ISOSTATIC UPLIFT, CRUSTAL ATTENUATION, AND THE EVOLUTION OF AN EXTENSIONAL DETACHMENT SYSTEM IN SOUTHWESTERN NEVADA

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Introduction

Geological and geophysical evidence supports the existence of extensional detachments between the Sheep Range and Death Valley (fig. 1). I propose that geographically separated pieces of detachments between Death Valley and the Sheep Range are parts of a regional detachment system that has evolved since the Miocene, and that the system consists of lenses of strata separated by an anastomosing network of low- and high-angle normal faults (fig. 2). This manuscript emphasizes the probability that isostatic uplift within the region of greatest crustal attenuation in this system, the Bullfrog Hills core complex, controlled the evolution of the detachment system between the breakaway zone at the Sheep Range and the core complex. Features in this system are described from east to west, which is the apparent direction of tectonic transport.

Interpretation of Detachment System

West of the Sheep Range breakaway (Guth, 1981; Wernicke and others, 1984), relatively few detachments are reported in the literature. Myers (1987) reported the detachment of the Oligocene Horse Springs Formation from the underlying Paleozoic strata a few kilometers north of Mercury. The Tertiary sedimentary rocks are tightly folded and locally overturned; they overlie a low-angle fault above relatively gently dipping, massive Paleozoic rocks. Based on other field evidence, principally at the northern end of Yucca Flat, Myers considered the Mercury detachment part of a regional feature, not a local phenomenon related only to bending of Paleozoic strata at the northwestern end of the Las Vegas shear zone.

South of Mercury and a few kilometers south of U.S. Highway 95, Burchfiel (1965) mapped three levels of low-angle faults in Cambrian and upper Precambrian clastic strata; this zone of faults separates middle Paleozoic carbonate rocks of an upper plate from Precambrian clastic rocks of a lower plate. The steep normal faults of the upper plate rocks are abundant and strike generally northeastward, whereas the normal faults of the lower plate rocks are less abundant and strike more nearly northward. These relationships suggest that a multitetiered system of detachment faults may exist throughout the region as shown conceptually on figure 2. The system south of Mercury is at a lower structural and stratigraphic level than the relatively shallow feature north of Mercury.

Seismic reflection data in the Mid Valley region, about 30 km northwest of Mercury, have been interpreted by McArthur and Burkhard (1986) to indicate the presence of a series of northeast-
and southwest-dipping listric normal faults that sole into a flat-lying detachment marked by a conspicuous reflector at a depth of about 3 km. The listric faults cut through surficial basin-fill deposits, Miocene volcanic strata, and Paleozoic rocks. McArthur and Burkhard further speculated from nearby field evidence that this Mid Valley detachment may be part of a regional feature.

Roughly 15 km to the southwest of Mid Valley in the Calico Hills, low-angle faults form complex anastomosing patterns within Miocene volcanic strata and possibly within Paleozoic rocks. These faults are considered to be part of the detachment system (Simonds and Scott, 1987). Structural geometry indicates that blocks at two localities in the Calico Hills have moved northward on local scoop-shaped low-angle faults, not in directions predicted from the geometry of gentle doming of the area. These local "scoops", which are similar to those in the upper plate of the Bullfrog Hills core complex (Maldonado, 1985), have moved in directions that are independent of the overall detachment system movement direction. The youngest rock affected by low-angle faulting in the Calico Hills area is the 11-Ma Timber Mountain Tuff on the northern side of the dome, and the oldest unaffected rock is the 9-Ma Shoshone Mountain Rhyolite on the eastern side of the dome. Two low-angle faults that are exposed along the western flank of the Calico Hills dip westward toward Yucca Mountain. Fault striae, which are essentially dip slip, indicate a westward movement of the upper plate at this locality.

