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The Black Mountains turtlebacks: Rosetta stones of Death Valley tectonics

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Abstract

The Black Mountains turtlebacks expose mid-crustal rock along the western front of the Black Mountains. As such, they provide keys to understanding the Tertiary structural evolution of Death Valley, and because of the outstanding rock exposure, they also provide valuable natural laboratories for observing structural processes. There are three turtlebacks: the Badwater turtleback in the north, the Copper Canyon turtleback, and the Mormon Point turtleback in the south. Although important differences exist among them, each turtleback displays a doubly plunging antiformal core of metamorphic and igneous rock and a brittle fault contact to the northwest that is structurally overlain by Miocene–Pleistocene volcanic and/or sedimentary rock.

The turtleback cores contain mylonitic rocks that record an early period of top-southeastward directed shear followed by top-northwestward directed shear. The earlier formed mylonites are cut by, and locally appear concurrent with, 55–61 Ma pegmatite. We interpret these fabrics as related to large-scale, basement-involved thrust faults at the turtlebacks, now preserved as areally-extensive, metamorphosed, basement over younger-cover contacts.

The younger, and far more pervasive, mylonites record late Tertiary extensional unroofing of the turtleback footwalls from mid-crustal depths. Available geochronology suggests that they cooled through 300 °C at different times: 13 Ma at Badwater; 6 Ma at Copper Canyon; 8 Ma at Mormon Point. At Mormon Point and Copper Canyon turtlebacks these dates record cooling of the metamorphic assemblages from beneath the floor of an ~11 Ma Tertiary plutonic complex. Collectively these relationships suggest that the turtlebacks record initiation of ductile extension before ~14 Ma followed by injection of a large plutonic complex along the ductile shear zone. Ductile deformation continued during extensional uplift until the rocks cooled below temperatures for crystal plastic deformation by 6–8 Ma. Subsequent low-angle brittle fault slip led to final exposure of the igneous and metamorphic complex.

The turtleback shear zones can constrain models for crustal extension from map-view as well as cross-sectional perspectives. In map view, the presence of basement-involved thrust faults in the turtlebacks suggest the Black Mountains were a basement

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high prior to late Tertiary extension. In cross-section, the turtleback geometries and histories are most compatible with models that call on multiple faults rather than a single detachment to drive post-11 Ma extension.

Keywords: turtlebacks; Death Valley; extension; ductile shear zones; basin; range

1. Introduction

The three Black Mountains turtlebacks have long been considered important but enigmatic features of Death Valley geology. They were named "turtlebacks" by Curry (1938) because their convex-upwards morphologies resemble turtleshells. In terms of bedrock geology, however, the turtlebacks stand out because they offer the only exposures of crystalline basement rock along the Black Mountains front (Curry, 1938, 1954; Fig. 1). They are probably the single most important features in deciphering Death Valley's complex tectonic story.

Each of the turtlebacks displays the essential features of Cordilleran Metamorphic Core Complexes (Davis, 1980; Lister and Davis, 1989): a ductilely deformed metamorphic core, an overlying body of highly faulted upper crustal rock, and at their northwest margins, a brittle extensional fault zone between them. Additionally, mylonitic rocks of the core reflect a sense-of-shear that is similar to, but older than, the fault zone. Post- to syn-mylonitization folding about axes subparallel to shear zone transport produced up to 4 km of structural relief both at high angles and parallel to transport. Thus, each turtleback individually represents a "core complex" that occupies an area of only about 6 km^2, but collectively, the turtlebacks represent different parts of a large-scale extensional system. This complex 3D geometry provides outstanding opportunities to observe both shallow- and moderately deep-level processes of shear zone evolution.

The Death Valley region is an especially fertile area for testing models for crustal extension. There, tectonic interpretations generally fall into one of two categories (Fig. 2). One category, the "Rolling Hinge" model (Stewart, 1983; Hamilton, 1988; Wernicke et al., 1988; Snow and Wernicke, 2000), calls for ~80 km of horizontal translation and unroofing of the Black Mountains on a detachment fault of regional extent. Because the Black Mountains contain ~11 Ma plutons, this faulting must postdate 11 Ma. This model views strike-slip faults, such as the en echelon Furnace Creek and Sheephead faults, as upper crustal edges of the detachment system. The other category calls for extension by slip on numerous, distinct fault zones (Wright and Troxel, 1984; Wright et al., 1991; Serpa and Pavlis, 1996; Miller and Prave, 2002). This category, the "Pull-Apart" model, calls on the strike-slip faults to penetrate deeply into the crust and drive extension between their terminations, similar to the model proposed by Burchfiel and Stewart (1966) for modern Death Valley. Both interpretations rely heavily on findings from the turtlebacks because they each describe the turtlebacks as the principal shear zones. In the Rolling Hinge model, the turtlebacks are different exposures of the same detachment fault; in the Pull-Apart model, the turtlebacks define three of the largest, and distinct, faults.

Both tectonic interpretations also rely on differing views of the original configuration of the Mesozoic fold-thrust belt. The Rolling Hinge model requires an originally narrow thrust belt in which the Panamint and Chicago Pass thrusts, now separated by about 80 km, were originally the same structure. Detachment faulting during late Tertiary extension cut this fault and displaced the two parts to their present locations (Figs. 1 and 2A). By contrast, the Pull-Apart model requires an originally wider thrust belt in which the Panamint and Chicago Pass thrusts originated as separate features (Fig. 2B).

The turtlebacks are here described as "Rosetta Stones" because they provide keys to decipher both the original fold-thrust belt geometry as well as the geometry and mechanisms of late Tertiary extension. Their locations at the western edge of the Black Mountains place them in the middle of the fold and thrust belt. Most recently, Miller and Friedman (1999) and Miller (2003) have found evidence in their footwalls for mid-crustal, pre-55 Ma, basement-involved thrust faulting. The addition of the Black Mountains to the fold-thrust belt helps constrain its original