Quaternary Fault and Fold Database of the United States

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Black Mountains fault zone, Copper Canyon section (Class A) No. 142c

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Compiled in cooperation with the California Geological Survey

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Synopsis	**General:** The Black Mountains fault zone is marked by prominent Holocene and late Pleistocene scarps that are more-or-less coincident with strongly uplifted western margin of the Black Mountains in central Death Valley and their northward continuation as low hills cored by upper Tertiary sedimentary rocks. The fault zone is part of the much longer Death Valley fault system, which extends from Fish Lake Valley (Nevada) in the north, to the Garlock fault [69] in the south. The Black Mountains fault zone is characterized by primarily normal to normal-oblique along its length, and its footwall block is a spectacular example of

active tectonic uplift. The fault zone is somewhat irregular in map plan, strikes roughly north-south (on average). It joins the northwest-striking Northern Death Valley fault zone [141] and the predominately pre-Quaternary Furnace Creek fault zone on the north, and the northwest-striking Southern Death Valley fault zone [143] on the south to form a nearly continuous 300-km-long feature that is one of the most active fault systems in the region. Detailed studies of offset alluvial fans along the Black Mountains suggest normal-dip slip rates of 1-3 mm/yr as recorded by near vertical scarps as much as 10 m high on Holocene alluvium at Willow Wash, east of Mormon Point. Recurrent Holocene movement characterizes the entire fault zone, and some portions may have been active as recently as 200 years ago. Continuous scarps associated with the Black Mountains fault range from 2 to 13 km in length, and although the majority of the range front is fault controlled, active sedimentation has obscured some traces of the fault. Although no trenching studies have been conducted on the fault zone, the entire trace is well mapped, and morphometric studies suggest potentially different times of movement along the fault zone and amount of offsets in a variety of Holocene to late Pleistocene deposits.

Sections: This fault has 4 sections. In general, the Black Mountains fault zone strikes shows little evidence for major steps or potential section or segment boundaries (Machette and others, 2001 #4773). The exceptions are a large embayment in the range north of Mormon Point (Mormon Point Turtleback), a 12-13 km-long gap in terms of scarp continuity north of Natural Bridge (Klinger and Piety, 1996 #3873), and the lack of fault continuity north of Furnace Creek). Very little substantial paleoseismic work has been done to support potential subdivision of this roughly 70-km long fault zone. Various schemes have been proposed, the most recent being two sections for the south half of the fault based on scarp morphometric data (Frankel and others, 2001 #4776), six sections based on topical studies by Knott and others (2001 #4772), and eleven sections based on geometric considerations (Brogan and others, 1991 #298). Knott (1998 #5116) subdivided the range front into six distinct geometric segments based on variations in the mountain front sinuosity, mountain front-piedmont intersection profiles, range crest profile, the strike of the fault, and several other factors. For purposes of estimating the potential magnitude of future earthquakes on the Black Mountains fault zone, Knott (1998 #5116) recombined his six segments into three longer segments with lengths similar to

	the shorter historical ground ruptures reported by Wells and Coppersmith (1994 #546). The most distinct geomorphic boundaries (or anomalies) along the range, Mormon Point and Natural Bridge, separate each of these three longer segments. This is consistent with a 3-part segmentation scheme of the range-front fault based solely on scarp morphology (Klinger and Piety, 1996 #3873)). For this database, we divided the Black Mountains fault zone into three subequal length sections and include the transition zone (modified from Machette and others, 2001 #4773). This subdivision is based primarily on fault trend, structural features (bedrock salients and asperities), fault continuity, location of the fault relative to the range, and apparent recency of movement. From north to south, these are defined as the 1) Mustard Hills transition zone, 2) Artists Drive section, 3) Copper Canyon section, and 4) Smith Mountain section. Each of these are named for prominent geographic features with the section
Name comments	**General:** The Black Mountains fault zone is defined as the zone of Quaternary normal/oblique-slip faults that are more-or-less coincident with the western margin of the Black Mountains in Death Valley (Machette and others, 2001 #4773). It is the third of four fault zones that comprise the much larger Death Valley fault system of Machette and others (2001 #4773). Levi Noble (1926 #1592) first named the normal fault at the base of the Black Mountains escarpment the "Death Valley fault zone," but did not mention other faults or faulted areas to the north or south. Thus, on the basis of first usage, the fault along the front of the Black Mountains should be known as the "Death Valley fault zone" (senso stricto). Noble (1941 #1593) later mapped many of the Quaternary (i.e., post-Funeral Formation) strike-slip faults that continue north and south from the Black Mountains without naming them. Noble and Wright (1954 #1536) and Curry (1954 #1489) continued to use the term Death Valley fault zone, but designated parts of the fault zone as the "Black Mountains frontal fault" and the "Artists Drive fault." Machette and others (2001 #4773) attempted to straighten out the confusing usage of terms, and suggested using the name of the primary geographic feature (i.e., the Black Mountains) that forms the footwall of the fault zone. The northern end of the coherent range-front portion of the fault zone [142b] is considered to be about 1 km north of Furnace Creek, where the Black Mountain fault zone starts to bifurcate into a transition zone [142a] that extends about 10-12 km north of Furnace Creek (Machette and others, 2001 #4771). The southern end of the fault zone [142d] is taken as Ashford Mill (ruins), which is about 3 km east of Shore Line Butte. The portion of the

