Basement-involved thrust faulting in a thin-skinned fold-and-thrust belt, Death Valley, California, USA

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ABSTRACT

Although dominated by a strong late Tertiary extensional overprint, the turtlebacks of the Black Mountains of Death Valley display evidence for earlier, possibly Laramide-age, basement-involved thrust faulting. The thrust faults consist of now highly deformed contacts in which >200-m-thick bodies of basement gneiss structurally overlie upper Proterozoic metasedimentary rock. In addition, the faults contain locally preserved, east-directed mylonitic fabrics in their footwalls that are demonstrably early Tertiary or older. The association of these fabrics with Laramide-age pegmatite suggests that they may have formed concurrently with the intrusions. These basement thrust faults are significant because they formed in a region long considered to have exclusively thin-skinned deformation. Their presence also places new constraints on this part of the fold-and-thrust belt's preextension geometry by limiting the amount of late Tertiary extension. Specifically, these faults disallow the correlation of thin-skinned structures that currently exist to the east and west of the Black Mountains.

Keywords: basement tectonics, extension tectonics, Laramide Orogeny, thrust faults.

INTRODUCTION

Worldwide, the thin-skinned parts of fold-and-thrust belts are generally considered to be devoid of basement involvement (Rodgers, 1995). This generalization is particularly true of parts of the North American Cordillera, where Sevier thin-skinned deformation occurred to the west, and Laramide thick-skinned deformation occurred to the east, of the Cordilleran hinge line (Allmendinger, 1992). The Death Valley region is west of the hinge line and hosts numerous thin-skinned structures. The original geometry of the fold-and-thrust belt in Death Valley, however, is subject to interpretation; there is great disagreement over the style and magnitude of the late Tertiary extension that preceded it (e.g., Wright and Troxel, 1999; Snow and Wernicke, 2000).

The Death Valley region also contains exposures of basement rock, including the three turtlebacks of the Black Mountains (Fig. 1). The turtlebacks have been recognized as extensional features since the study by Wright et al. (1974); each turtleback contains a late Cenozoic low-angle normal fault that separates upper Cenozoic sedimentary and volcanic rock in the hanging wall from mylonitic, upper Proterozoic basement gneiss and metasedimentary rock in the footwall. Partly because of the intense late Tertiary overprint, the preextensional history of the turtleback footwalls has been largely ignored. Moreover, with the exception of Wright et al. (1974) and some earlier workers (e.g., Curry, 1954; Hunt and Mabey, 1966), there has been general consensus that because fold-and-thrust belt deformation in Death Valley is thin skinned, it should not be expected in the crystalline turtleback footwalls. However, the turtlebacks contain early Tertiary pegmatite that locally cuts across older mylonitic fabrics to suggest some degree of basement involvement in earlier, probably Mesozoic shortening, deformation (Miller and Friedman, 1999; Turner and Miller, 1999).

This paper interprets older-over-younger relations observed at the Badwater, Copper Canyon, and Mormon Point turtlebacks as basement-involved thrusts (Figs. 1B, 1C). This interpretation is important because it shows that the thin-skinned and thick-skinned styles of deformation are not mutually exclusive. Furthermore, these newly identified thrusts help clarify the original configuration of the fold-and-thrust belt at this latitude, thereby helping define the style and magnitude of late Tertiary extension.

TURTLEBACK FOOTWALLS, PEGMATITE, AND PREEXTENSIONAL MYLONITIC FABRICS

Each turtleback footwall consists of variably mylonitic, quartz-feldspar gneiss, calcite, and dolomite marble, and minor, typically nonmylonitic, pelitic schist. The gneiss, which forms part of the regional crystalline basement complex, has an age of 1.7 Ga (DeWitt et al., 1984). The marble and associated schist have been correlated with various units of the Proterozoic sedimentary succession, including the Noonday Dolomite and Johnnie Formations at the Copper Canyon and Mormon Point turtlebacks (Otton, 1976), the Kingston Peak Formation and Noonday Dolomite at the Mormon Point turtleback (Holm et al., 1992), and the Crystal Spring Formation and Noonday Dolomite at the Badwater turtleback (Miller, 1992).

