in the Pz surface are therefore interpreted as high-angle faults. Most of these topographic features, or faults, bound ridges or depressions that give an indication of the sense of offset. Four perspectives were used to examine the topographic offsets and determine which ones were significant: (1) color-contoured plan view, (2) profiles or cross-sections, (3) three-dimensional perspective views, and (4) points on the topographic surface that locally define its maximum slope ("max-spots").

Using visual selection from the color-contoured surface, linear features along areas of steep, apparently down-dropped or uplifted topography, were marked as probable faults. This is equivalent to making faults along closely spaced contours on a contour map, but has the advantage of using the smoother range of depth display created by the color shaded relief map. A contour map, like a histogram, can only display data in discrete intervals and therefore biases the observer by showing only a subset of the data. A color shaded relief map introduces bias via sun angle and color gradations, but displays elevation values across a continuous range better than a contour map. Figure 1 shows the color shaded relief map of the Pz surface and overlays the results of our final fault interpretation (the preliminary interpretations are not shown).

To minimize any bias introduced by the shading sun angle and color scheme the plan view perspective of the Pz surface offsets was checked by profiles across the surface which highlight the topographic highs and lows (fig. 2). Areas of steep slopes and down-dropped topography were marked as locations of probable faults. The linear features selected from the contoured plan view were compared with these picks and modified accordingly. The faults in the updated interpretation were separated into two categories, certain and approximately located, based on the slope and how continuous the features appeared from one profile to the next.

To create the three-dimensional views the model surface, a raster dataset, was brought into "Earthvision" (Dynamic Graphics, Inc.), a proprietary three-dimensional visualization and analysis software package. The surface was viewed from many angles (fig. 3) to explore the most prominent features and compare with the plan view and profile evaluations. Faults were again modified accordingly.

As an independent check of the three previous visualization methods for defining faults, the max-spots of the Pz surface were calculated and plotted on the colored plan view. The max-spots algorithm is designed to find the maximum horizontal gradient in any direction. This is used to determine the cells of maximum slope. Linear features show as points that line up along a continuous maximum slope. Traditionally max-spots are used to find slope maximums on a potential field surface such as gravity, where a change in density is marked by an inflection point on the surface. In the case of Yucca Flat, the Pz surface, itself a model topographic surface rather than a potential field surface, was used because it contains more information than the gravity surface on which it was, in part, based. The Pz surface has its topography based not only on extensive gravity coverage, but also on the 179 drill holes that reached the Paleozoic surface. These drill holes constrain and significantly alter the resultant topographic surface, and thus the Pz surface shows features the gravity surface does not. We chose to examine the max-spots of the model topographic surface. The max-spots (fig. 4) give a neutral perspective of the alignment of dipping linear features which agree to a first approximation with the linear features (faults) chosen by color contour plan view, profile evaluation, and 3D evaluation. Note that when examining the max-spots, the slopes returned by the max-spots are the slope of the Pz surface at that point and are not necessarily indicative of the slope of a fault at that point. The Pz surface is a smoothed dataset based primarily on gravity and constrained by point data from drill holes, so though local extrema on the Pz surface will occur at the same location as true topography, the slope values will not necessarily be of the same magnitude.

DISCUSSION

The model Paleozoic surface beneath Yucca Flat is reproduced as a derivative product of the isostatic gravity surface, itself a derivative product. Caution must be used, therefore, when interpreting morphological features on this surface. Pits and spikes in the dataset, which in this interpretation occur at single sample locations as features on the order of up to 300m in diameter, are common in gravity datasets. The authors assume these features are the result of errors in data collection or reduction rather than abrupt changes in the gravitational field. The authors chose linear features greater than two km in length as significant. This length is ten times the resolution of the Pz surface model (which has a 200m data point spacing) and was judged to be sufficiently large to eliminate spurious features.

Previous work by Cole and others (1997) interprets faults on an earlier model of the Paleozoic basement surface. They assume N-S trending offsets in basement topography are faults. Our model differs from theirs by considering all vertical offsets as faults regardless of direction, and uses a more recent interpretation of the depth to Paleozoic basement.

Three major linear trends are apparent in the fault interpretation. The first is N-S trending horst and graben topography 5 km or more in length (Healy, 1968; Cole, 1997). The second is NW-SE trending horst and graben topography typically 2-3 km in length. The third is variable length short faults that offset both features. All the features are interpreted as high-angle extensional faults.

