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by

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Three-dimensional model of pre-Cenozoic basement beneath Amargosa Desert and Pahrump Valley, California and Nevada: Implications for tectonic evolution and water-resources

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ABSTRACT

A three-dimensional inversion of gravity data from the Amargosa Desert and Pahrump Valley reveals a topographically complex pre-Cenozoic basement surface concealed by younger sedimentary and volcanic deposits. The Amargosa Desert is underlain by a deep, steep-sided trough extending from the southwest Nevada volcanic complex to the Nevada-California state line. The linear margins of the Amargosa Desert trough and its internal topography suggest that it formed as a series of transtensional basins that transferred strain between right-stepping, northwest-striking, right-lateral, strike-slip faults. Pahrump Valley is underlain by two deep, steep-sided sub-basins separated by a narrow basement ridge aligned parallel to the state line. The Pahrump Valley sub-basins also formed as transtensional pull-apart basins, accommodated in part by displacement along the northwest-striking State Line fault zone. The state-line ridge at Pahrump Valley is on strike with a narrow basement ridge beneath Ash Meadows, also lying along the state line and within the State Line fault zone. Both ridges are associated with late Cenozoic faulting. The ridges may have formed as transpressional structures, caught slightly askew of the northwest-directed strain that formed the sub-basins. Carbonate rocks probably compose the basement beneath most of the Amargosa Desert and Pahrump Valley. Because carbonate rocks are important aquifers in this region, the three-dimensional aspects of the concealed basement surface strongly influence ground-water flow paths and transport rates. For example, the deeper parts of the Amargosa Desert trough, or faults that bound the western margin of the trough, may impede the westward flow of ground water through the carbonate aquifer. If so, the gravity analysis predicts that water discharging at Ash Meadows originates entirely from the carbonate flow path north and northeast of Ash Meadows, whereas water discharging at Furnace Creek originates from the volcanic flow path north and northwest of Furnace Creek.

INTRODUCTION

Gravity anomalies over the Basin and Range geologic province reflect to first order the sharp contrast between high-density pre-Cenozoic rocks exposed in many of the mountain ranges and low-density, unconsolidated to slightly lithified materials that fill the structural basins. From gravity measurements taken at the ground surface, we can use this density contrast to infer certain characteristics about the underlying pre-Cenozoic rocks, even where these rocks are concealed beneath younger deposits. Specifically, we can estimate the three-dimensional shape of the interface between dense basement rocks and overlying deposits. In many parts of the Basin and Range, this interface, referred to here as the *basement surface*, corresponds to the contact between pre-Cenozoic rocks and younger deposits.

In this paper, we provide an analysis of gravity measurements from the Amargosa Desert and surrounding regions of California and Nevada. The flat expanses of the basins in this area belie a complex basement surface, which in turn reflects the complex tectonic evolution of this part of the Basin and Range province. Because much of the basement is composed of carbonate rocks, presumed to be the principal aquifer lithology in this region, a three-dimensional view of the basement surface provides important clues about ground-water flow and water resources of this arid region.

GEOLOGIC AND TECTONIC SETTING

The study area (Figure 1) lies within the southern Basin and Range geologic province and includes the towns of Beatty, Amargosa Valley, and Pahrump in Nevada, and Furnace Creek, Death Valley Junction, and Shoshone in California. The area is centered about the Amargosa Desert and Pahrump Valley. These broad, relatively flat basins are surrounded by mountain ranges, including the Funeral Range, Bare Mountain, Specter Range, Spring Mountains, Resting Springs Range, Nopah Range, and Greenwater Range.

Most of the ranges in the study area are composed of pre-Cenozoic rocks of diverse age and lithology (Figure 2). Paleozoic carbonate rocks (limestone and dolomite) are exposed in the Spring Mountains, Specter Range, and other ranges, and probably underlie most of the alluvial basins. Carbonate rocks are believed to be the most important aquifers of this part of the Basin and Range (Winograd and Thordarson, 1975; Dettinger, 1989; Laczniak and others, 1996; McKee, 1997).

Several authors (e.g., Stewart, 1983; Wernicke and others, 1988; Hamilton, 1988) have concluded that large crustal extensions during the last 15 m.y. were accommodated on regionally continuous detachment surfaces lying beneath most of this region. Rocks of the upper plate, above the detachment surface, are characterized as permeable, brittle, and fractured carbonate rocks (McKee, 1997). Rocks of the lower plate, on the other hand, are highly metamorphosed, ductilely deformed, and could act as impediments to the flow of ground water (McKee, 1997). The detachment surface crops out in the Funeral Range and at Bare Mountain, exposing Proterozoic lower-plate siliceous rocks formerly buried to middle crustal depths (Hamilton, 1988).

The basins that separate the mountain ranges are filled with non-marine sedimentary and volcanic rocks, Oligocene and younger in age. These include fluvial conglomerate, sandstone, siltstone, lacustrine claystone and limestone, volcanic ash deposits of various types, and local lava flows. These unconsolidated to weakly lithified alluvial deposits have significantly lower densities on average than the pre-Cenozoic rocks that form the neighboring mountain ranges.

Tertiary volcanism was also important in the evolution of the southern Basin and Range, especially the formation of large collapse calderas. Thick Tertiary volcanic sections of the southwest Nevada volcanic complex extend from the north into the northern and northwestern parts of the study area (Figure 2). Volcanic rocks also dominate the landscape at Brown Peak and the Greenwater Range in the southwestern part of the study area.

GRAVITY INVERSION

Methodology

Figure 3a shows the isostatic residual gravity field of the study area. This map is based on thousands of gravity measurements made by many investigators and organizations during the last several decades (Fig. 3b). Gravity stations are very closely spaced in some parts of the study area, especially near the northern margin because of recent interest in the Nevada Test Site and the proposed nuclear waste disposal site at Yucca Mountain. Stations are more widely spaced elsewhere, especially in the inaccessible parts of the mountain ranges. As part of the present investigation, an additional 530 stations were acquired from Ash Meadows, Pahrump Valley, Amargosa Valley, the Funeral Range, and the Greenwater Range (Morin and Blakely, 1998). These new measurements are incorporated in Figure 3.

To first order, isostatic residual anomalies reflect the sharp contrast between high-density rocks (typically > 2650 kg m^{-3}) that underlie the ranges and low density deposits (typically < 2450 kg m^{-3}) that fill the basins. Large, positive anomalies (>20 mGal) lie over the Funeral Range, Black Mountains, and Spring Mountains, for example, whereas relatively low values are seen over Death Valley, the Amargosa Desert, and Pahrump Valley. The very large negative gravity anomalies (<-30 mGal) at the northern edge of the map are caused by thick, low-density volcanic deposits at the southern margin of the southwest Nevada volcanic complex.

Using the method of Jachens and Moring (1990), we separated isostatic residual anomalies into two components: that caused by basement rocks and that caused by younger basin-filling deposits. In this gravity inversion, the density of basement rocks is allowed to vary horizontally, whereas the density of basin-filling deposits is forced to increase with depth according to specified density-depth relationships (Table 1). Well and seismic information constrains the calculations where available, as discussed below. The method is an iterative approach. A first approximation to basement gravity is derived from gravity stations that lie on exposed pre-Cenozoic rocks. This is only a crude approximation to basement gravity because basement stations also include the gravitational effects of all local basins. Subtracting this initial calculation of basement gravity from observed gravity provides a first approximation to the basin gravity field. This is inverted according to prescribed density-depth functions to produce a first approximation for the thickness of basin-filling deposits. The gravitational effect of these deposits is then computed at each basement station, and the basement station is adjusted accordingly. These steps are repeated in an iterative fashion until changes to basement gravity and deposit thickness are negligible.

These calculations are constrained in places where the depth to Paleozoic basement is known from independent measurements. Various types of information were used in this study, including hydrocarbon-exploration wells (Grow and others, 1994), Department of Energy drill-holes (Ward Hawkins, written communication), water wells from State of Nevada driller's logs, an east-west seismic reflection profile north of Devil's Hole (Brocher and others, 1993), and two seismic reflection profiles in the Crater Flat region (Brocher and others, 1998).

Results

Two products result from the inversion: A map of gravity anomalies caused by basement rocks (Figure 4) and a map reflecting the thickness of basin-filling deposits (Figure 5). Basement gravity anomalies (Figure 4) reflect density variations within the basement section without the effects of overlying, low-density deposits. The largest basement gravity anomaly in the study area is a positive anomaly centered over the northern Funeral Range (Figure 4). Here the detachment fault has ramped upward to expose lower-plate rocks, described by Hamilton (1988) as metamorphosed siliceous Proterozoic rocks. These rocks, formerly buried to middle crustal depths, are metamorphosed, hydrothermally altered, and typically more dense than upper-plate rocks lying elsewhere beneath the basement surface but above the detachment surface. A hand sample from the Funeral Range (latitude 36°38.77'N., longitude 116°43.11'W.) has a grain density of 2820 kg m^{-3}, roughly six to seven percent greater than typical carbonate rocks of the upper plate. Bare Mountain also lies within the Funeral Range gravity high (Figure 4) and exposes lower-plate rocks (Hamilton, 1988); the densities of 75 hand samples from Bare Mountain average 2750 kg m^{-3}. Other positive anomalies in the region may be caused by similar high-density siliceous rocks lying at relatively shallow depth, and such rocks may figure prominently in directing the flow of water through the region.