Pegmatite intrudes the footwalls of each turtleback in the Black Mountains. It occupies ~30% of the Badwater turtleback footwall, but decreases in volume toward the south. U-Pb geochronology of zircons from pegmatite in the Badwater and Copper Canyon turtlebacks yields concordant ages of 55 Ma and 61 Ma, respectively (Miller and Friedman, 1999; R. Friedman, 2000, personal commun.). For the most part, the pegmatite shows clear evidence for late Tertiary extensional deformation. It forms mylonitic sills and pods that are concordant with, and show the same top-to-the-northwest shear sense, as the surrounding mylonitic gneiss and metasedimentary rock. Ar geochronology by Holm et al. (1992) that showed that the gneiss cooled through the 300 °C isotherm at 13 Ma at Badwater and at 6 Ma at the Copper Canyon turtleback gives the approximate timing for the ductile, extensional deformation.

The pegmatite also cuts across an earlier mylonitic fabric (Fig. 2A). This fabric is concordant with the later extensional fabric, and appears to exist in raft-like bodies of rock that escaped the later deformation. Consequently, clear examples of the earlier fabric are relatively rare and tend to exist locally at deeper (>50 m) structural levels of the turtleback footwalls. The only way to distinguish the earlier fabric from the later extensional fabric is that rocks having the earlier fabric are cut by undeformed, crosscutting pegmatite. Much of the earlier fabric shows top-to-the-southeast sense of shear as determined from mica fish, asymmetric porphyroclasts, and grain-shape–preferred orientations (Turner and Miller, 1999). Its presence in Late Proterozoic metasedimentary rocks rules out Middle Proterozoic deformation, and the region did not again undergo a known deformational event until the onset of active margin tectonics in either the Permian (Snow, 1992) or early Mesozoic. Therefore, Miller and Friedman (1999) interpreted this earlier fabric as a product of Mesozoic shortening. The southeast-directed shear sense is consistent with this interpretation.

It is significant that the pegmatite locally displays relations with the country rock that are suggestive of intrusion during deformation. In some places where a dike crosscuts foliation, offshoots of the dike appear to be

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involved with the foliation. Elsewhere, pegmatite is deformed with foliation that is cut by an adjacent body of similar-looking pegmatite. If these pegmatites are of the same generation as the dated ones, as they appear to be, then these relations would suggest a Laramide age for the deformation. Because these specific bodies of pegmatite are currently undated, however, this age can be regarded as only tentative.

OLDER-OVER-YOUNGER RELATIONS

Each of the three turtlebacks exhibits unambiguous older-over-younger relations where basement gneiss structurally overlies the metasedimentary rock (Figs. 1B, 1C, 3A, 3B). However, the contact between the two units is markedly nonplanar because of the subsequent late Tertiary extension. This relationship is evident over most of the Badwater turtleback and near the southeastern edge of the Mormon Point turtleback.

The Badwater turtleback provides a window through the gneiss into the structurally lower, but stratigraphically higher, carbonate marble. Much of the central part of the Badwater turtleback surface is near the contact of the gneiss and structurally underlying carbonate marble. The contact generally dips outward along the margins of the turtleback. The same gneiss-over-marble contact can be traced from the northwest edge to the southeast edge of the Badwater turtleback (Fig. 1B). In some places, the gneiss and marble are interleaved to preserve a stack of two or more older-over-younger contacts.

A deep, wineglass-shaped canyon, named Tank Canyon by Curry (1954), exposes metapelitic rocks beneath the marble as well as crosscutting pegmatite dikes. In upward succession, rock types in the canyon consist of kyanite-muscovite schist, mylonitic feldspathic quartzite, garnet-muscovite schist, dolomite, calc-silicate marble, and calcite marble. The mylonitic quartzite preserves most of the preextension, east-directed shear-sense indicators recorded at the Badwater turtleback. Whitney et al. (1993) estimated a pressure of 7 ± 1 kbar for the kyanite schist.