Of the features delineated, only the Yucca fault and the Carpetbag fault are seen at the surface, and they do not have vertical offsets which approach the vertical offsets apparently seen in the subsurface (200 – 400m for the Yucca fault and hundreds of meters for the Carpetbag fault). This indicates that the main faults seen by offset of the Pz surface beneath Yucca Flat pre-date the alluvial filling of Yucca Flat, and that structure in the basement surface is not necessarily reflected at the surface of Yucca Flat. The basement faulting is probably related to late Tertiary extension of this part of the Basin and Range province.

CONCLUSION

Major extensional faults can be inferred from a gravity-inversion model of the Paleozoic surface topography beneath Yucca Flat. The faults were delineated using several different perspectives of the model surface. These faults do not appreciably offset the surface topography and therefore are likely to have been formed during the Neogene extensional period that formed the Yucca Flat basin.

FUTURE WORK

Future work should include a comprehensive analysis of the accuracy of the Pz surface and subsequent interpretations based on it. The interpreted faults should also be compared to the magnetic data to help constrain the age relationships by examining offsets in the subsurface magnetic volcanic units beneath Yucca Flat. The interpreted faults could then be compared to the known structural history of the area.

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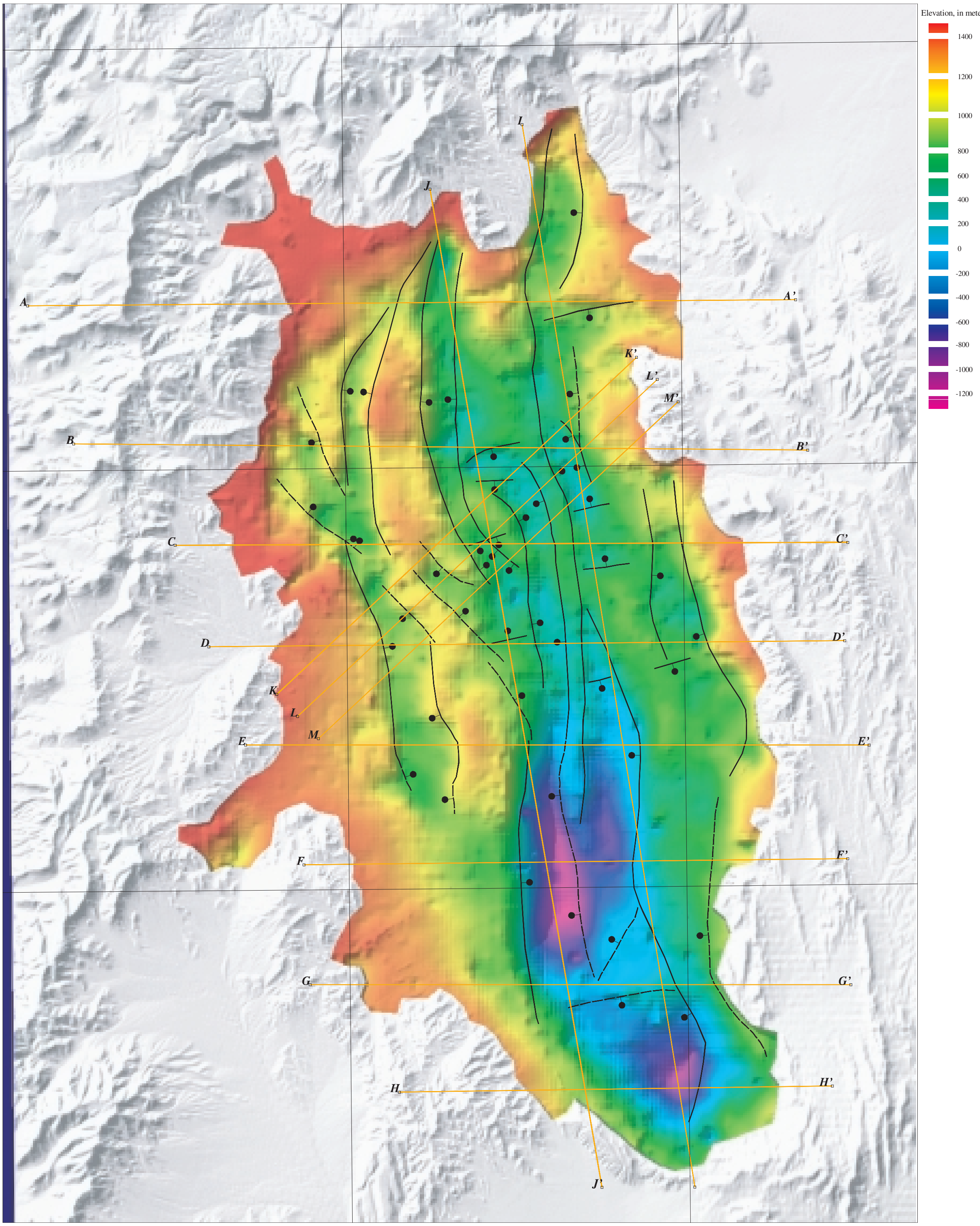