Subtracting the thickness of basin-filling deposits (Figure 5) from topographic elevations provides a model for the three-dimensional shape of the basement surface (Figure 6). This surface is more complex than might have been predicted from the relatively flat land surface of the basins. The basement surface is relatively flat and shallow around the margins of the basins, but this flat surface is interrupted by numerous deep, steep-sided sub-basins. At Pahrump Valley, for example, the basement surface is generally flat and lies within 200 m below the land surface throughout most of the basin, but this gentle topography is punctuated by two prominent, laterally restricted sub-basins. The sub-basins are separated by a gravity ridge that strikes northwest parallel to and a few kilometers north of the Nevada-California state line. The thickness of deposits exceeds 2 km in the southwestern sub-basin and 5 km in the northeastern sub-basin. Both sub-basins are elongated in the northwest-southeast direction and have exceptionally steep margins, with dips ranging from about 25° along the southwest margin to 65° along the northeast margin, significantly exceeding average slopes of the surrounding mountain ranges. The basement surface, from the summit of the Nopah Range to the bottom of the northeastern Pahrump Valley sub-basin, has greater than 7 km of total relief.

The Amargosa Desert is underlain by a deep, relatively narrow trough extending southward from the southwest Nevada volcanic complex to south of the Nevada-California state line (Figures 5 and 6). Here we refer to this feature as the Amargosa Desert trough. Basin-fill deposits within the trough are exceptionally deep north of latitude 36°40'N., often exceeding 7 km in thickness; this latitude corresponds with the southern extent of the southwest Nevada volcanic complex (Figure 2). South of latitude 36°40'N., basin-fill is typically less than 3.5 km thick. A basement ridge crosses the Amargosa Desert trough parallel to and slightly north of the state line, approximately on strike with the basement ridge beneath Pahrump Valley. Like the sub-basins in Pahrump Valley, the eastern and western margins of the Amargosa Desert trough have generally linear, steep-sided boundaries, suggestive of tectonic origins. The linear western margin of the trough south of the state-line ridge (passing just west of Death Valley Junction), for example dips at about 50°, and the linear eastern margin just north of the state-line ridge (lying west of Devil's Hole) dips at about 40°.

It is important to understand the limitations of the gravity inversion and the data on which it is based. Errors can occur because of the simplifying assumptions of the basin-basement model and because of scarcity of data in some locations. Moreover, basement topography and basement gravity are calculated at regular intervals on a rectangular grid, with grid values spaced 0.25 km apart in both north-south and east-west directions. This grid spacing establishes the limiting resolution of the method. Although the shapes and relative depths of the basins yielded by this method are generally reliable, the calculated thicknesses of basin-filling deposits depend critically on the density depth function used in the inversion. Densities of basin-fill deposits below a few kilometers are poorly understood, and the details of the deeper parts of the basins should be viewed accordingly. Finally, basin depths may be in error because of a lack of understanding of the basement gravity field. For example, a low-density pluton directly underlying a basin may be incorrectly interpreted by the calculation as extra accumulations of low-density deposits in the basin. This last problem may be of special concern north of latitude 36°40'N., where volcanic deposits are prevalent.

DISCUSSION

Tectonic evolution

The deep and steep-sided sub-basins beneath the Amargosa Desert and Pahrump Valley reflect the extensional evolution of the Basin and Range province during late Tertiary and Quaternary time. The linear and segmented nature of the margins and internal topography of the Amargosa Desert trough and Pahrump Valley suggests that faulting must have been important in their evolution.

The State Line fault zone, also referred to as the State Line fault (Hewett, 1956), Pahrump Valley fault zone (Wright and others, 1981; Hoffard, 1991; Louie and others, in press), Amargosa River fault zone (Donovan, 1991), and Amargosa fault zone (Schweickert and Lahren, 1997), figures prominently in this evolution. This regionally extensive, right-lateral, strike-slip fault zone, part of the Walker Lane belt (Stewart, 1988), lies more-or-less parallel to the Nevada-California state line. As a topographic feature, the State Line fault zone extends northwest from Ivanpah Valley (immediately southeast of the study area), through Mesquite Valley and Ash Meadows, and may continue along the northeastern range front of the Funeral Range, a total distance greater than 175 km (Figures 5 and 6). Shields and others (1998) and Louie and others (in press) have suggested that the State Line fault may have a potential rupture length of 50 to 150 km and constitutes a significant seismic hazard for the city of Las Vegas and surrounding communities.

Wright (1988) proposed that the sub-basins beneath Pahrump Valley and Ash Meadows are pull-apart structures, transtensional structures caused by right steps in the State Line fault zone (Figure 7). Following Wright (1988), we suggest that the entire Amargosa Desert trough evolved as a complex system of transtensional basins transferring strain between en echelon, northwest-striking, right-lateral, strike-slip faults, as schematically illustrated in Figure 8. The State Line fault zone was one strike-slip element of this evolution.

This interpretation may seem at odds with the geographic positions of the sub-basins at Pahrump Valley and Ash Meadows, which are situated in a left-lateral sense with respect to the State Line fault zone. However, the geographic positions of pull-apart basins are determined primarily by the location of the original extensional structures, as shown in Figure 7, and it is quite possible to generate sub-basins that are geographically offset in an opposite sense with respect to the strike-slip displacement.

Narrow, northwest-striking ridges are seen on the basement surface at both Pahrump Valley and Ash Meadows. These ridges lie parallel to the state line and are clearly associated with Quaternary faulting and the location of lineaments in the overlying alluvium, as demonstrated by Figures 9 and 10. This association is particularly clear at Pahrump Valley (Hoffard, 1991), where individual fault strands and lineaments are mapped directly along each side of the state-line ridge.

The state-line ridges at Ash Meadows and Pahrump Valley are very nearly on strike with each other and lie within the State Line fault zone (Wright, 1988; Blakely and others, 1998). The overall strike of the fault zone is roughly parallel to the state line, very nearly 45°W, whereas both ridges have slightly more westerly trends. We believe the state-line ridges interpreted from gravity anomalies represent compressional features in the pre-Cenozoic basement, either anticlinal folds or horsts bounded by reverse faults. The compression may have resulted from slightly more westerly orientations of intermediate faults within the State Line fault zone, as described by the caption to Figure 7.

Water Resources

Carbonate rocks are believed to be the principal aquifers beneath the Amargosa Desert and surrounding regions (Winograd and Thordarson, 1975; Laczniak and others, 1996; Dettinger, 1989; McKee, 1997). The basement surface shown in Figures 5 and 6 presumably corresponds to the upper surface of carbonate rocks, and the shape of this surface should be important in understanding the flow of ground water through the region. Two elements from the gravity analysis are important in this regard. The first comes from the basement gravity field (Figure 4), which indicates areas of anomalously high density in the upper crust. The largest anomaly in the basement gravity field is caused by high-density, Proterozoic rocks exposed in the Funeral Range, described by Hamilton (1988) as metamorphosed siliceous rocks that have been elevated from mid-crustal depths. Positive anomalies elsewhere may indicate similar high-density rocks near the land surface, and such rocks could impede the flow of ground water (Winograd and Thordarson, 1975; Laczniak and others, 1996; Dettinger, 1989).

The second element comes from the thickness of low-density basin-filling deposits (Figure 5). Basin fill can act as either an aquifer or an aquitard, depending on the degree of compaction, sorting, and clay content (e.g., Dettinger, 1989). Because the degree of compaction increases with sediment thickness and because fine sediments (clay) tend to concentrate within the basin axis, we assume that the deepest parts of the Cenozoic basins are impediments to the flow of ground water. This assumption is supported by exploratory drilling of tracer wells near Devil's Hole (Johnston, 1968), which found a significant permeability contrast between Paleozoic carbonate rocks (9,300 mD for Dolomite) and overlying alluvium (1 to 440 mD). Johnston (1968) concluded that these measured permeabilities provide a lower limit to the overall permeability contrast; the carbonate aquifer beneath the Amargosa Desert probably has a permeability two to four orders of magnitude greater than overlying alluvium (Johnston, 1968).

Figure 11 shows areas of dense basement rocks and deep basin-fill predicted by the gravity interpretations (Figures 4 and 5, respectively). Deep basins are so designated on Figure 11 because they are large in contiguous area and have >600 m of basin-fill deposits. Basins of relatively small areal size, such as the one north of Devil's Hole, are not designated on Figure 11, although they probably do affect water flow. Considering these regions to be impediments to the flow of ground water, we can offer suggestions as to how ground water might move through the subsurface. The Death Valley ground water flow system consists of two paths, both flowing into the study area from the north (Winograd and Thordarson, 1975; Laczniak and others, 1996). An eastern path originates in a system of carbonate aquifers north and east of the study area, and a western path originates in Tertiary volcanic rocks north and northwest of the study area. The eastern flow path is recharged by precipitation in the Spring Mountains and other high mountain ranges of the area.

