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Are the Benches at Mormon Point, Death Valley, California, USA, Scarps or Strandlines?

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The benches and risers at Mormon Point, Death Valley, USA, have long been interpreted as strandlines cut by still-stands of pluvial lakes correlative with oxygen isotope stage (OIS) 5e/6 (120,000–186,000 yr B.P.) and OIS-2 (10,000–35,000 yr B.P.). This study presents geologic mapping and geomorphic analyses (Gilbert's criteria, longitudinal profiles), which indicate that only the highest bench at Mormon Point (∼90 m above mean sea level (msl)) is a lake strandline. The other prominent benches on the north-descending slope immediately below this strandline are interpreted as fault scarps offsetting a lacustrine abrasion platform. The faults offsetting the abrasion platform most likely join downward into and slip sympathetically with the Mormon Point turtleback fault, implying late Quaternary slip on this low-angle normal fault. Our geomorphic reinterpretation implies that the OIS-5e/6 lake receded rapidly enough not to cut strandlines and was ∼90 m deep. Consistent with independent core studies of the salt pan, no evidence of OIS-2 lake strandlines was found at Mormon Point, which indicates that the maximum elevation of the OIS-2 lake surface was −30 m msl. Thus, as measured by pluvial lake depth, the OIS-2 effective precipitation was significantly less than during OIS-5e/6, a finding that is more consistent with other studies in the region. The changed geomorphic context indicates that previous surface exposure dates on fault scarps and benches at Mormon Point are uninterpretable with respect to lake history.

Key Words: **Death Valley; pluvial lakes; fault scrapes.**

INTRODUCTION

Midlatitude, midcontinent pluvial lake basins, like Death Valley, may preserve better records of past precipitation and global barometric patterns than deep-sea cores or ice sheets, which are dominantly high-latitude records (Smith, 1991a). Death Valley is inferred to be the terminal basin for the Owens, Mojave, and Amargosa Rivers by sequential spillover of upstream lakes during the highest effective moisture periods of the Quaternary (Smith, 1984, 1991b). Thus, Death Valley pluvial lakes record the magnitude and duration of climate change over a large area of the western United States during the wettest times of the Quaternary as well as provide a record of global barometric patterns.

Unfortunately, geomorphic evidence of Death Valley pluvial lakes is sparse and subtle (Fig. 1) (Hunt and Mabey, 1966). Moreover, the active faulting complicates interpretation of strandlines and fault scarps. For example, the strandlines on the Warm Springs Canyon fan have been described as a beach cliff cut into a fault scarp, and the Hanaupah fan strandline may be the southerly expression of the Hanaupah fault scarp (Hooke, 1972, p. 2092). These examples show that in tectonically active areas, like Death Valley, purported strandlines must be scrutinized closely to determine the geologic processes (i.e., faulting vs. wave action) responsible for such features.

In this paper, we present field observations, geologic mapping, and geomorphic analysis from Mormon Point (Fig. 2), one of the most studied strandline locations in Death Valley (Noble, 1926; Blackwelder, 1933, 1954; Hunt and Mabey, 1966; Hooke, 1972; Dorn, 1988; Dorn *et al.*, 1989, 1990; Burchfiel *et al.*, 1995; Pack and Reid, 1995; Trull *et al.*, 1995; Meek, 1997; Ku *et al.*, 1998). Here, it has been reported that oxygen isotope stage (OIS) 5e/6 strandlines are only 45 m above OIS-2 strandlines (Dorn *et al.*, 1990), implying that effective precipitation was nearly equal during these two pluvial periods, which is inconsistent with observations elsewhere in the region (e.g., Searles Lake; Jannik *et al.*, 1991). We examined these purported strandlines by applying geologic mapping (Fig. 3) and the same