Deep canyons at the north and south ends of the Badwater turtleback allow an estimate for the minimum thickness of the gneiss that overlies the metasedimentary rock. At the north end, Natural Bridge Canyon exposes ~200 m of gneiss. At the south end, the mountain front and canyon immediately north of Badwater expose ~1 km of gneiss, all of which overlies carbonate rock (Fig. 3A).

The Copper Canyon turtleback also displays older-over-younger relations. As described by Curry (1954) and Wright et al. (1974), it consists of a core of quartz-feldspar gneiss overlain by a carapace of ductilely deformed Noonday Dolomite. Otton (1976) showed that the 11 Ma Willow Spring Pluton intrudes the turtleback as a sill-like body along the top of the Noonday Dolomite. Gneiss locally exists structurally above the dolomite along its contact with the pluton (Fig. 1C; Holm, 1992). Within the pluton, an irregularly shaped enclave of the gneiss, ~2 km long and as wide as 1 km, also structurally overlies the Noonday Dolomite (Fig. 1C; Otton, 1976).

At the Mormon Point turtleback, ~300 m of quartz-feldspar gneiss structurally overlies marble of the Noonday Dolomite and diamictite of the Kingston Peak Formation (Figs. 1C, 3B). Similar to exposures on the Badwater turtleback, this contact is nonplanar, broadly conforming to the antiformal shape of the turtleback. This contact was first mapped as a thrust by Otton (1976) and later remapped by Holm (1992), who also reported associated top-to-the-east kinematic indicators.

