Geological Society of America Bulletin

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Geological Society of America Bulletin 1966;77;435-438
doi:10.1130/0016-7606(1966)77[435:TODVRC]2.0.CO;2

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Abstract: The north-northwest-trending Death Valley and Furnace Creek right-lateral slip fault zones border the Black Mountains, California. Other tectonic features in the Death Valley region appear compatible with this strike-slip strain system of northeast-southwest shortening and northwest-southeast relative extension. Accordingly, some of the Basin and Range structures of Tertiary to Recent age may be characterized by strike-slip rather than dip-slip faulting, and result from compressional rather than tensional dynamics.

Introduction

Death Valley, a structural depression lying east of the Panamint Range and west of the Black and Funeral mountains, is in the southwestern part of the Basin and Range geologic province. Following the earliest published interpretation by Gilbert (1874) this province has been considered the classic example of the late Tertiary to Recent development of mountains and basins by relative uplift and depression on bounding normal slip faults (variously called normal, gravity, or tension faults, and often referred to as block, or Basin and Range, faulting).

Later work, especially in the Black Mountains, has revealed geology which apparently cannot be resolved by the application of the usual Basin and Range tectonic concepts. These anomalies include the turtleback surfaces (Curry, 1938; 1954; Noble and Wright, 1954; Drewes, 1963), the Amargosa thrust fault and associated "chaos" (Noble, 1941; Noble and Wright, 1954; Drewes, 1963), and evidence for strike-slip on some of the faults (Noble and Wright, 1954, p. 157; Drewes, 1963, p. 5).

According to Nolan's review of Basin and Range geology (1943, p. 184), "Most of the theories advanced have been affected by the beliefs of their authors as to the nature of the faulting—whether it is normal or reverse. They fall into three general groups—(1) theories postulating simple tensional stress, (2) those postulating simple compressive stress, and (3) those requiring a combination of tensional and compressive forces. . . ." And speaking of strike-slip on the Garlock fault (p. 185) he writes ". . . the implication seems strong that the ultimate force causing the horizontal shift may well have been the same as that causing the block faulting [of the Basin and Range province]." In this connection, King (1959, p. 157) said, "The tension suggested by the local structures may be a component of a more pervasive crustal compression. . . ." He further (p. 158) states that ". . . it remains to be determined whether strike-slip movements . . . are sufficient to have produced the crustal tension . . . in the intervening blocks."

The present authors now suggest that a single tectonic strain system, including the Death Valley and Furnace Creek fault zones, may also include the unusual turtlebacks and Amargosa thrust. We also suggest that this strain system of northeast-southwest horizontal shortening and northwest-southeast relative extension may result from a compressional force couple. Therefore, we doubt that tension has been the dominant tectonic influence in at least this part of the Basin and Range province. We believe that the strain system proposed here may be part of a much larger system of deformation, including tens to possibly a few hundred miles of right-lateral slip on the San Andreas fault (Hill and Dibblee, 1953), the probable right-lateral slip of approximately 25 miles on the Las Vegas shear zone to the east (Longwell, 1960; Burchfiel, 1965), and the probable left-lateral slip of approximately 40 miles on the Garlock fault to the south (Smith, 1962). Although cumulative strike-slip on segments of the Death Valley and Furnace Creek fault zones may be only a few miles (Wright and Troxel, ms. submitted for publication) or possibly as much as 50 miles (Stewart, in press) such differences can be accommodated in the presently proposed strain system, or in a similar proposal by Burchfiel

Geological Society of America Bulletin, v. 77, 435–438, 1 fig., April 1966

and Stewart (1966). Furthermore, substantial dip-slip components of fault displacement are likewise compatible with this strain system.

Tectonics

Figure 1 shows: (1) the Furnace Creek, Death Valley, and some other north-northwest to northwest-trending right-lateral slip fault zones (S1 of the strain ellipse insert); (2) relatively minor north-northeast- to northeast-trending right-lateral slip faults (and dikes) within, and offsetting the west margin of, the Black Mountains (CC axis of insert); (3) the *en echelon* northwest-plunging Badwater, Copper Canyon, and Mormon Point turtlebacks (AA axis of insert); (4) the Amargosa thrust fault and chaos; and (5) the Garlock fault zone (S2 of the insert).