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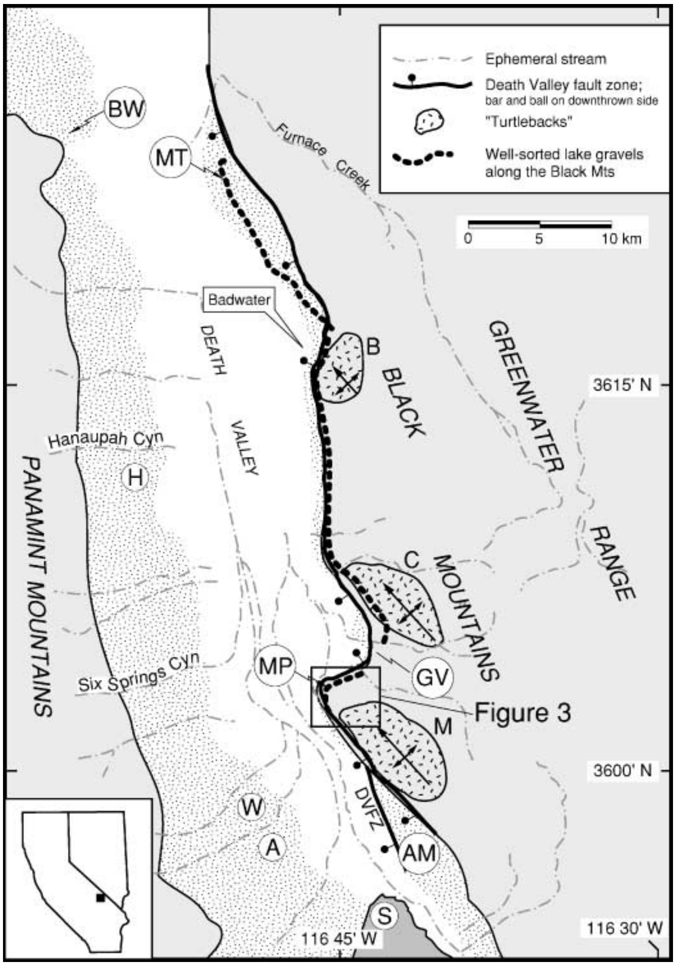

FIG. 1. Map showing the locations of reported shoreline features in Central Death Valley: A: Anvil Canyon fan; AM: alluvial fan north of Ashford Mill Canyon; BW: basalt south of Blackwater wash; GV: Gold Valley; H: Hanaupah Canyon fan; MT: Manly Terrace; S: Shoreline Butte; W: Warm Spring Canyon fan. Dashed black line marks the extent of interbedded well-sorted gravel and tufa from near Mormon Point to Manly Terrace. Also shown are the Death Valley turtlebacks (B = Badwater; C = Copper Canyon; M = Mormon Point).

field criteria to Mormon Point that G. K. Gilbert (1890) employed to interpret the geologic processes (e.g., wave action, tectonics, landsliding) responsible for forming the benches and risers along Lake Bonneville, Utah. Our observations suggest that many of the risers at Mormon Point are fault scarps and that the lowest bench is the surface of an uplifted alluvial fan. We then use these new interpretations to make inferences regarding the pluvial lake depth and recession, the OIS-5e/6 effective precipitation, the maximum elevation of the OIS-2 lake surface, and low-angle normal faulting.

GEOLOGIC SETTING

Stratigraphy and Structure

The stratigraphic and structural relations at Mormon Point are shown schematically in Fig. 4. Two of the more important stratigraphic units are the lower to middle Pleistocene Mormon Point formation of Knott *et al.* (1999) and the overlying well-sorted, near-shore lacustrine conglomerates of Drewes (1963) and Hunt and Mabey (1966). The well-sorted conglomerate (Ql) is clast-supported and cross-bedded with rare interbeds of massive, fine- to medium-grained sand, and thickly bedded tufa. These deposits are, for all practical purposes, continuously exposed along the Black Mountains (Fig. 1) from Mormon Point to Badwater (Hooke, 1972).

Ku *et al.* (1998) reported uranium-series ages between 150,000 and 216,000 yr on tufa at Mormon Point (Table 1). They suggest an age of 128,000–186,000 yr (OIS-5e/6) for the well-sorted conglomerate, which is correlative with uranium-series dated lacustrine deposits of the same age in a core drilled near Badwater (Lowenstein *et al.*, 1999). Knott *et al.* (1999) established that the well-sorted conglomerate overlies the Dibekulewe ash bed, indicating a maximum age of ∼510,000 yr.