If the Amargosa Desert trough acts as a barrier to ground water, most water discharging at Ash Meadows originates from the northeastern, carbonate-rock flow path, with no or very little ground water coming from the western volcanic flow path (Figure 11). On the other hand, most ground water entering central Death Valley through and around the Funeral Range apparently originates from the western volcanic flow path.

Major springs in the area appear spatially associated with the state-line ridges and the deep sub-basins at Ash Meadows and Pahrump Valley, but the association is somewhat different at the two locales (Figure 11). At Ash Meadows, water discharges in a north-south alignment of springs along the eastern margin of the Amargosa Desert trough, near the intersection of the state-line ridge and the margin of the trough. The alignment of springs implies that the Amargosa Desert trough is acting as a barrier to the westward flow of water, caused either by the marked permeability contrast between Paleozoic carbonate basement and overlying Cenozoic alluvium or by one or more north-south faults that presumably bound the trough margin. In either case, water flowing westward toward the trough at depths shallower than the depth of the Amargosa Desert trough (approximately 3 km) would encounter a flow barrier at the trough margin. Apparently this barrier moves westward flowing water to the surface, where it discharges along the north-south alignment.

At Pahrump Valley, water discharges along the northeastern margin of the state-line ridge itself. The basement ridges are presumably composed of carbonate rocks and therefore could serve as conduits for ground water moving northwest-southeast. Perhaps the basement ridge at Pahrump Valley acts like a leaky pipe; water flowing freely northwest-southeast within the ridge is very near the topographic surface relative to water beneath the deep sub-basins, and this may promote the rise of water to the surface where it discharges at springs lying parallel to the ridge (Figure 11). More likely, reverse faults that bound the northeastern and southwestern margins of the ridge act as barriers to ground-water flow. Water reaching the basement ridge from the north and east may be shunted to the surface. The clear association of Pahrump Valley springs and the northeastern margin of the state-line ridge argues for this interpretation. On this basis, we would predict that water is more abundant along the northern margin of the state-line ridges than elsewhere in Pahrump Valley.

CONCLUSIONS

Geophysical methods help define in three-dimensions the subsurface structure beneath the Amargosa Desert and Pahrump Valley. The vast flat expanse of the basins belie a much more complex basement topography. Some of this topographic expression is related to tectonism, active at least as recently as Quaternary time. We believe that several of the sub basins are extensional features that have developed between right-stepping, north-west-striking, dextral fault zones. The basement surface in most places reflects the top of the carbonate-rock aquifer, and the shape of this surface must figure prominently in the hydrologic framework of the region.

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Table 1. Density-depth functions used to determine thickness of basin-filling deposits.

Depth Range (m)	Density contrast with basement rocks (kg m^{-3})	
	Sedimentary section	Volcanic section
0–200	–650	–450
200–600	–550	–400
600–1,200	–350	–350
>1,200	–250	–250

FIGURE CAPTIONS

Figure 1.— Physiography of the study area. Rectangular boundaries indicate map areas shown on Figures 9 and 10, respectively.

Figure 2.— Generalized geologic map, simplified from statewide compilations of California (Jennings, 1977) and Nevada (Stewart and Carlson, 1978).

Figure 3.— (a) Isostatic residual gravity anomalies of the Amargosa Desert, Pahrump Valley, and surrounding areas. Line contour interval 5 mGal; gray-shade contour interval 10 mGal. Positive and negative anomalies reflect to first order the average density of middle and upper crustal rocks. (b) Location of gravity stations. Black triangles are existing stations from a variety of sources. White triangles are stations acquired as part of this study (Morin and Blakely, 1998).

Figure 4.— Gravity anomalies caused by basement rocks, without the effect of low-density sedimentary and volcanic deposits, as derived from inversion of gravity measurements and constrained by available well and seismic-reflection information. Line contour interval 5 mGal; gray-shade contour interval 10 mGal.

Figure 5.—Thickness of low-density, basin-filling deposits, derived by inversion of gravity measurements and constrained by available well and seismic-reflection information. Color-contours represent thickness of deposits, with contour interval 200 m. Stipple pattern indicates exposed pre-Cenozoic rocks, as taken from Figure 2.

Figure 6.— Three-dimensional view of the pre-Cenozoic basement beneath Amargosa Desert and Pahrump Valley. (a) Topographic surface. (b) Basement surface. View is to north, with no vertical exaggeration. Arrows indicate the State Line fault zone as expressed in the topography of the basement surface.

Figure 7.— A model for the formation of basement ridges at Pahrump Valley and Ash Meadows. The sub-basins are extensional depressions caused by step-overs in the State Line fault zone. The relative position of the two basins (displaced left-laterally in this case) is determined by the relative position of the original extensional deformation (dashed lines) and do not necessarily reflect the sense of strike-slip displacement (right-lateral). The central strike-slip fault (flags B and C') would become a transpressional structure if it rotated slightly counterclockwise from the orientation shown.

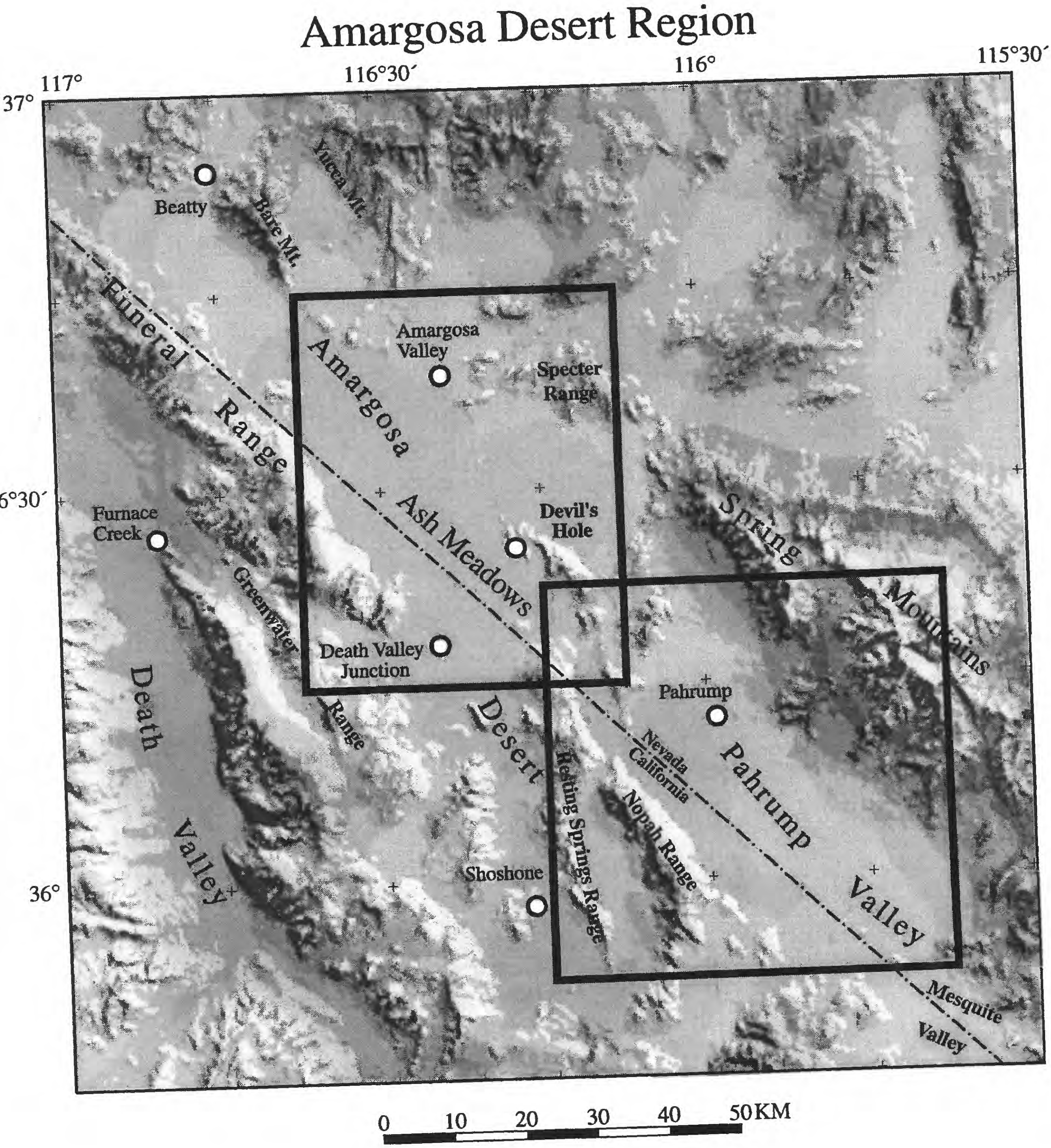
Figure 8.— An interpretation of the origin of the Amargosa Desert trough. Normal, extensional faults trending generally north-south (bold gray lines) have transferred strain from northwest-trending, right-lateral, strike-slip faults (bold black lines).