The evidences of right-lateral slip on the various north-northwest-trending faults are: (1) striations plunging approximately 30° northwestward on fault-zone surfaces bounding the Black Mountains; (2) drag folds where the faults transect Tertiary to Recent sediments; (3) the right-lateral offset of a volcanic cone (in southern Death Valley); (4) right-lateral offsets of drainage lines; (5) the northeast-trending "gash" faults with oblique-slip striations and the northeast-trending dikes east of the Death Valley fault zone; and (6) the *en echelon* pattern of northwest-trending turtlebacks (anticlines) along the east side of the Death Valley fault zone (*see* Fig. 1).

The evidences of a component of right-lateral slip on the northeast-trending faults in, and on the west side of, the Black Mountains are oblique-slip striations on some of the fault surfaces and the offsetting of the range front in this sense at Mormon Point. The northeast-trending dikes indicate the tension fracture position of the strain system (CC of the insert on Fig. 1). The right-lateral slip component on faults of this trend is attributed to clockwise rotation of the Black Mountains block between the Furnace Creek and Death Valley fault zones.

The northwest-plunging *en echelon* turtlebacks are interpreted here as exhumed surfaces of an unconformity. We suggest that a fault contact developed between the Precambrian crystalline rocks and the overlying and relatively incompetent Tertiary sediments while the unconformity was being rapidly folded under a relatively thin overburden. The trend and plunge of these folds is compatible with components of right-lateral slip and uplift of the Black Mountains between the Death Valley and Furnace Creek fault zones. Also, this northwest trend of the turtlebacks and Desert Hound anticline is normal to the northeast-southwest shortening of the Black Mountains fault block (AA of the insert on Fig. 1).

The southeastward-plunging Desert Hound anticline occurs as the southeastern projection of the Mormon Point turtleback and has the same core of Precambrian crystalline rocks. However, these competent crystalline rocks are separated from the overlying later Precambrian and early Paleozoic marine sediments by the Amargosa thrust fault. This thrust fault and the overlying chaos of tectonically broken and thinned rocks are also attributed to rapid and shallow deformation accompanying folding.

The sense of slip on the Garlock fault zone is left-lateral, as shown in this area by the orientation of drag folds. This sense of displacement is also compatible with the Death Valley strain system proposed here (*see* Fig. 1 and S2 of the strain ellipse insert).

Conclusions

We propose that the structures of the Death Valley region, including the turtlebacks and Amargosa thrust fault, are manifestations of shortening in a northeast-southwest direction and relative extension in a northwest-southeast direction. This is essentially a strike-slip fault system, with major and minor strain axes approximately horizontal. (Substantial components of dip-slip are probably also required to develop some of the topographic relief, and adjustments within the Black Mountains block are needed to produce a component of right-lateral slip on the northeast-trending faults.) The apparent contemporaneity and compatibility of these structures further indicate that this single system of deformation has been active since perhaps early Tertiary time.

Although the Black Mountains are regionally atypical in the prominent development of turtlebacks and chaos and the eroded and tectonically thinned to missing Paleozoic section, these anomalies may result from the northeast-southwest shortening with folding, faulting, uplift, and erosion of the confined block between the subparallel Furnace Creek and Death Valley strike-slip fault zones. Therefore, this strike-slip fault system may eliminate the need for special processes occurring at widely spaced times, such as great landslides,