Core sediments retrieved from the lowest part of Death Valley also indicate the presence of a perennial lake during OIS-2 from 10,000 to 35,000 yr B.P. (Lowenstein *et al.*, 1999). This result is consistent with studies by Hooke (1972) and Anderson and Wells (1996), which found evidence of an OIS-2 lake in cores drilled at various locations on the salt pan well below sea level.

Inset below the well-sorted conglomerate at Mormon Point, are angular to subangular, poorly sorted conglomerates and breccias (Qg_2 in Fig. 3) that form terraces (Burchfiel *et al.*, 1995) and alluvial-fan deposits (Hunt and Mabey, 1966). These deposits are most apparent in Mormon Point Canyon (Fig. 3). The position of the terrace closer to the active channel (Qg_4) and below the OIS-5e/6 conglomerate (Ql) indicates the terraces are younger than OIS-5e/6.

The Mormon Point promontory extends into the Death Valley salt pan (Fig. 1) at an en-echelon right step in the Death Valley fault zone that is coincident with the Mormon Point turtleback. The term turtleback refers to three antiformal surfaces exposed along the Black Mountains near Badwater, Copper Canyon, and Mormon Point that have the general appearance of a turtle carapace (Curry, 1938). The turtleback surfaces are defined by low-angle normal faults, locally called turtleback faults. The Mormon Point turtleback fault dips ∼20° to the north and separates the underlying Precambrian rocks from the overlying Cenozoic sedimentary rocks (Fig. 3).

Geophysical data suggest that the Mormon Point turtleback fault extends in the subsurface north and west of the mountain front where it is interpreted to be offset by high-angle faults (Keener *et al.*, 1993). High-angle faults south of the mountain front, including the Willow Wash fault, cut the Mormon Point formation; however, exposures show that these high-angle faults merge with, but do not offset, the turtleback fault (Fig. 3) (Troxel, 1986; Burchfiel *et al.*, 1995). Based on these and other structural relations, Burchfiel *et al.* (1995) inferred that the high-angle faults slip sympathetically with the turtleback fault. Knott *et al.* (1999) showed that the Mormon Point turtleback fault offsets