The resulting extension has developed a series of pull-apart basins that form the Amargosa Desert trough. Near Devil's Hole and Pahrump, the strike-slip faults are oriented slightly west of the maximum horizontal stress direction, creating a transpressive zone along the faults and consequent uplift of the state-line ridges. Earthquake epicenters from the Council of the National Seismic System (http://www.cnss.org).

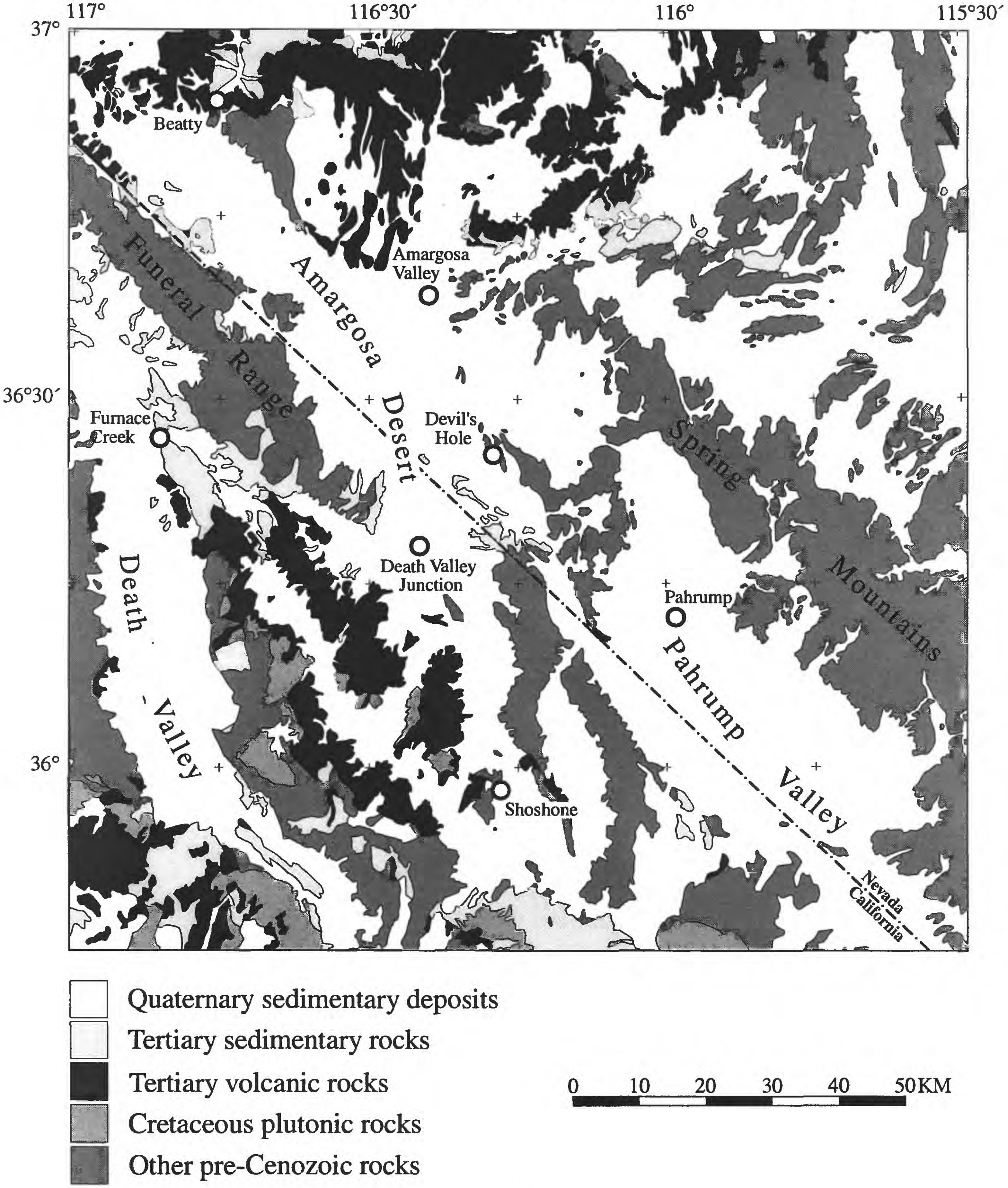
Figure 9.— Thickness of basin-filling deposits at Pahrump Valley. Contours at 200, 500, 1000, 1500, 2000, and 2500 m. Stipple pattern indicates exposures of pre-Cenozoic rocks, as taken from Figure 2. Bold white lines show Quaternary faults and lineaments as mapped by Hoffard (1991), Reheis (1992), and McKittrick (1988).

Figure 10.— Thickness of basin-filling deposits at Ash Meadows. Same contour intervals as Figure 9. Stipple pattern indicates exposures of pre-Cenozoic rocks, as taken from Figure 2. Bold white lines indicate Quaternary faults and lineaments as mapped by Donovan (1991), Hoffard (1991), and McKittrick (1988).

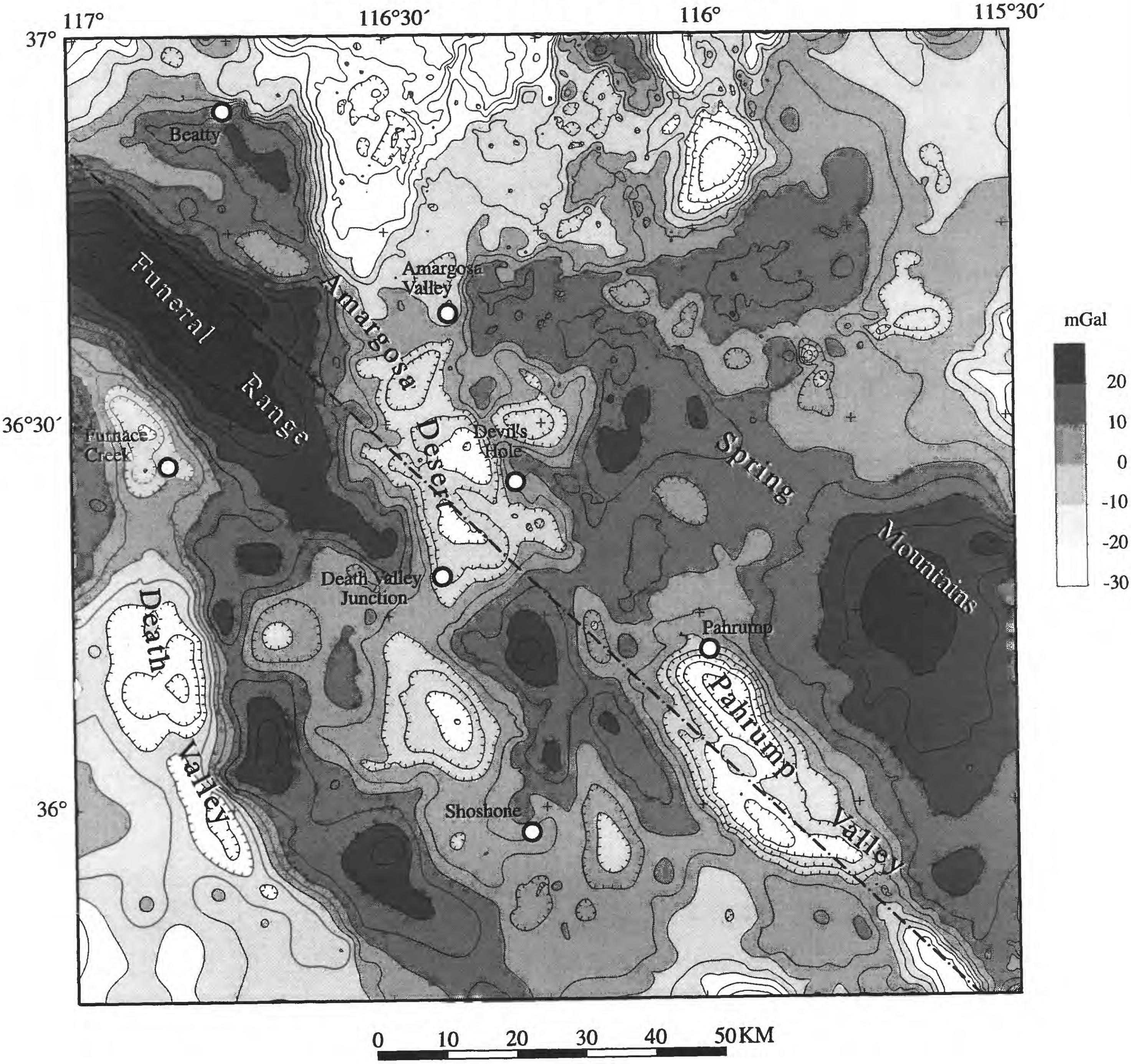
Figure 11.— A model for the flow of water in the Amargosa Desert area. Cross-hatch patterns indicate features interpreted from the gravity inversion: positive anomalies in the basement gravity field, presumed to be caused by anomalously high-density rocks, and thick sequences of Cenozoic deposits. Arrows indicate the general flow of ground water, assuming that high-density rocks and deep Cenozoic basins impede the flow of water. State-line ridges are shown by black-dotted areas. White dots indicate the location of springs.