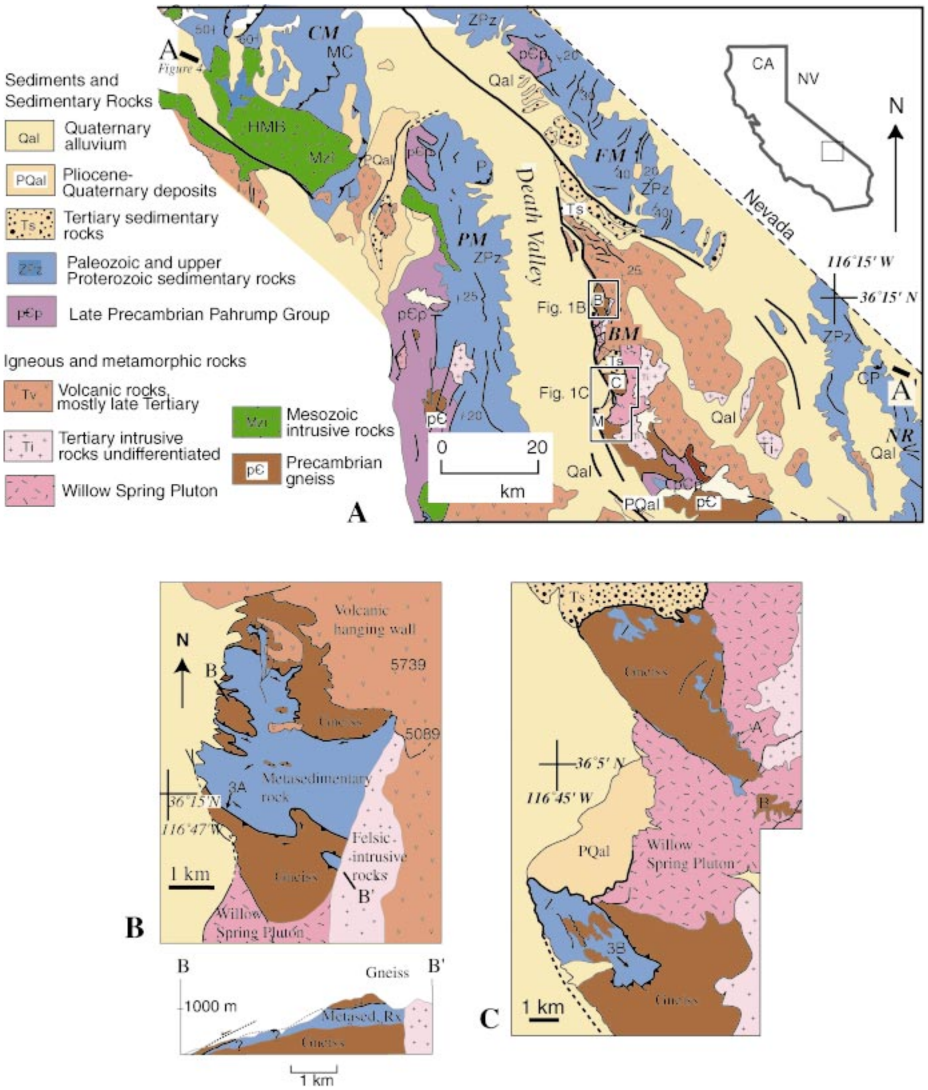

Figure 1. Geologic maps of central Death Valley and Black Mountains turtlebacks. A: Central Death Valley; insets show locations for B and C. Abbreviations: B—Badwater turtleback; BM—Black Mountains; C—Copper Canyon turtleback; CM—Cottonwood Mountains; CP—Chicago Pass thrust; FM—Funeral Mountains; HMB—Hunter Mountain Batholith; L—Lemoigne thrust; M—Mormon Point turtleback; MC—Marble Canyon thrust; NR—Nopah Range; P—Panamint thrust; PM—Panamint Mountains. B: Map and cross section of Badwater turtleback. Badwater Turtleback normal fault shown as line separating gneiss and metasedimentary rock from Quaternary alluvium, "volcanic hanging wall," or Willow Spring Pluton. Badwater Turtleback thrust fault is shown by heavy line with teeth that separates metasedimentary rock from structurally overlying basement gneiss. Because bottom of metasedimentary rock is not exposed, its contact is queried in cross section. Location of photograph in Figure 3A is designated 3A. C: Map of Copper Canyon and Mormon Point turtlebacks, modified from Otton (1976) and Holm (1992). Exposures of basement gneiss above Noonday Dolomite (Z) exist at location A. Large enclave of gneiss that structurally overlies dolomite is at location B. Exposed thrust fault at Mormon Point is marked by heavy line with teeth. Location of photograph in Figure 3B is designated 3B.

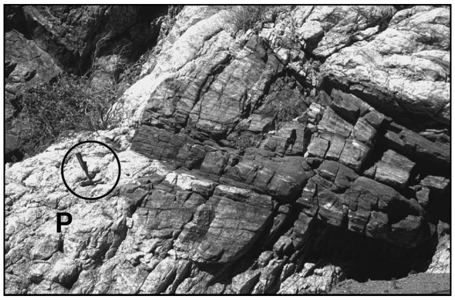

Figure 2. Photograph of pegmatite cutting earlier mylonitic fabric at Badwater Turtleback. In thin section, these rocks show top-to-southeast sense of shear. Hammer (circled) for scale.

BASEMENT THRUST FAULTS

The contacts with older-over-younger rocks are here interpreted as basement thrust faults that are related to the east-directed, prepegmatite or synpegmatite mylonitic fabrics. Other explanations may consist of either large-scale recumbent folding or large-scale transposition of the gneiss and carbonate units. Both alternatives, however, appear unlikely. Although each turtleback displays abundant folding and transposition at the outcrop scale, the contact between the gneiss and metasedimentary rocks in each footwall is continuous over several kilometers. Such continuity is not suggestive of either recumbent folding or transposition at the scale necessary to overturn the entire exposed footwall of each turtleback. Moreover, the presence of Noonday Dolomite in southern Gold Valley, structurally above the gneiss of the Mormon Point and Copper Canyon turtlebacks, suggests that the section is not overturned. The presence of east-directed mylonites conflicts with either alternative.

DISCUSSION AND CONCLUSIONS

The thrust faults described here may be either parts of a single large basement thrust or separate, distinct faults. In either case, they are sufficiently large to be important structures in the fold-and-thrust belt of Death Valley. The cross section of Figure 1B, for example, shows the length of the thrust fault parallel to the transport direction at the Badwater turtleback to be 4.5 km, to indicate a displacement of at least that much. Other features, such as the thick section of gneiss in the hanging wall and the near-concordance of foliation across the contact, suggest that the displacement is much greater. For comparison, the thin-skinned Lemoigne and Marble Canyon thrusts in the Cottonwood Mountains have stratigraphic throws of between 2 and 3 km (Wernicke et al., 1988).