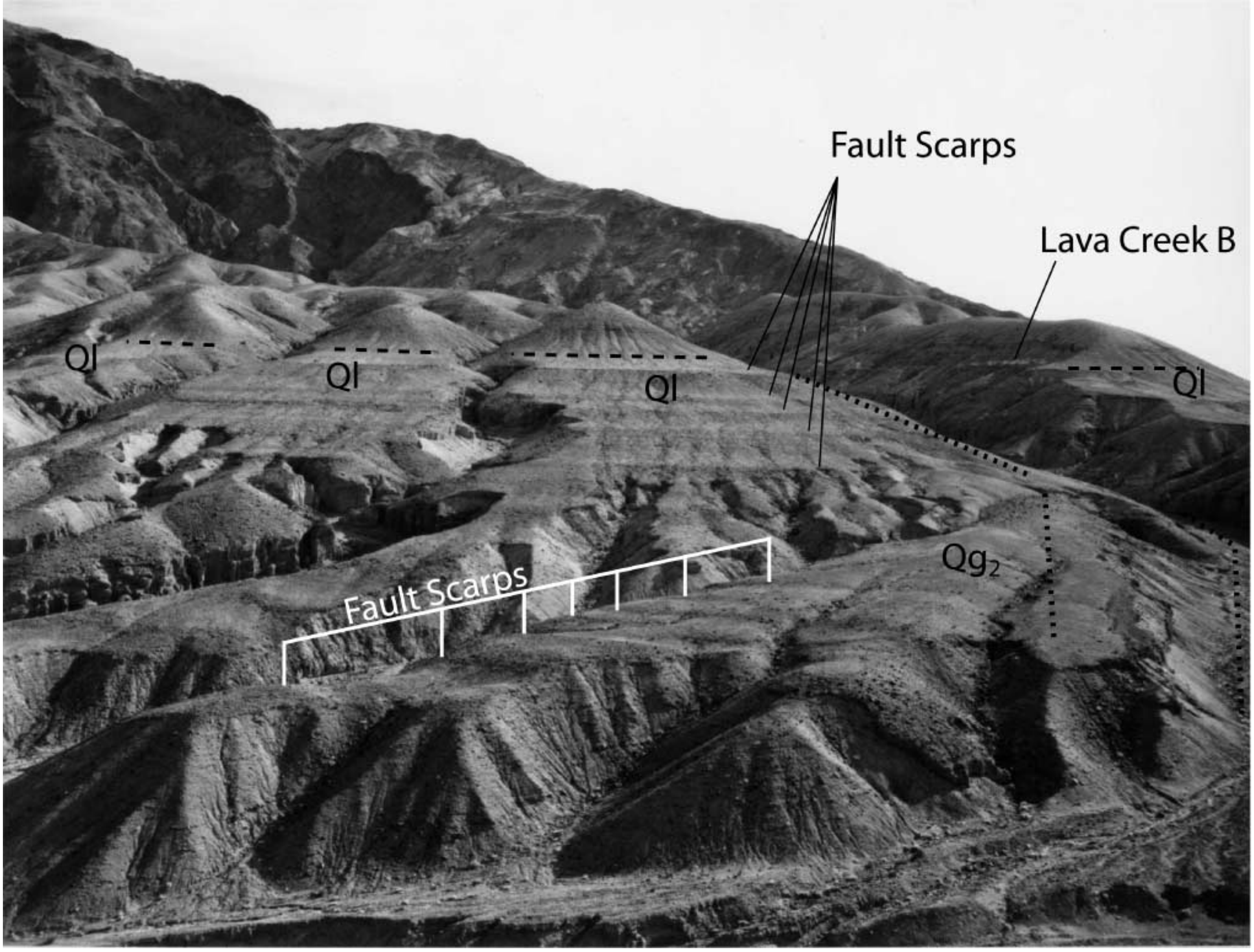

FIG. 2. A. Oblique aerial photograph, looking south at Mormon Point, Death Valley, California. Mormon Point Canyon is the larger canyon to the right. Ql = well-sorted lacustrine gravels; Qg_2 = alluvial fan deposits. Dashed line shows the approximate location of the base of the beach cliff of the strandline near +90 m msl. Dotted line just east of Mormon Point Canyon is the trend of schematic profile (Fig. 4) and the longitudinal profile for Qg_2 and Ql shown on Figure 5. The dotted line on the right edge of the photograph is the active channel profile shown on Figures 4 and 5. Features are labeled as fault scarps based on Gilbert's criteria and exposures in Mormon Point Canyon walls. The ~660,000-yr-old Lava Creek B ash bed is visible in west wall of Mormon Point Canyon. The field of view is approximately 300 m. Photograph by John Shelton (used by permission).

the 760,000 yr B.P. Bishop tephra bed, but does not offset the 120,000–186,000 yr B.P. well-sorted conglomerate southwest of Mormon Point (Fig. 3).

Previous Work on the Mormon Point Benches

Table 1 summarizes the shoreline measurements and chronologic data collected from Mormon Point. The field relationships of the published dates and the mapping are shown schematically in Figure 4 with respect to the true elevation of the samples. When all the data are compiled in this way, it is clear that there is no relationship between decreasing age and shoreline elevation, and that the number and elevations of shorelines are not consistent from one study to another. The variation in the shoreline elevations might be due to the accuracy of the survey methods employed, which ranged from topographic map interpretation (Drewes, 1963), to laser theodolite (Meek, 1997), or possibly to differences in the location of measurements. The age differences may be attributable to the accuracy and precision of the dating method or the type of feature dated (riser vs. bench). For example, clasts on the risers may have different exposure histories due to local erosion. The different number of shorelines (steps or terraces) may be attributable to transect location or interpretation of what constitutes a bench or riser.