Amargosa Desert Region
117°
116°30′
116°
115°30′
37°
36°30′
36°
Beatty
Bare Mt.
Yucca Mt.
Funeral
Range
Amargosa
Valley
Specter
Range
Amargosa
Ash Meadows
Devil's
Hole
Furnace
Creek
Greenwater
Range
Death Valley
Junction
Spring
Mountains
Pahrump
Death
Valley
Desert
Resting Springs Range
Nevada
California
Nopah Range
Pahrump
Valley
Shoshone
Mesquite
Valley
0 10 20 30 40 50KM

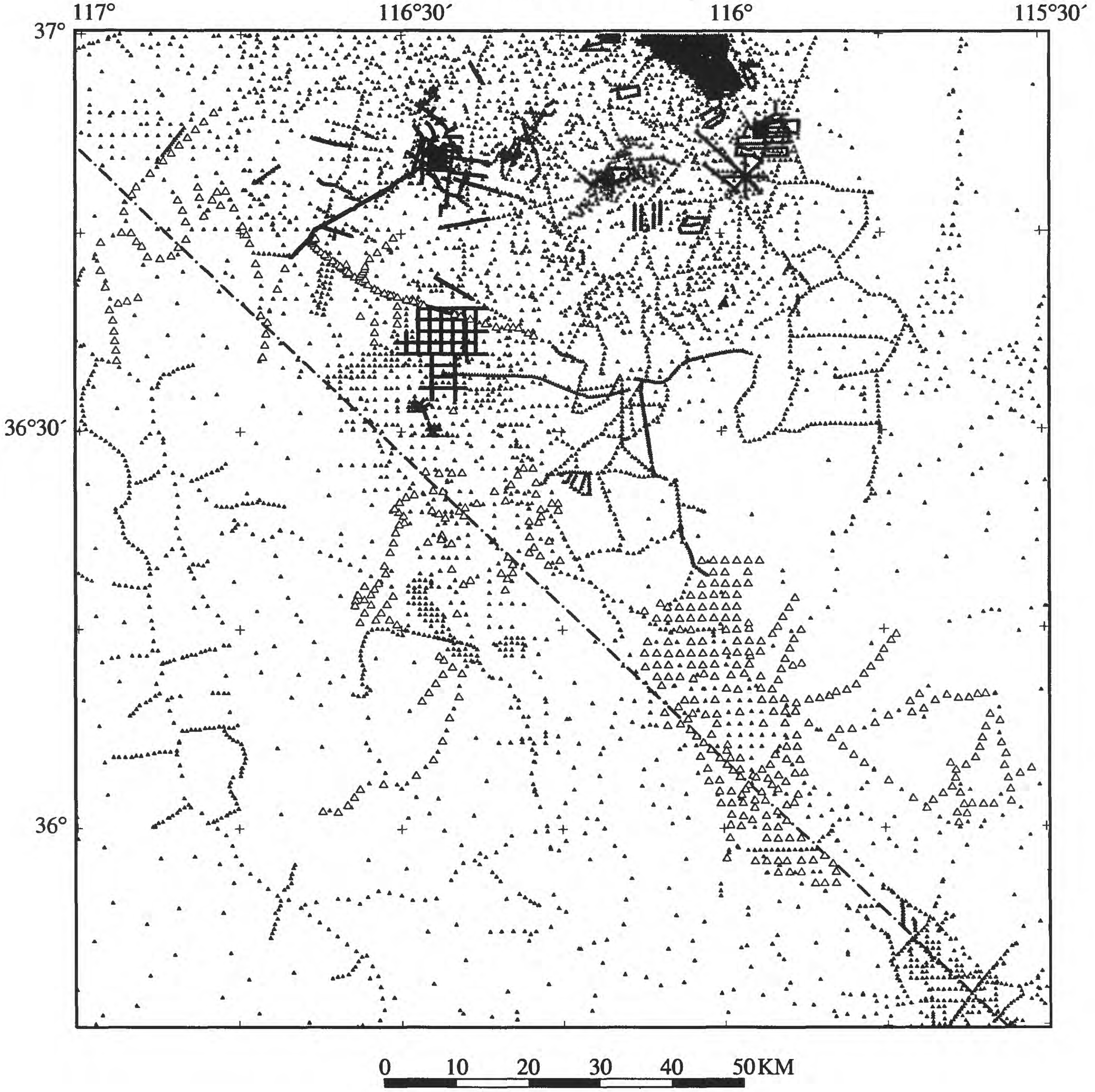
Generalized Geology, Amargosa Desert Region