Although detachment surfaces are not exposed on Yucca Mountain itself, there is geometric structural evidence that the mountain is underlain by a detachment surface and that the degree of extension increases from north to south (Scott, 1986). Miocene ash-flow tuffs, which dip uniformly eastward, are repeated by west-dipping normal faults (Scott and Bonk, 1984). The strata dip 5–10° in the northern part but dip 20–50° in the southern part of the mountain. The amount of offset on and abundance of normal faults increase southward. Also, paleomagnetic evidence of a progressive, vertical-axis, clockwise 350 rotation of the tuffs may indicate an interaction between a relatively shallow detachment and underlying right-lateral oroclinal bending and shearing that were associated with the Walker Lane belt as suggested by Scott and Rosenbaum (1986). The 11-Ma Timber Mountain Tuff at Yucca Mountain is significantly less affected by extension than is the 13-Ma Paintbrush Tuff. Extension continued to affect the Yucca Mountain area at a greatly reduced rate after 11 Ma and into the Quaternary along a secondary "breakaway" fault system (Scott and Whitney, 1987).

The detachment fault that is postulated to exist under Yucca Mountain appears to extend westward under Crater Flat. At the northern end of Bare Mountain, Cornwall and Kleinhampl (1961) mapped a north-dipping low-angle fault that separates Tertiary strata from underlying Paleozoic strata. This fault may be the uplifted northwestern extension of the detachment under Crater Flat and Yucca Mountain. Three lines of evidence suggest Bare Mountain
began to rise between 11 and 13 Ma and uplift has continued to the present. 1) Monolithologic Paleozoic carbonate strata are intercalated as sedimentary breccias immediately above a 11-Ma basalt in Tertiary basin-fill deposits and are exposed only in adjacent Bare Mountain (Carr and Parrish, 1985). 2) The 13-Ma Paintbrush Tuff does not thin against Bare Mountain, as does the 11-Ma Timber Mountain Tuff (Paul P. Orkild, USGS, oral commun., 1985). 3) Studies of the steep normal faults along the eastern side of Bare Mountain suggest that movement occurred during the Holocene or late Pleistocene (Reheis, 1986).

Uplift of Bare Mountain along normal faults on its eastern flank has disrupted and tilted northward the southern part of the upper detachment surface between Tertiary and Paleozoic strata (figs. 1 and 2). At the northern end of the mountain, this detachment progressively thins the Paleozoic sequence, cuts Devonian strata on the east and Cambrian strata on the west, tectonically, and removes most of the Paleozoic rocks (Cornwall and Kleinhampl, 1961). Below the upper detachment surface, the northwestern part of Bare Mountain is cut by numerous low-angle faults that further attenuate Paleozoic strata (Monsen, 1982). North of the Paleozoic exposures, in the east-dipping upper-plate Miocene tuffs, rocks as young as the Timber Mountain Tuff are tilted eastward and west-dipping normal faults terminate at the detachment surface. Striae on the detachment fault plunge northwestward.

Maldonado (1985) demonstrated that the upper detachment surface in northwestern Bare Mountain can be traced across the Amargosa Narrows into the Bullfrog Hills south and west of Beatty and can be extended westward where it forms a nearly horizontal fault that bounds the Bullfrog Hills core complex. The geometry of these relationships had been previously mapped by Ransome and others (1910). At the core complex, steeply dipping Miocene volcanic strata abut a gently domed fault surface that overlies amphibolite-grade gneisses, schists, granites, and pegmatites. The rocks in the core complex may consist of the metamorphosed equivalent of upper Precambrian sedimentary rocks (Bennie Troxel, University of California at Davis, oral commun., 1987), but the rocks appear to have experienced multiple periods of deformation similar to that expected in older Proterozoic crust. Based on the amphibolite grade of metamorphism and the thickness of missing upper Precambrian and Paleozoic strata, the amount of attenuation and uplift can be estimated to be roughly 10-15 km. This conclusion is supported by other examples of similar core complexes in the Death Valley area (Wright and Troxel, 1984; Wright and others, 1974) and by regional geophysical relationships. Seismic refraction and gravity data west of Yucca Mountain show a shallowing of midcrustal rocks; rocks with velocities of 6.3 km/sec are estimated to be at a depth between 1.5 and 0.5 km, and rocks with densities of 2.74 g/cm³ are at a depth of about 2 km beneath the core complex (Ackermann and others, in press). A minor Bouger gravity crest runs southeastward through the core complex to follow the western edge of Bare Mountain (Healey and others, 1980). The
youngest rocks involved in the tilting of upper plate rocks are 7-Ma tuffs (Maldonado, 1985). Lineations on the detachment surface and in the mylonitized core complex trend westward.