	fault between Furnace Creek and Ashford Mill coincides with the Death Valley fault of Piety (1995 #915) and Central Death Valley fault of dePolo (1998 #2845). At the latitude of Ashford Mill, the Death Valley fault system changes orientation and sense of slip, from north-trending normal-oblique on the Black Mountains fault zone [142] to southeast-trending, predominately strike-slip on the Southern Death Valley fault zone [143]. **Section:** Name derived from Copper Canyon, one of the more prominent geographic landmarks along this the base of the Black Mountains and on this section of the fault. This section coincides with Knott's sections 3 and 4 in Machette and others (2001 #4773)) and the northern part of Frankel and others' (2001 #4776) medium-age section and all of the young-age section (Copper Canyon to Badwater). In addition, the Copper Canyon section includes four of Brogan and others sections: Badwater Turtleback (BT), Black Mountain (BM), Copper Canyon Turtleback (CO), and the Willow Creek (WC). The Copper Canyon section extends from Natural Bridge, south past Badwater and Copper Canyon to Mormon Point, where it becomes the Smith Mountain section [142d]. **Fault ID:** Refers to the southern part of fault 211 and northern part of fault 248 of Jennings (1994 #2878), fault DV-1F and part of DV-1G of dePolo (1998 #2845), and fault DV of Piety (1995 #915).
County(s) and State(s)	INYO COUNTY, CALIFORNIA
Physiographic province(s)	BASIN AND RANGE
Reliability of location	Good Compiled at 1:100,000 scale. *Comments:*
Geologic setting	This Death Valley fault system is comprised of major strike-slip fault zones on the north and south, and an intervening (linking) primarily normal fault zone. The fault system is comprised of the Fish Lake Valley fault zone [49], the Northern Death Valley fault zone [141], the Black Mountains fault zone [142], and the Southern Death Valley fault zone [143]. The fault system forms the strongly uplifted eastern margin of Death Valley and the

	western margin of Fish Lake Valley and marks a highly extended portion of the western Basin and Range Province. Structural studies by Stewart (1983 #1653) and Wernicke and others (1988 #1686) reported >80 km of northwestward extension across the valley, and proposed that much of the adjacent Panamint Range to the west has moved to its present location from atop the Black Mountains since late Miocene time. The Black Mountains fault zone is more-or-less coincident with the uplifted western margin of the Black Mountains and is characterized by primarily normal to oblique-slip along its entire length. The Black Mountains fault zone, which strikes about north, joins the northwest-striking Northern Death Valley fault zone [141] and the predominately pre-Quaternary Furnace Creek fault zone to form a nearly continuous feature that is one of the most active fault systems in the region.. Noble (1926 #1592) described, the Black Mountains fault zone (his Death Valley fault) as irregular in detail, with a zigzag pattern that results from a succession of faults that displace each other and create indented "cusps" along the front of the Black Mountains. Similarly, Hamilton (1988 #593) suggested that the fault is not likely a single steep range-front fault, but is probably "a series of step faults or the downdip continuation of the turtleback faults or a combination of steep and gentle faults." Estimates of vertical displacement on the Black Mountains fault zone range between 2 and 20 km. These estimates are based on a variety of stratigraphic and structural markers of different ages, as discussed by Piety (1995 #915). Fleck (1970 #1514) concluded that most of the vertical displacement on the fault zone probably occurred since about 6 Ma (before deposition of the Furnace Creek Formation), although Death Valley may have begun to form before this time. The maximum age for the onset of faulting is assumed by Brogan and others (1991 #298) to be middle Miocene on the basis of K-Ar ages for displaced volcanics believed to be coeval with faulting.
Length (km)	This section is 27 km of a total fault length of 70 km.
Average strike	N2°W (for section) versus N17°W (for whole fault)
Sense of movement	Normal *Comments:* This section has predominately normal movement with suggestions of oblique movement owing to a dextral (right-

