Quaternary Fault and Fold Database of the United States

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Black Mountains fault zone, Mustard Hills transition zone (Class A) No. 142a

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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:** The Northern Death Valley fault zone [141] merges with the Black Mountains fault zone [142] over a broad area between Salt Springs and Furnace Creek in an area referred to by Klinger and Piety (1996 #3873) as the "Transition Zone." This area is herein termed the Mustard Hills transition zone, and is considered herein to be the northernmost section of the Black Mountains fault zone [142]. Brogan and others (1991 #298) extended the Black Mountains fault zone (there Death Valley fault zone) north of Furnace Creek Wash to Salt Springs. The portion of the fault between Furnace Creek Wash and Salt Springs is about 11 km long as estimated from Brogan and others (1991 #298). The Mustard Hills transition zone is marked by short discontinuous faults that trend northwest and northeast in an elongate N-S zone, and is associated with active folds in the Mustard Hills that also follow northwest trends (Machette and others, 2001 #4771), such as the Texas Springs Syncline [181]. The Mustard Hills transition zone represents a structurally complex area that allows the transfer of normal-oblique slip from the Black Mountains to the dextral-slip of the Northern Death Valley fault zone (Machette and others, 2001 #4771). The zone is characterized by a series of northwest-trending fault-bounded en echelon folds (mainly anticlines at the surface) that are bounded by young faults. The extent, geometry, and apparent young formation of these features have only recently been recognized (Machette and others, 2001 #4771) and their association with well established more continuous faults [141c, 142b] of the Death Valley system is only starting to be understood. **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:* Faults within the transition zone have been mapped at 1:24,000 scale by McAllister (1970 #1572) and Wills (1989 #1693), at 1:62,500 scale by Wright and Troxel (1993 #1701) and Brogan and others (1991 #298) (using 1:12,000 scale low sun-angle photos), at 1:96,000 scale by Hunt and Mabey (1966 #1551), and at 1: 100,000 scale by Reheis and Noller (1991 #1195). Recently, Machette and others (pl. 1 1999 #3874) produced a 1:2,000 scale geologic map showing faults over a small area around the Cow Creek Administrative Facility and Machette and others (fig. B2-2, 2001 #4771) have shown the transition zone at smaller scale (about 1:230,000). The traces used herein are adapted from Brogan and others (1991 #298), Hunt and Mabey (1966 #1551) and Reheis and Noller (1991 #1195) under the general context of Machette and others (fig. B2-2, 2001 #4771). The faults were transferred to a 1:100,000-scale map with topographic base.
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 8 km of a total fault length of 70 km.
Average strike	N34°W (for section) versus N17°W (for whole fault)
Sense of movement	Normal *Comments:* Near surface dips of the north-trending faults near Cow Creek Administrative facility are essentially vertical suggesting normal displacement, but the northwest-trending faults in the Mustard Hills area are of unknown dip and sense. There is some weak evidence of dextral offset in the geomorphology (Machette and others, 2001 #4771), but Arthur Sylvester (oral commun., 2001) has argued that these latter faults are thrusts that represent out of syncline (and anticline) motion.
Dip Direction	W; SW; NE
Paleoseismology studies	Site 142a-1. Two large backhoe trenches and a small hand-dug trench [142a-1] have been excavated near the National Park Service's Cow Creek administrative facility, about 5 km north of Furnace Creek Ranch. The two larger trenches were sited for the purpose of building construction, and no late Quaternary faults

	were found in either trench (pl. 2 in Machette and others, 1999 #3874). The smaller hand-dug trench [142-1] was excavated across a small scarp that is about 1 km NNW of the facility. This trench is shown in detail by Machette and others (pl. 2, 1999 #3874). The trench revealed evidence for a single faulting event of about 0.8 m offset in deposits that are considered to be 2-4 ka. Detailed mapping of these and older deposits in the vicinity of the Cow Creek Administrative Facility provided some basic limits on the timing, recurrence and amounts of offset associated with faulting on the transition zone [142a] between the Black Mountains [142] and Northern Death Valley [141] fault zones.
Geomorphic expression	Wills (1989 #1693) noted that the northernmost well-defined surface trace of the fault zone is just south of the Harmony Borax Works about 4 km north-northwest of Furnace Creek, however, more recent mapping by Machette and others (2001 #4771) shows clear evidence for young faulting north of the Cow Creek Administrative Facility (5 km north of Furnace Creek Ranch) The north-trending faults west and north of the facility form indistinct rhombohedral patterns that are controlled largely by the interaction of north-trending and northeast-trending normal faults. This rhombohedral pattern was recognized by Machette and Crone (Stop B3 in Machette and others, 2001 #4771) as a result of detailed (1:2,000 scale) mapping of the most recent surface ruptures. These include small antithetic faults with sand-filled fissures and associated larger (0.7- to 1.1-m high) event scarps. To the north, they documented scarps as much as 7 m high (minimum offset) on older, probable late Quaternary alluvial gravels. Wills (1989 #1693) noted two northwest-trending, en echelon anticlines, one at Mustard Canyon and the other south of the Harmony Borax Works and interpreted the anticlines to be the result of right-lateral displacement. In the Mustard Canyon Hills (Stop B2 in Machette and others, 2001 #4771) the faults are predominately northwest-trending as first shown by Hunt and Mabey (1966 #1551). These faults offset and cause abrupt tilting of older (unit Q2) gravels along the northeast and southwest margins of the hills. There is some weak geomorphic evidence of dextral offset (Wills, 1989 #1693; Machette and others, 2001 #4771), but there are no systematic measurements of offset channels along the margin of these folds. Further south (ca. 400 m north of the NPS Visitors Center north of Furnace Creek Ranch), Wills (1989 #1692) reported clear youthful dextral offset of