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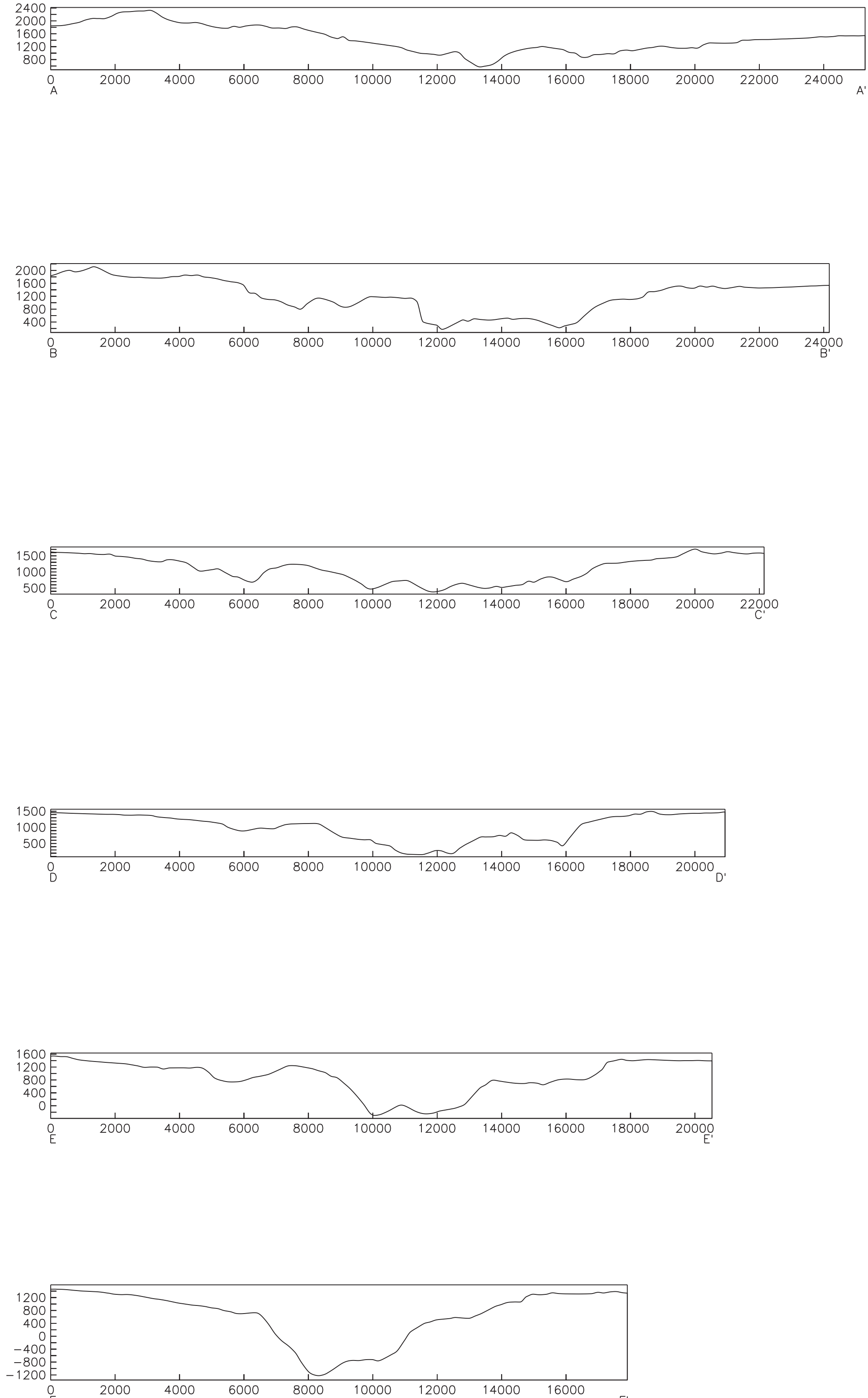
Figure 1. Tertiary high-angle faults beneath Yucca Flat based on the Pz surface.
Black lines, faults (dashed where less certain) with bar & ball on downthrown side.
Orange lines, cross-section lines