	lateral) component. Wills (1989 #1693) considered the Black Mountains fault zone a "right-oblique fault with the west-side down." He noted right-lateral deflection of small drainages and along a northwest-striking section of DV south of Copper Canyon [locality 9 in \Wills, 1989 #1693]. Because deposition has been concentrated on the southwestern sides of alluvial fans between Badwater and Copper Canyons, Hooke (1972 #1546) inferred that the youngest displacements on the Black Mountains fault zone have been right-lateral strike slip. On the basis of oblique-slip striations on some fault surfaces, Hill and Troxel (1966 #1539) inferred a component of right-lateral slip on northeast-striking faults along the Black Mountains (e.g., north of Mormon Point). Slemmons and Brogan (1999 #5115) suggest that the evidence for lateral slip on the Black Mountains fault zone is more persuasive than generally recognized and suggest that the fault is oblique-normal in accord with the pull-apart origin of Death Valley suggested by Burchfiel and Stewart (1966 #1322). Brogan and others (1991 #298) noted some evidence for right-lateral separations of 3.6 m along the Copper Canyon Turtleback section and 0.2 m along the Badwater turtleback section of Brogan and others (1991 #298). Both of these displacements are on older Holocene (2 ka to 10 ka) surfaces and both are measured across subsidiary faults rather than the main trace of DV. Wills (locality 9, 1989 #1693) reported 1.8 to 3.6 m of right-lateral displacement for a gully on a northwest-striking section of the fault zone south of Copper Canyon.
Dip	40°-75° W *Comments:* Noble (1926 #1592) noted that fault planes, where they are exposed in bedrock, are nearly vertical. On the basis of near-vertical fault scarps on alluvial surfaces and a steep fault-line scarp, Miller (1991 #1579) inferred that the Black Mountains fault zone near Badwater dips at least 60? W. Drewes (1963 #1501) reported that dips of 40? W. to 55? W. are common on individual fault planes along the fault zone, but that dips of up to 75? SW. were observed southwest of Badwater and near Mormon Point.
Paleoseismology studies	Site 142c-1. Fault exposures and well-preserved scarps near Mormon Point along the Black Mountains fault zone enabled Klinger and Piety (2001 #4775) to make a more extensive analysis of the Holocene behavior of the Black Mountains fault

	than is typically permitted by an analysis of the scarp morphology alone. An average vertical surface displacement of 2.5?0.5 m is estimated for the Copper Canyon section of the Black Mountains fault zone. This estimate is based on measured scarp heights and preserved bevels and free faces on compound scarps produced by the last four ground-rupturing earthquakes (Klinger and Piety, 2001 #4775). In addition, an average Holocene slip rate of 1-3 mm/yr and recurrence interval of 1,000-2,000 years was estimated from a 10.5-m-high scarp near Willow Creek [142c-1], east of Mormon Point. The character of the scarp and associated alluvial fan geomorphology at this site suggests that the scarp was produced by four ground-rupturing events. An estimated age of 4-8 ka for the repeatedly displaced alluvial fan surface was made based primarily on degree of soil development and a correlation of other relative age criteria to the regional Quaternary stratigraphy (Klinger and Piety, 2001 #4775).
Geomorphic expression	This section of the fault zone contains classic examples of active tectonic features, including (but not limited to) fault scarps and grabens, lateral spread features, uplifted lacustrine gravel and tufa, and rockfall avalanche deposits. Owing to the relative youthfulness of the faulted deposits, most of the scarps record offsets of several meters. However, the largest scarps on late Pleistocene (>10 ka; Q2) surfaces (Brogan and others (1991 #298) have about 15 m of vertical separation and vertical slopes (free faces) along the Copper Canyon turtleback section of Brogan and others (1991 #298). The highest Holocene scarps observed by Wills (1989 #1693) are at Badwater, where he reported that scarps are 10 m high and have free faces 3 to 4 m high. Wills (1989 #1693) interpreted a graben, which is as much as 3 m deep, at the toe of the alluvial fan south of Badwater to be the result of lateral spreading and liquefaction of sand beds within alluvium. There are similar ground-shaking features all along the fault zone where alluvial fans rest on lacustrine deposits along the toe of the range.
Age of faulted surficial deposits	Along this section of the fault, most of the deposits that lie juxtaposed to the fault zone are relatively young (late Pleistocene and Holocene), whereas older deposits are either preserved as uplifted remnants of one more extensive deposits, or are deeply buried by younger debris. These geomorphic relationships have long been recognized as the hallmarks of active tectonic uplift along the front of the Black Mountains, compared with the more