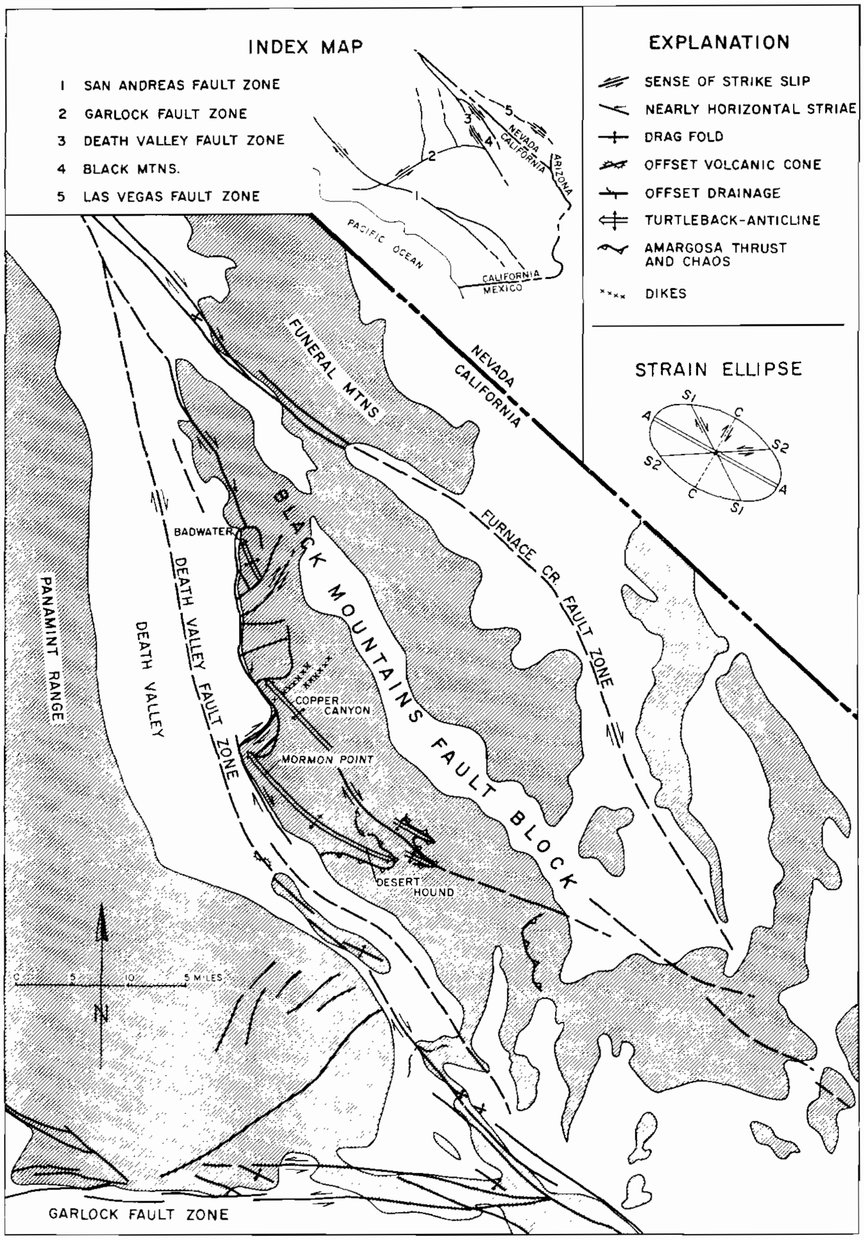

Figure 1. Tectonic sketch map, Death Valley region, California

forceful intrusions, and/or widespread thrust faults, to explain the turtlebacks and chaos of the Black Mountains.

Finally, we believe that a strike-slip strain system, as proposed here for the Death Valley region, may be more applicable to some other areas of the Basin and Range province than the traditional dip-slip (extensional) concept. Others have made similar suggestions: Wise (1963) proposed several hundred miles of right-lateral slip across the Basin and Range province, Shawe (1965) has emphasized the importance of strike-slip faulting in this region, and D. B. Slemmons reported, in 1965 (oral communication), that most Pleistocene to Recent northwest-trending faults in Nevada are characterized by right-lateral slips. Thus, we suggest that Basin and Range structure, although presumably settled long ago by Gilbert, needs more attention. Certainly there are reasons to question the traditional image of Basin and Range faulting, to be suspicious of the commonly held dynamic concept of tension (relaxation?), and to consider the role of strike-slip faulting in the late Tertiary to Recent tectonic history of this region.

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MANUSCRIPT RECEIVED BY THE SOCIETY NOVEMBER 12, 1964
REVISED MANUSCRIPT RECEIVED NOVEMBER 12, 1965