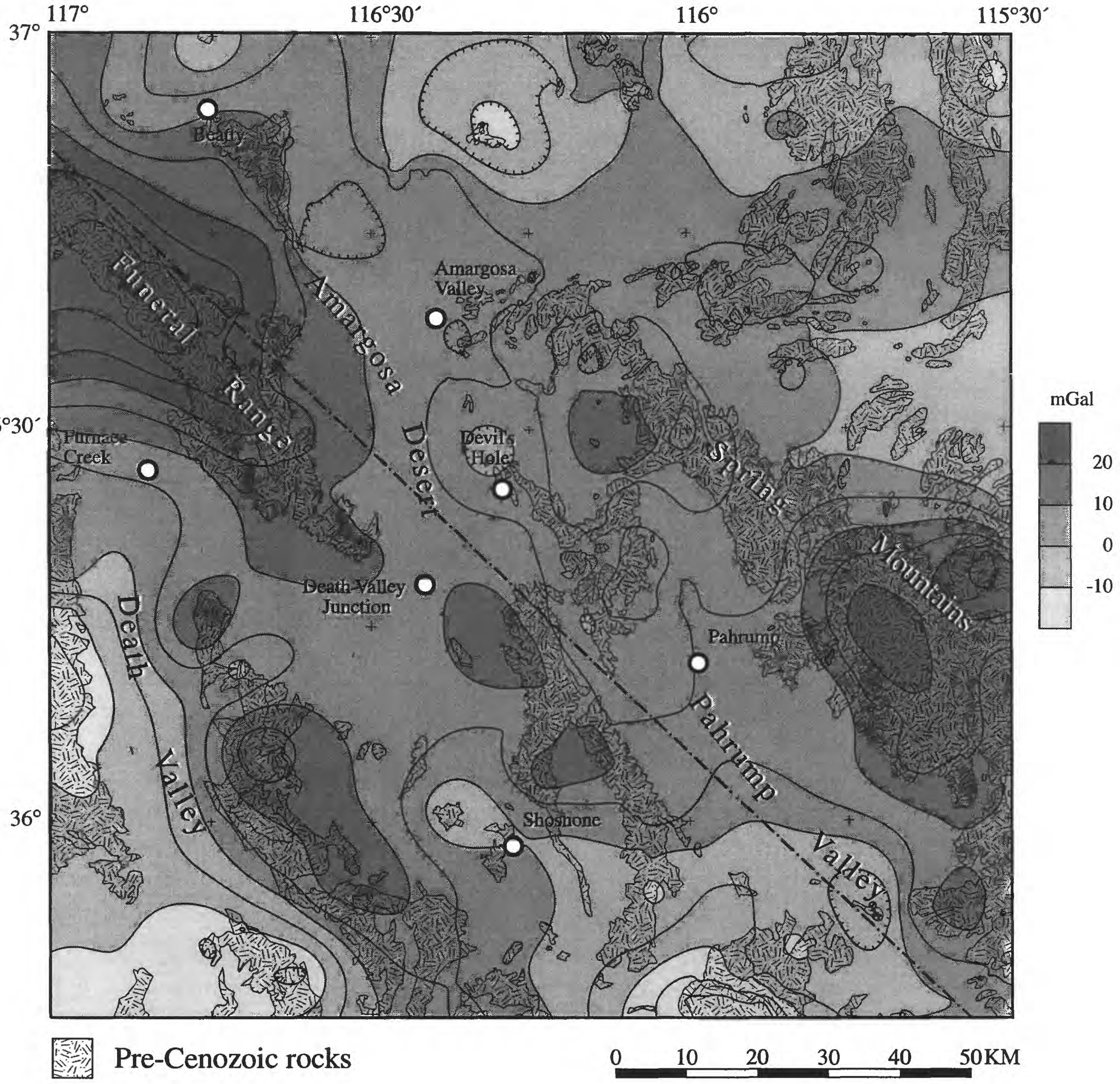
Isostatic Residual Gravity



Gravity Stations



Basement Gravity



Thickness of Cenozoic Deposits

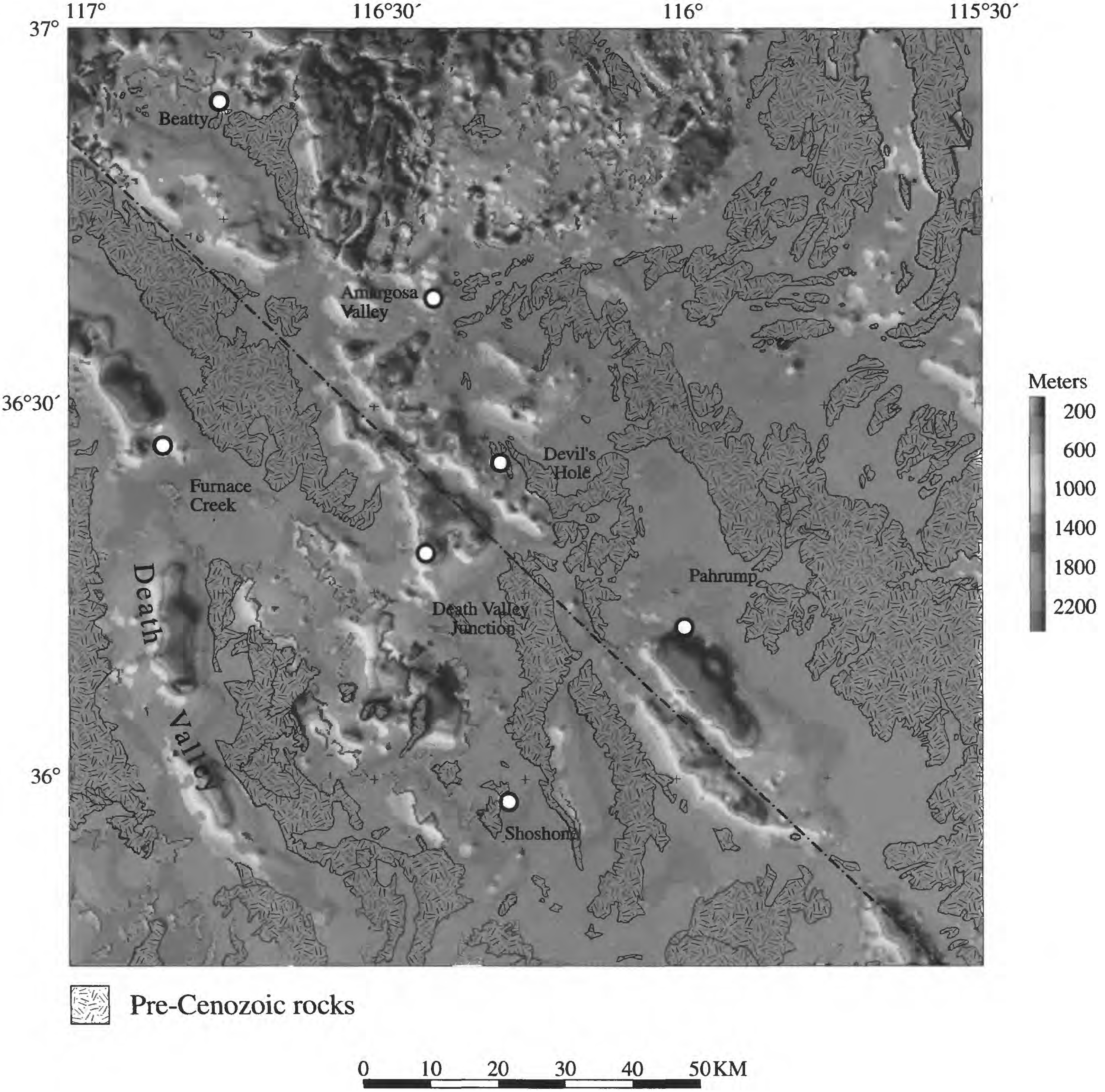


Figure 6