Because of their implied large displacements, these thrusts must have also deformed the overlying sedimentary sequence, which is no longer present in the Black Mountains. Therefore, any reconstruction of the fold-and-thrust belt in Death Valley that places bodies of existing Proterozoic to Paleozoic sedimentary rock over the Black Mountains needs to include structures that correlate with these basement thrust faults. Such structures would have originated east of the turtlebacks, in the direction of thrust propagation. They could include coeval thin-skinned thrust faults, fault-propagation folds, or even Rocky Mountain foreland-style monoclines. However, no satisfactory correlative structures exist, so the Black Mountains probably did not originate beneath any of the surrounding ranges. This observation conflicts with the reconstruction of Wernicke et al. (1988) and Snow and Wernicke (2000), who argued that the Panamint Mountains originated structurally above and east of the Black Mountains, adjacent to the Nopah Range.

In their reconstruction, the Panamint thrust fault, in the eastern Panamint Range, was originally the updip continuation of the Chicago Pass thrust, 80 km to the southeast in the Nopah Range; the two parts of the thrust were displaced to their present locations by late Tertiary extension (Figs. 1A, 4A, 4B). Consequently, the basement thrusts described here

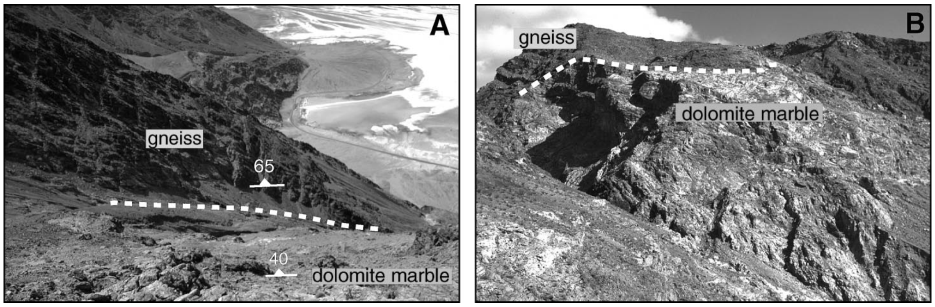

Figure 3. Photographs of exposed older-over-younger contacts. Photograph locations are shown as 3A and 3B in Figures 1B and 1C, respectively. A: At south side of Badwater turtleback; view is toward south. B: On Mormon Point turtleback; view is toward east.