South of the Bullfrog Hills core complex, the detachment surface disappears under alluvial deposits of the Amargosa Desert. South and west of the Amargosa Desert, the thickness of the Paleozoic and upper Precambrian strata increase in the Funeral and in the Grapevine Mountains as a result of a decrease in the degree of crustal attenuation. In the east-central part of the Funeral Mountains, low-angle faults that were mapped by Swadley and Carr (1987) between the Tertiary and underlying Paleozoic strata can be interpreted as detachment faults. Also, at Daylight Pass cobbles within the Tertiary sequence are sheared above a contact with Paleozoic carbonate rocks. In the Funeral Mountains, detachment faults (for example, the Boundary Canyon fault that forms the northern part of the detachment shown on figure 1) occur within the Precambrian sequence (Hamilton, in press). Although this stack of detachments seems to be the mirror image of the stack on the eastern side of the Bullfrog Hills core complex, the age of detachment decreases toward the southwest. The oldest rocks unaffected by detachment in the Funeral Mountains area are 4-Ma basalts (Hamilton, in press). Southwest of the Furnace Creek fault zone in the Death Valley area, the age of detachment is still younger (Hamilton, in press). Farther south, Burchfiel and others (1987) reported 8-10 km of movement during the Quaternary along a detachment fault between the northwestern end of the Panamint Range and the Darwin rise.

Summary

Before attenuation in the Bullfrog Hills area, the detachment system probably existed as a series of detachment surfaces at different stratigraphic levels, similar to that seen east and west of the core complex. These detachment surfaces now appear to be interconnected in an anastomosing pattern where lenses of Paleozoic strata are stranded between upper and lower detachment surfaces; this is similar to the structure seen on a smaller scale in the Calico Hills (Simonds and Scott, 1987). During the concentration of attenuation in the Bullfrog Hills area, the Paleozoic and upper Precambrian strata were te-tonically transported along low-angle faults until the Tertiary volcanic strata abutted midcrustal rocks and formed the core complex (fig. 2). Concurrent isostatic uplift probably caused doming of the detachment surfaces. Between about 13 and 11 Ma, Bare Mountain began to rise on the eastern shoulder of this uplift. Ultimately, the uplift created steep normal faults on the eastern flank of Bare Mountain and broke the upper detachment fault into two parts, one east of and one west of Bare Mountain (fig. 2). Bare Mountain continues to be uplifted or that steep normal fault system. Although the region east of Bare Mountain has been isolated since 11 Ma, it still experiences extension on a detachment (Scott and Whitney, 1987), but only at a much reduced rate. In contrast, more rapid extension occurs southwest of the Bullfrog Hills.
Figure 1. Generalized Cenozoic tectonic map of the Sheep Range-Death Valley area. At least two levels of major detachment fault planes exist; these detachment faults separate rocks into upper, middle, and lower plates. At the Bullfrog Hills core complex, the entire middle plate is locally missing.
Figure 2. Generalized conceptual cross section from the Bullfrog Hills core complex to the Calico Hills. No vertical exaggeration. The depths and configuration of lower detachment faults are speculative. The dips of generalized strata are shown conceptually by shaded "unit" in the upper plate. Because the original positions of the plates relative to one another are difficult to determine, no relative movement directions are shown. The lowest detachment surface, between 10 and 15 km is the theoretical modern shear between relatively ductile and brittle crust. Steep normal faults, not shown here, probably translate extension on this lowest detachment upward to shallower detachment faults and to the surface.
References