PRINCIPLES AND METHODS

Geologic and Geomorphic Mapping

Geologic and geomorphic mapping of the Mormon Point area was done on 1 : 24,000 topographic maps and 1 : 12,000

TABLE 1
Shoreline Elevations and Dates

Shoreline elevations (m msl)	Age (sample elevation in m msl)	Geomorphic feature dated	Dating method	Number of shorelines	Reference
79 to 46	ND	ND	NA	5	Drewes (1963)
88, 70, 61, 49, 32, 17	11,000 to 26,000 ^{14}C years B.P.[a]	ND	Correlation	10	Hooke (1972)
88	120,000 to 130,000 (88)	Shoreline	Cation-ratio rock varnish	ND	Dorn *et al.* (1990)
15	12,630 ± 110 ^{14}C years B.P. (15)	High shoreline	^{14}C rock varnish	ND	Dorn (1988)
3	12,970 ± 185 ^{14}C years B.P. (3)	Beach Ridge	^{14}C rock varnish	ND	Dorn *et al.* (1990)
3, 18, 55, 61, 91, 158	44,000 to 55,000 (3)	Lake Bottom	Cosmogenic ^{10}Be and ^{26}Al on quartzite cobbles	6[c]	Trull *et al.* (1995)
	24,000 (18)	Lowest Beach Terrace			
	53,000 to 68,000 (61)	Second Beach Terrace			
	17,000 to 69,000 (91)	Third Beach Terrace			
	41,000 to 135,000 (158)	Uppermost Beach Terrace			
116, 104–113[b], 92, 69, 52, 49, 39, 26, 12, −1,	ND	NA	NA	6 "major" 10 total	Meek (1997)
ND	150,000 ± 6,000 (57)[d] 171,000 ± 7,000 (63) 216,000 ± 15,000 (73)	Interbedded tufa	Uranium series	NA	Ku *et al.* (1998)

ND = not determined; NA = not applicable.

[a] Age range based on correlation with cores retrieved from the valley floor.

[b] Meek describes the elevation between 104 and 113 m as the bathtub ring and suggested a "paleolake level" of +92.8 m.

[c] Trull *et al.* described surfaces rather than shorelines.

[d] Ku *et al.* collected samples south of Mormon Point but did not specify if samples were from shoreline features.