Three-Dimensional View of Subsurface Beneath Greater Amargosa Desert

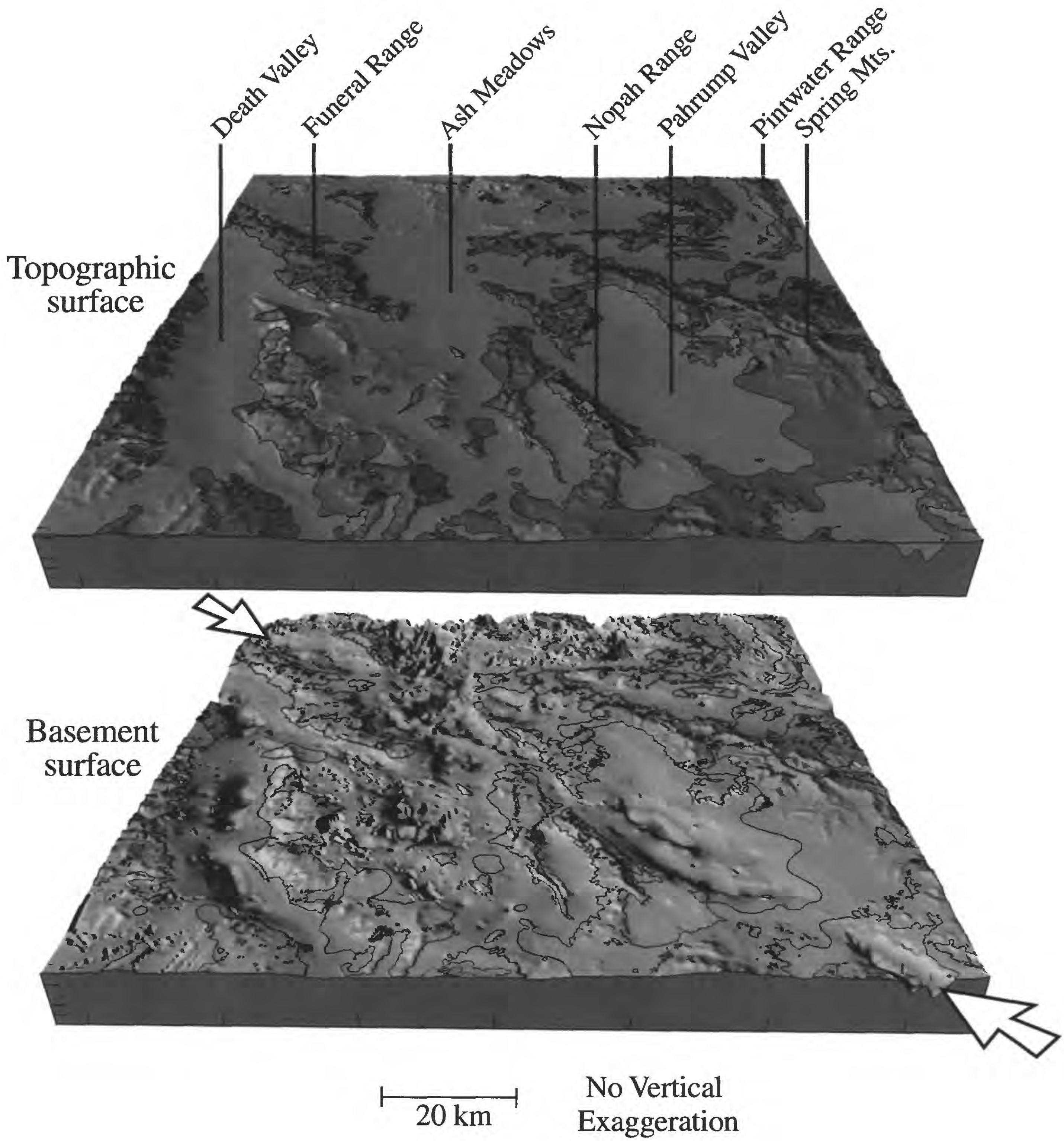
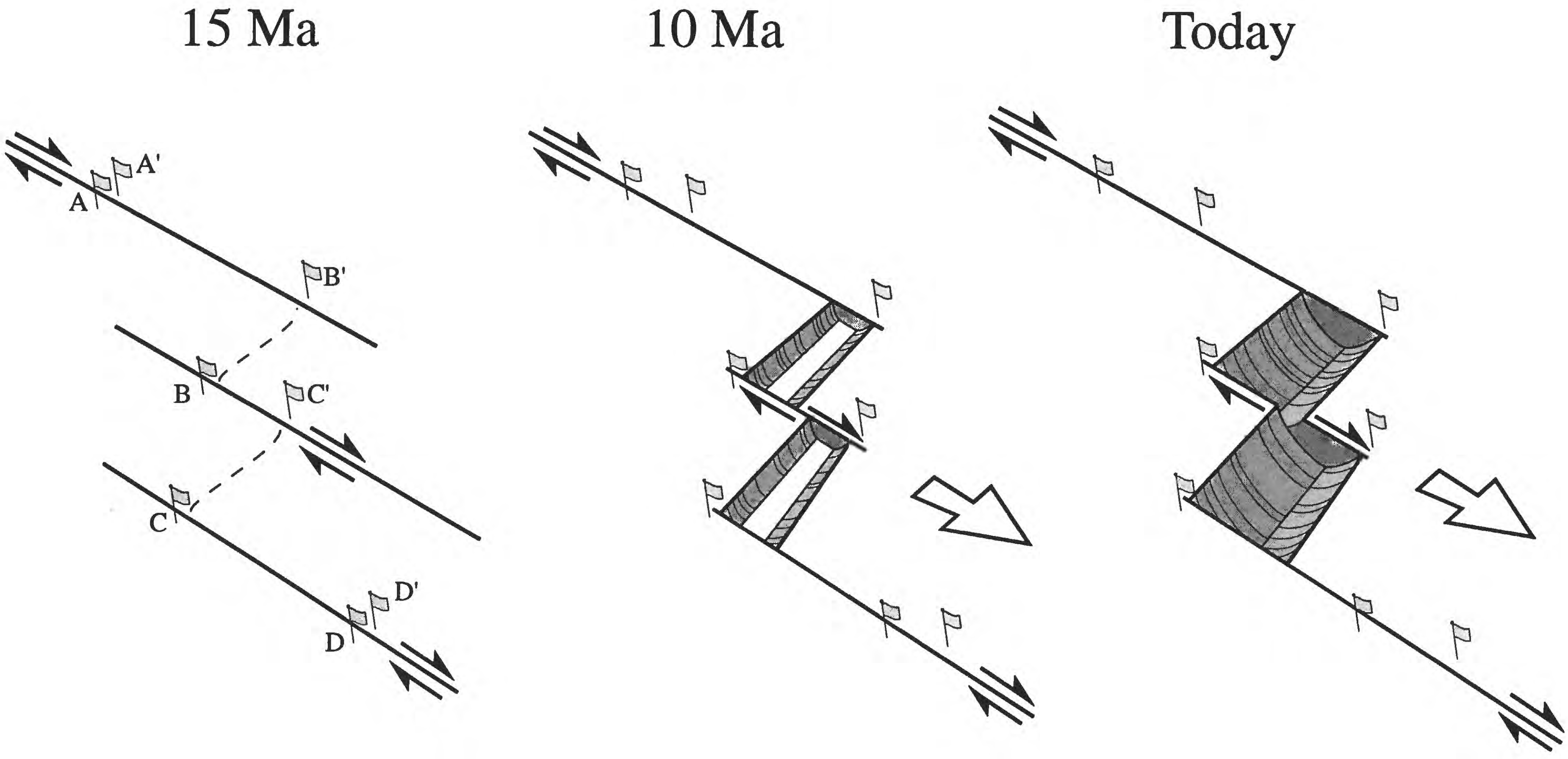
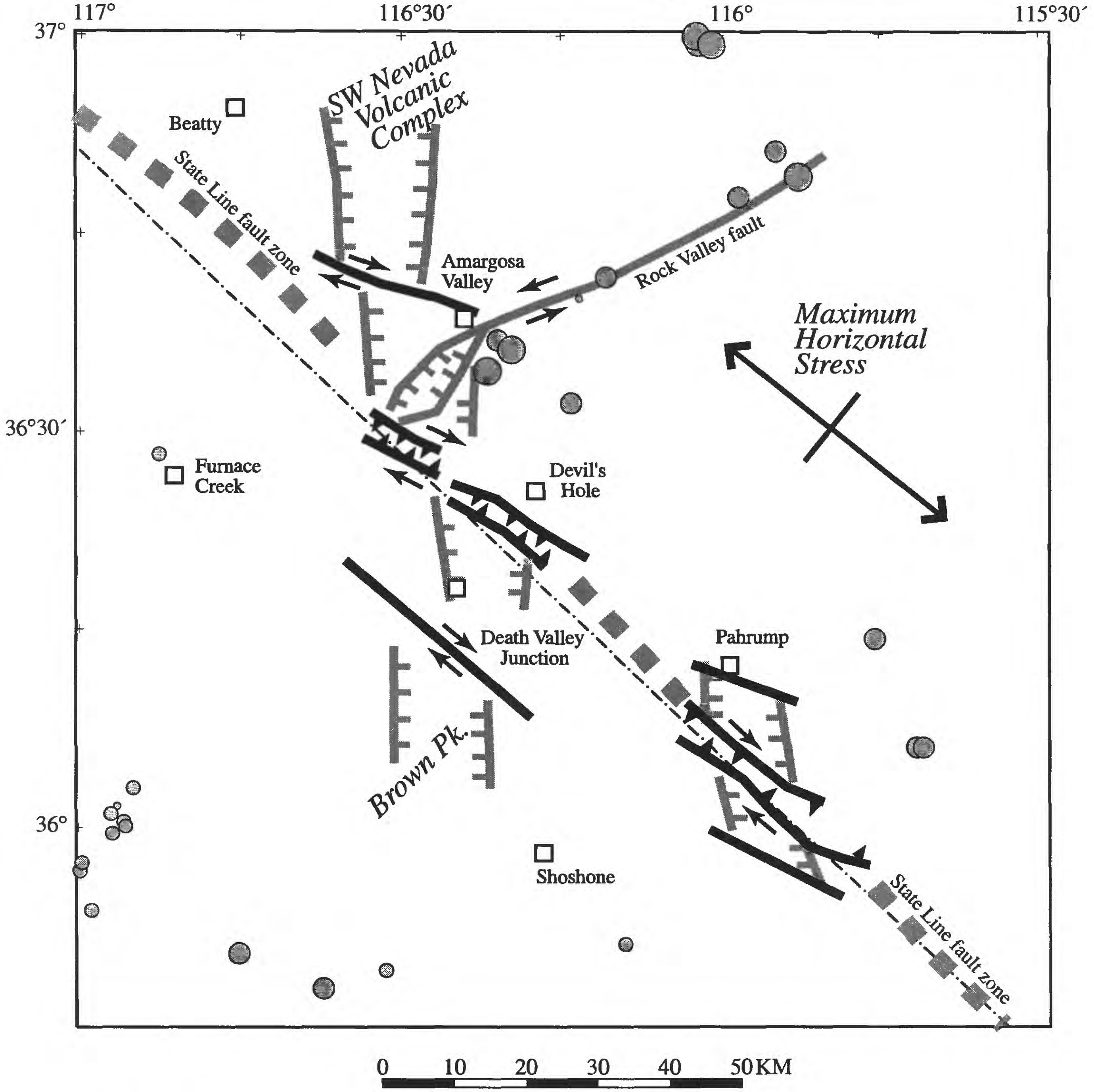