	passive eastern front of the Panamint Range. Wills (1989 #1693) (p. 7) noted that the alluvial fan with a scarp 10 m high at Badwater has only weak varnish and little or no carbonate in the associated soil suggesting a Holocene age for the disrupted surface. The maximum vertical separation that is reported by Brogan and others (table 4, p. 21 1991 #298) is 15 m across a scarp on a late Pleistocene surface (>10 ka; Q2). This is along their Copper Canyon turtleback section (Brogan and others (1991 #298). In the Mormon Point area, the fault zone changes trend from generally north (on the north) to more east-west, and the faults splays out into a 1- to 1.5 km wide zone to form an intermediate level structural block that preserved sedimentary deposits of late and middle Pleistocene to late Pliocene age (Knott and others, 2001 #4772).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* Following reconnaissance in the region in the early 1920's, Noble (1926 #1592) noted that the scarps along the Black Mountains fault zone were "fresher than any other scarps of similar magnitude in the West" comparing them to scarps he had observed along the Garlock and San Andreas faults. Jennings (1992 #473) portrayed nearly the entire Black Mountains fault zone (between Furnace Creek Wash or Salt Springs and south of Jubilee Pass) as having Holocene (<10 ka) displacement. Wills (1989 #1693) noted that the evidence for Holocene displacement on the fault zone is "abundant." Klinger and Piety (2001 #4775) report that the morphology of the scarp and associated alluvial fan geomorphology at the Willow Creek site [142c-1], east of Mormon Point, suggests four ground-rupturing events in the past 4-8 k.y., clearly demonstrating recurrent Holocene faulting.
Recurrence interval	1-2 k.y. (past 4 to 8 k.y.) *Comments:* Klinger and Piety (2001 #4775) report an average recurrence interval of 1,000-2,000 years for the past 4-8 k.y., as estimated from a 10.5-m-high scarp near Willow Creek [142c-1], east of Mormon Point.
Slip-rate category	Between 1.0 and 5.0 mm/yr *Comments:* Various attempts have been made at estimating slip rates for this section of the fault zone, mainly as a result of the

	preservation and dating of tufa and lake strandlines in this area. Using differences in elevation of tufa and strandlines correlated with stands of Lake Manly, Hooke (1972 #1546) estimated late Pleistocene tilting rates on the Black Mountain fault zone. From his tilt-rate estimate of 0.016?/1 k.y. and assumption that the axis of tilting is 25 km west of the fault zone, Hooke (1972 #1546) estimated a total post-Wisconsin (<10-11 k.y.) displacement of about 63 m and a vertical slip rate of 7 mm/yr for fault zone since late Pleistocene time. This analysis relies on some fundamental assumptions (age, correlation) that are as yet unproven (Machette and others, 2001 #4433). Hunt and Mabey (1966 #1551) noted that the eastern shoreline of a late Holocene lake is 6 m (20 ft.) lower than the western shoreline and suggested that the tilting of the shoreline across the valley occurred as the result of movement on the fault. They estimated an age of 2,000 years for the tilted shorelines on the basis of archaeological artifacts in sand dunes that overlie lake deposits along the west side of Badwater Basin (Hunt, 1960 #1550; Hunt and Mabey, 1966 #1551). Assuming an age of 2 ka for the 6 m of offset yields an apparent late Holocene tilt rate (at the fault) of 3 mm/yr. More recently, Knott and others (2001 #4772) estimated a slip rate for the section just south of Badwater, where rockfall-avalanche deposits are offset by the fault zone. Here the fault forms a 28 m high scarp on deposits that are considered to be no older than 120-186 ka, based on U-series dating of nearby tufas. Hunt and Mabey (1966 #1551) didn't recognize these tufas on the faulted deposits, whereas Knott and others did. Nevertheless, Knott and others (2001 #4772) reported a minimum slip rate of 0.15-0.2 mm/yr for the singular trace of the fault that crosses the rockfall-avalanche deposits. Klinger and Piety (2001 #4775) reported an average Holocene slip rate of 1-3 mm/yr based on formation of a 10.5-m-high scarp near Willow Creek [142c-1]. An estimated age of 4,000 to 8,000 years for the repeatedly displaced alluvial-fan surface was made based primarily on degree of soil development and a correlation of other relative age criteria to the regional Quaternary stratigraphy.
Date and Compiler(s)	2001 Michael N. Machette, U.S. Geological Survey, Retired Lucy A. Piety, U.S. Bureau of Reclamation
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