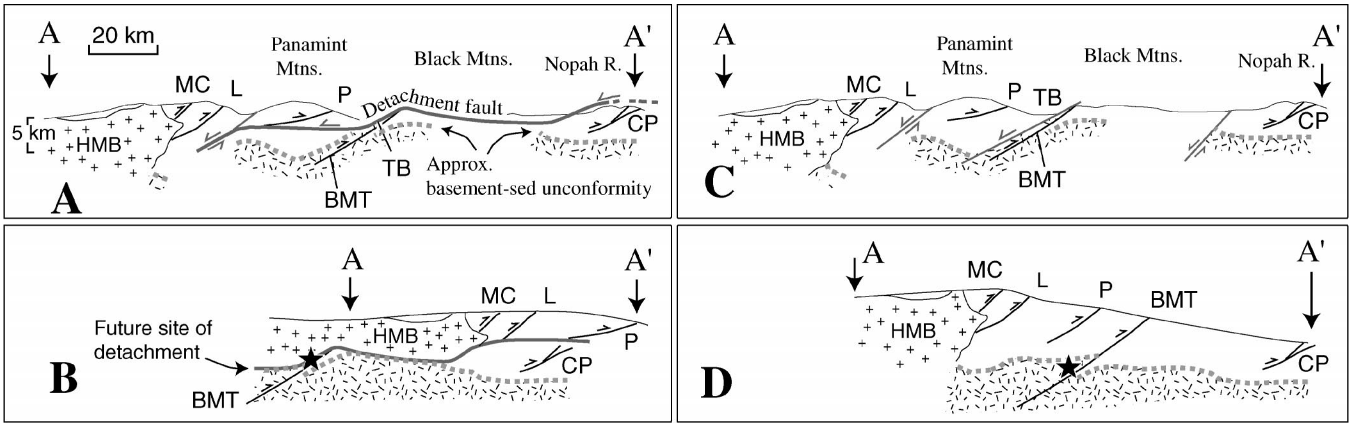

Figure 4. Schematic cross sections from A to A′ of Figure 1 that compare interpretations of present-day and preextension structure of Death Valley region. Abbreviations: BMT—Black Mountains thrusts; CP—Chicago Pass thrust; HMB—Hunter Mountain Batholith; L—Legmoigne thrust; MC—Marble Canyon thrust; P—Panamint thrust; TB—turtlebacks. BMT and TB are both projected into line of section. A: Present-day structure as interpreted by Wernicke et al. (1988) and Snow and Wernicke (2000). Note that extensional turtleback faults (TB) are part of regional detachment. Not shown on east edge is deeper part of detachment system that underlies Nopah Range. B: Restoration of Panamint thrust (P) to coincide with Chicago Pass thrust (CP) places HMB over Black Mountains basement. Star marks location of turtlebacks. C: Present-day structure as described in this paper. Note that extensional turtleback faults are deep-seated faults. D: Restoration proposed in this paper keeps HMB west of Black Mountains.

would have originated to the west of the Panamint thrust, beneath the Cottonwood Mountains. There, faults such as the Lemoigne or Marble Canyon thrusts might be possible correlatives with the Black Mountains thrusts, but they are intruded by the Jurassic Hunter Mountain Batholith. If the Black Mountains thrusts are Laramide in age, they would be significantly younger than the pre–Hunter Mountain Batholith structures of the Cottonwood Mountains. Furthermore, any such correlation would place the batholith on top of the Black Mountains and Greenwater Ranges (Figs. 1A, 4D). Because no Mesozoic intrusive rock has ever been observed anywhere in the Black Mountains, it is unlikely that the Black Mountains could have originated beneath those plutons.

Figures 4C and 4D show a preferred interpretation, in which the Panamint Range restores to a position adjacent to the Black Mountains. In this scenario, the turtlebacks are individual, deep-seated extensional fault zones, rather than exposures of a single regional detachment. Moreover, the Hunter Mountain Batholith remains west of the Black Mountains, and at higher structural levels, the Black Mountains thrusts cut the overlying sedimentary sequence.

The position of these basement thrusts in the Black Mountains indicates that they formed within the belt of thin-skinned deformation. They are between the Chicago Pass and Baxter Mine thrusts to the east (Burchfiel et al., 1983) and the Panamint and structurally higher thrusts to the west. Even with the reconstruction of Wernicke et al. (1988) and Snow and Wernicke (2000), they would be within the belt between the Panamint thrust and those in the Cottonwood or Last Chance Mountains. Such basement-involved thrust faulting, although common in the foreland and hinterland areas, is generally considered atypical of the main belt of thin-skinned imbricate thrusts (Rodgers, 1995). This exclusion exists almost by definition: ‘‘thin-skinned’’ areas are so named because deformation is restricted entirely to the sedimentary sequence and does not involve the basement. Some notable exceptions, however, are the Willard thrust near Salt Lake City, Utah (Yonkee, 1992), and the Pachalka thrust in the Clark Mountains of southern Nevada (Walker et al., 1995).

The addition of basement-involved thrust faults in the Black Mountains to this list suggests that unrecognized basement deformation may exist in other areas considered to reflect only thin-skinned deformation. Unlike the Willard and Winters Pass thrusts, however, the potential Laramide age of the Black Mountain thrusts suggests that basement-involved deformation postdated the better-known thin-skinned deformation. Because no other shortening structures of that age have yet been identified in the Death Valley region, their presence further suggests that Laramide-age deformation may have extended more westward than previously thought.

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