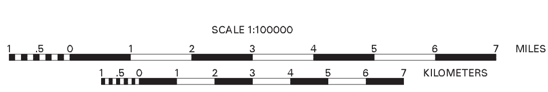
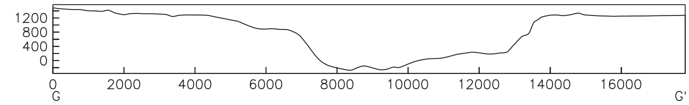
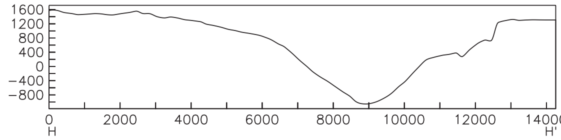


Figure 2a. Cross-sections A - F across the Pz surface beneath Yucca Flat derived from isostatic gravity inversion





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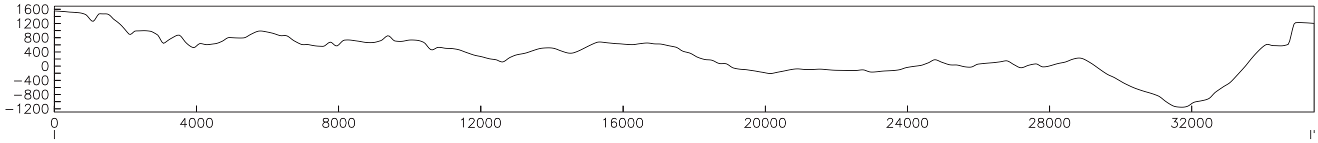

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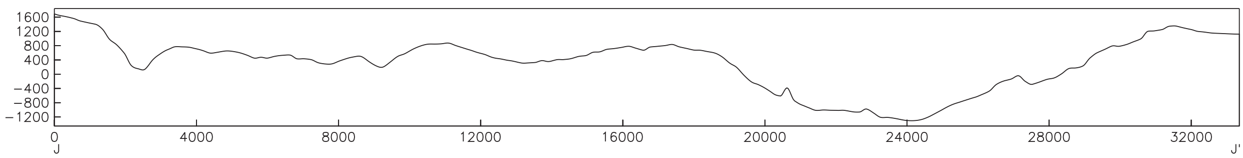

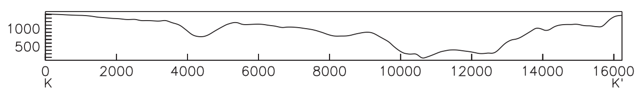

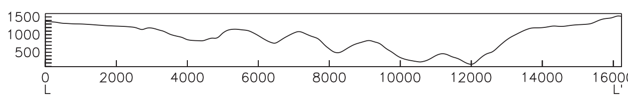

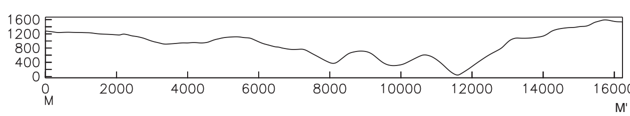

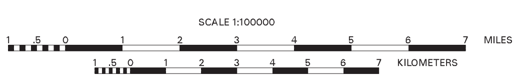

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Figure 2b. Cross-sections G - M across the Pz surface beneath Yucca Flat derived from isostatic gravity inversion