Figure 7



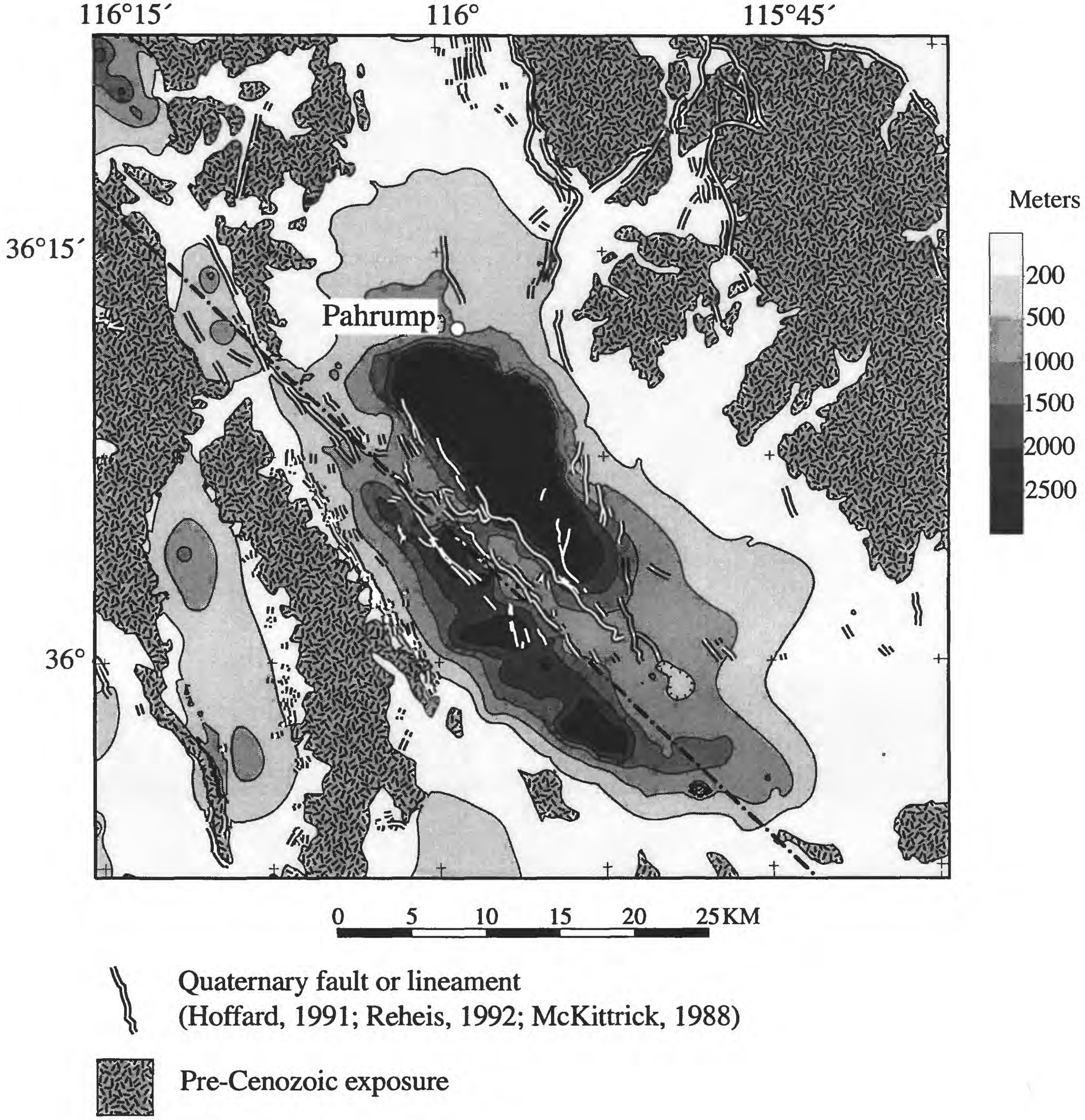
Interpretation of Deep Basins



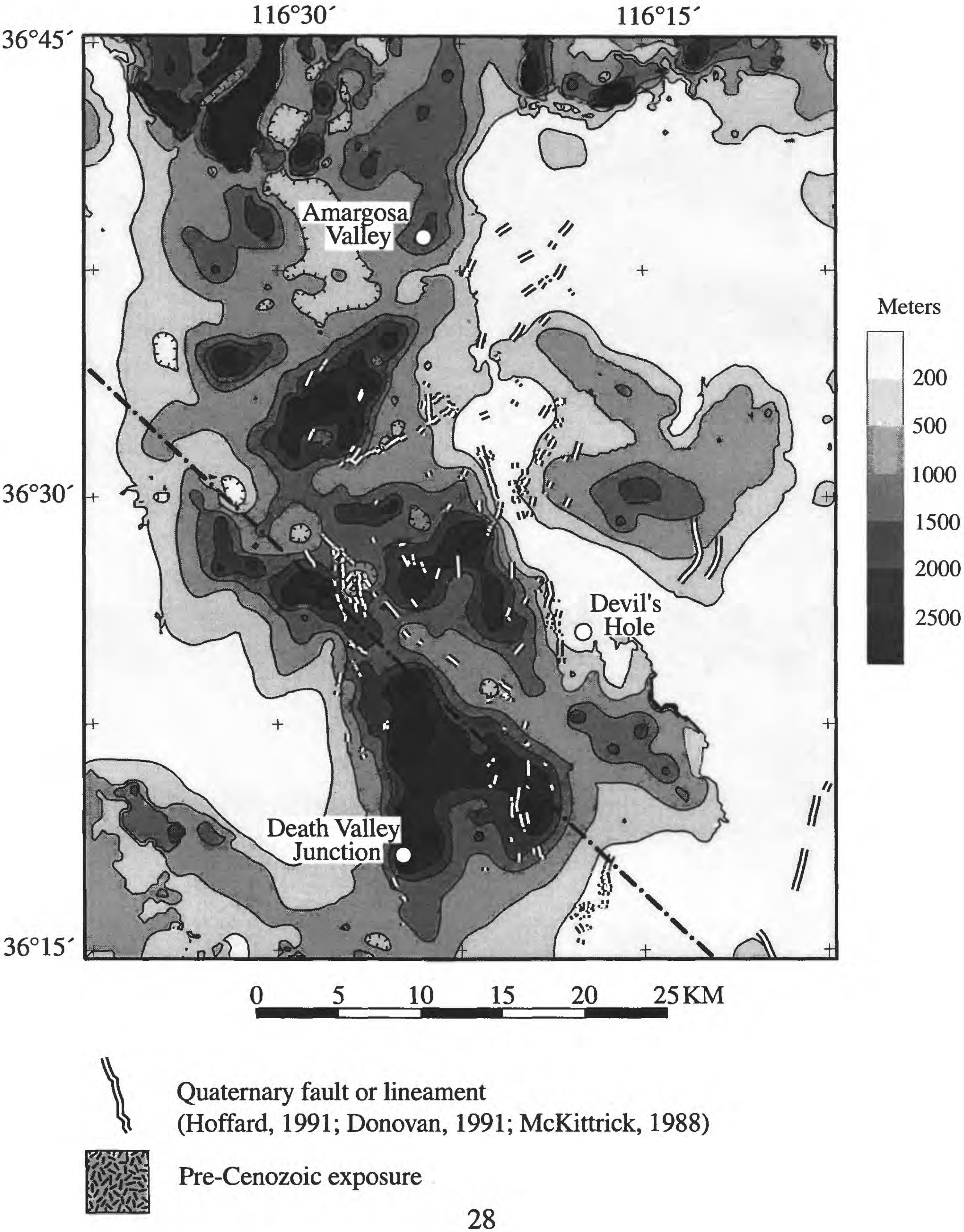
Earthquakes
- $1 \leq M < 2$
- $2 \leq M < 3$
- $3 \leq M < 4$
- $4 \leq M$

(1975-1998; high-quality locations only)

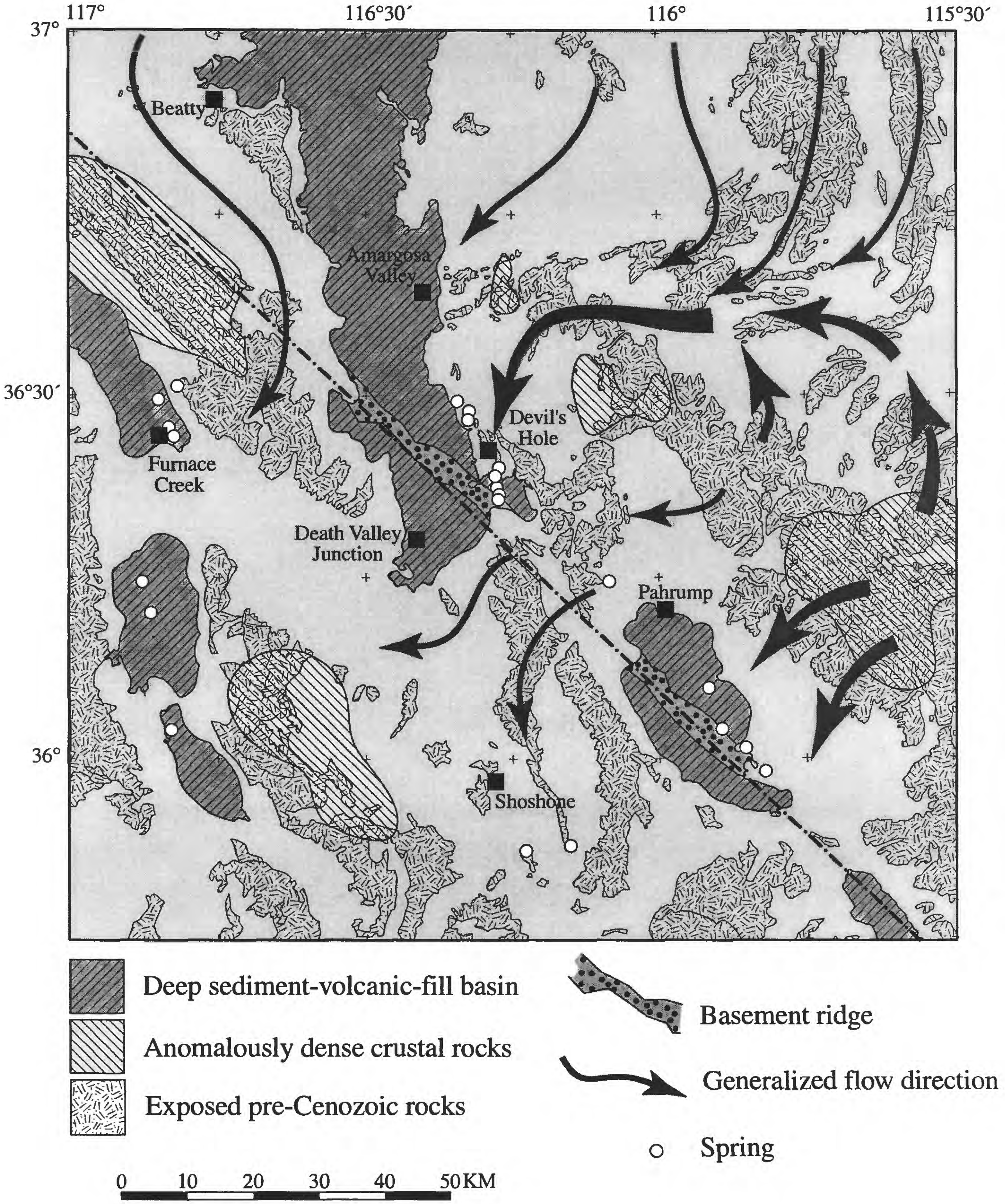
Thickness of Sedimentary Deposits, Pahrump Valley



Thickness of Sedimentary Deposits, Ash Meadows



Water Flow


117°
116°30′
116°
115°30′
37°
36°30′
36°
Beatty
Amargosa Valley
Furnace Creek
Devil's Hole
Death Valley Junction
Pahrump
Shoshone
Deep sediment-volcanic-fill basin
Anomalously dense crustal rocks
Exposed pre-Cenozoic rocks
Basement ridge
Generalized flow direction
Spring
0 10 20 30 40 50KM