	channel margins and a small sag pond along a northwest-trending trace of the fault. The geomorphology of the active faults in the transition zone suggest late Holocene movement, and morphometric analysis of small scarps at Stop B3 (near the Cow Creek facility) by Machette and Crone (figs. B3-5 and B3-6 in Machette and others, 2001 #4771) suggests that these single event scarps may have formed as recently as 500-600 years ago.
Age of faulted surficial deposits	The youngest deposits that are offset along this section of the fault are late Holocene in age. These units are mapped as Q3c (youngest subdivision of Q3), and are estimated to have been deposited between 2-4 ka according to Machette and others (1999 #3874). Units mapped as Q4 (<200 yrs) are not offset, whereas older alluvium (Q2, late Quaternary) are offset from several to perhaps as much as 14 m (Machette and others, 2001 #4771), indicating multiple faulting events.
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* 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. Brogan and others (1991 #298) recognized Holocene surface rupture on all of the Black Mountains fault zone except for their Mustard Canyon section, which is between the Park Service facilities at Cow Creek and about 2 km north of Furnace Creek Ranch [i.e., [142a]). However, more detailing mapping by Machette and others (1999 #3874; Machette and others, 2001 #4771) indicates that this is not true. Their morphometric studies of the fault scarps suggest late Holocene movement, perhaps as recently as 500-600 years ago. Wills (1989 #1692) reported evidence for youthful dextral offset of channel margins and a small sag pond along a northwest-trending trace of the fault that is perched on the western end of a down-faulted alluvial surface about 400 m north of the NPS Visitors Center north of Furnace Creek Ranch).
Recurrence interval	6.7 k.y. (0-100 ka) *Comments:* Machette and Crone (Stop B3.3, table B3-2 in Machette and others, 2001 #4771) calculated minimum, preferred and maximum recurrence intervals for the faulting events

	recorded in young and old scarps north of the Cow Creek Administrative Facility. They used 2/3 m as the characteristic amount of offset from the most recent event, and considered ages of <70 ka, 100 ka, and <200 ka for the large (7 m) scarps on unit Q2c. In addition, they stated that the scarp height is a minimum estimate of fault offset, and thus considered three offset amounts (7 m, 10 m , and 14 m) as the probable lower, median, and upper bounds. Using this data, they calculated a preferred recurrence interval of about 6.7 k.y. for the past 100 ka. The lower and upper bounds were 3.5 k.y. and 20 k.y., respectively. However, as a note of caution, one should only consider these values as representative of the transition zone [142a]: sections of the Black Mountains fault zone to the south are likely to be more active owing to their position along the main (large offset) fault zone.
Slip-rate category	Less than 0.2 mm/yr *Comments:* Machette and Crone (Stop B3.3, table B3-2 in Machette and others, 2001 #4771) calculated minimum, preferred and maximum slip rates for the faulting events recorded in young and old scarps north of the Cow Creek Administrative Facility. They used 2/3 m as the characteristic amount of offset from the most recent event, and considered ages of <70 ka, 100 ka, and <200 ka for the large (7 m) scarps on unit Q2c. In addition, they stated that the scarp height is a minimum estimate of fault offset, and thus considered three offset amounts (7 m, 10 m, and 14 m) as the probable lower, median, and upper bounds. Using this data, they calculated a preferred slip rate of about 0.10 mm/yr for the past 100 ka. The lower and upper bounds were 0.04 mm/yr and 0.2 mm/yr, respectively. However, as a note of caution, one should only consider these values as representative of the transition zone [142a]: sections of the Black Mountains fault zone to the south are likely to be more active owing to their position along the main (large offset) fault zone.
Date and Compiler(s)	2001 Michael N. Machette, U.S. Geological Survey, Retired Ralph E. Klinger, U.S. Bureau of Reclamation Lucy A. Piety, U.S. Bureau of Reclamation
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