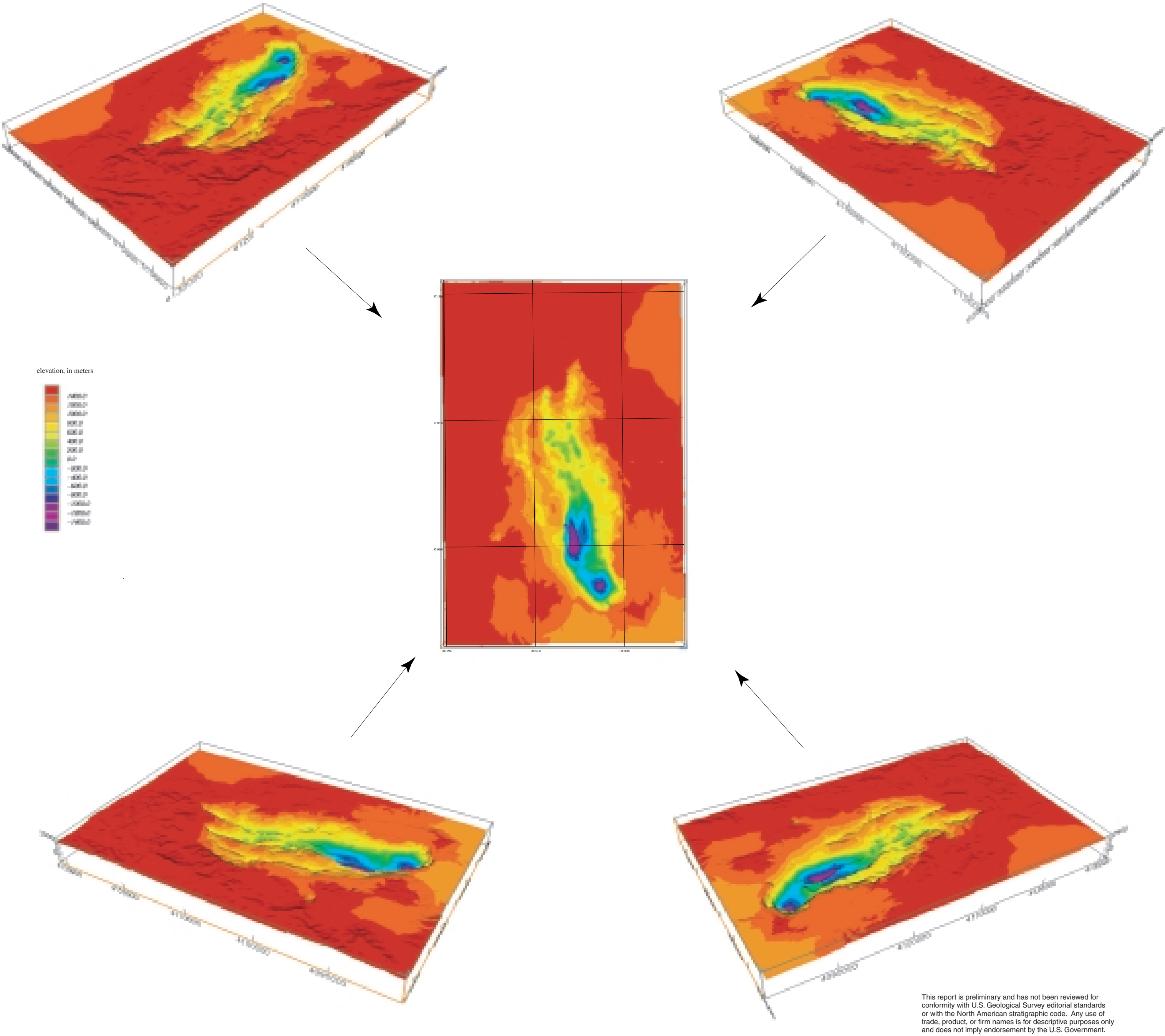
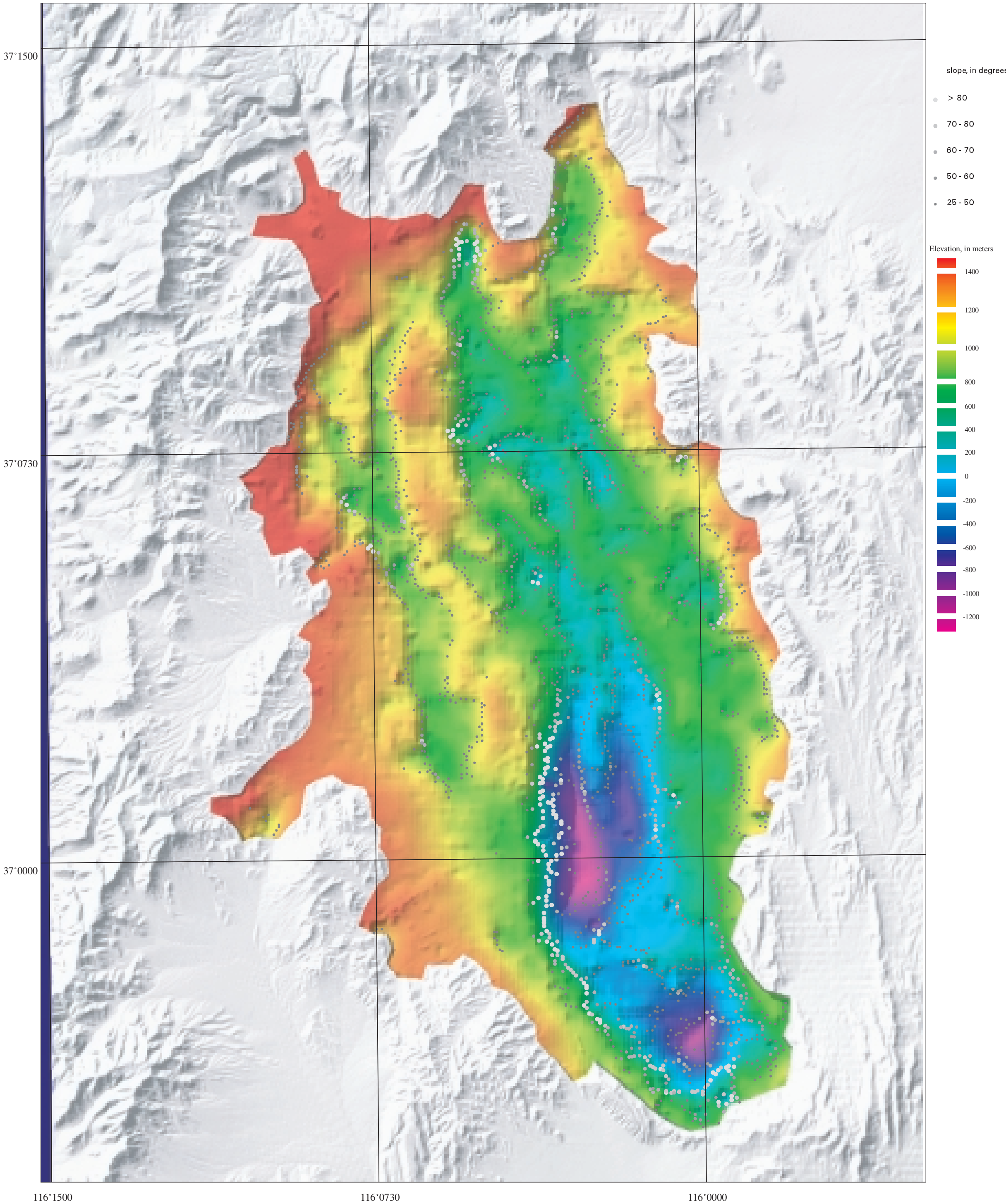


Figure 3. Perspective views of the Pz surface beneath Yucca Flat derived from gravity inversion



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SCALE 1:100000

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0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 THOUSAND FEET

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Figure 4. Location and value of slope for points of maximum horizontal gradient (max-spots) on the PZ surface beneath Yucca Flat.

APPENDIX

The digital data is available from the following URL: http://geopubs.wr.usgs.gov/open-file/of99-383/ Digital release date 11/17/99

DATA CONTENTS

The digital dataset consists of one file: lines representing major extensional faults in the Paleozoic surface topography beneath Yucca Flat.

The file is an ASCII data file, created by the Arc/Info (Environmental Systems Research Institute, inc.) UNGENERATE command, with the vertices for each line bracketed by the line ID and the key word END. There are two types of information stored in the ASCII file in addition to the location of the lines, which represent faults. The first is the line ID, which distinguishes between certain and approximately located faults. Faults that are certain are coded with ID numbers below 100, and faults that are approximately located are coded with ID numbers above 100. The ID numbers are arbitrary within these groupings. The second type of information stored in the ASCII file is line direction. The lines are stored as vectors, which have a starting point and an ending point. The lines represent normal faults, which have an up-thrown and a down-thrown side. The lines are coded using a right-hand rule: that is, if one were to stand on the line near where it begins and face along the line towards the end, the down-thrown side (where the bar-and-ball symbol would be on a geologic map representation) is on the right, and the up-thrown side is on the left.

faults.asc ASCII data file of the major extensional faults in the Paleozoic surface topography beneath Yucca Flat, coded as follows:

```
id, longitude,latitude
   longitude,latitude
   longitude,latitude
   longitude,latitude
   etc.
END
id, longitude,latitude
etc.
```

The longitude and latitude are in projected coordinates and represent the vertices of the line. The end of each line is defined by the word END. The projection for the coordinates is:

UTM meters, zone 11, NAD27, Clarke 1866 spheroid