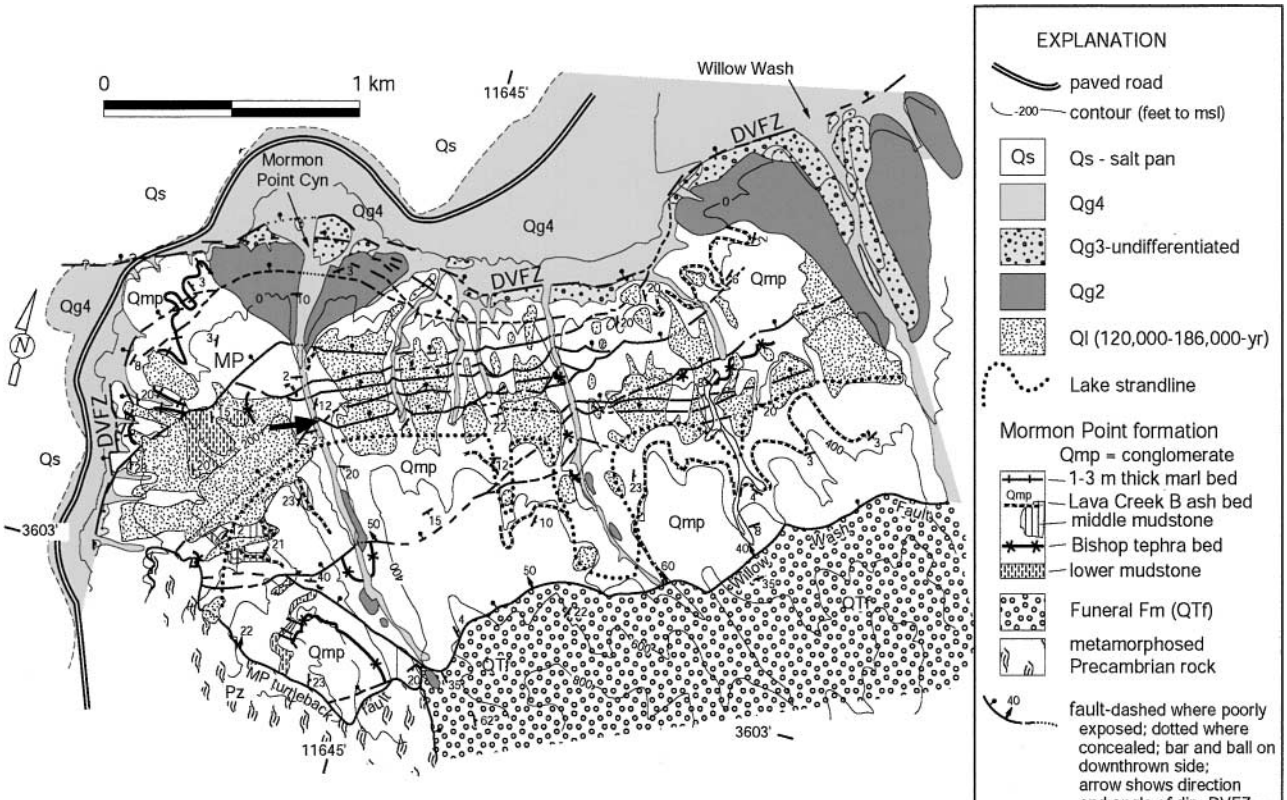

FIG. 3. Geologic map of Mormon Point and vicinity. The explanation provides the stratigraphic relationships for the area. Arrow shows view of canyon wall in Figure 6. MP indicates the location of Mormon Point.

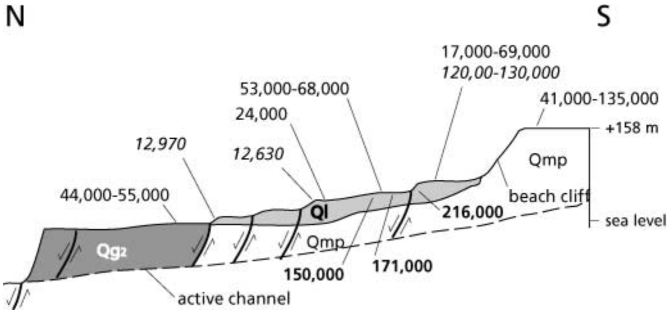

FIG. 4. Schematic of a 1-km-long profile of the east wall of Mormon Point Canyon (dotted line on Fig. 2) showing the relative stratigraphic and elevation relations of the geochronologic data collected in previous studies and the geologic mapping from this study. The dashed line at the base of the profile represents the active channel profile. Regular fonts are ^{10}Be ages from Trull *et al.* (1995). Italicized fonts are uncalibrated ^{14}C and cation-ratio varnish dates from Dorn (1988) and Dorn *et al.* (1989, 1990). Ages in bold font are U-series ages from Ku *et al.* (1998) collected south of Mormon Point and shown here based on the elevation of the sample. All ages are in years except ^{14}C varnish data, which are in ^{14}C years. See Table 1 for a listing of ages and elevations, including analytical error for the chronology.

low sun-angle aerial photographs. Geomorphic surfaces are distinguished by position relative to the active channel, degree of desert pavement development, and percentage of varnish-coated clasts. Hunt and Mabey (1966) and Hooke (1972) used these characteristics successfully for mapping throughout Death Valley. McFadden *et al.* (1989) showed that these parameters are sufficient to distinguish between Pleistocene and Holocene alluvial fan surfaces.

Geomorphic Analysis

The geomorphic field criteria of Gilbert (1890) were used to infer the geologic processes responsible for bench and riser formation at Mormon Point. Gilbert, while working along the shores of pluvial Lake Bonneville, found that hillslope benches might form by differential erosion, landsliding, fluvial incision, faulting, or wave action. Dissimilar rock types on either side of the riser distinguish benches formed by differential erosion from all others. Distinctive geomorphic features such as lateral fissuring or toe bulging accompany landslide benches, while fluvial benches, or terraces, trend parallel to a channel.

Benches formed by wave action and faulting are geomorphically very similar to each other; however, they may be discriminated by the following criteria (Gilbert, 1890). Wave-cut benches, or strandlines, are (1) independent of underlying structure, (2) associated with clastic lacustrine deposits at either end (e.g., bars and spits), and (3) the base of the riser is horizontal. In contrast, fault-generated benches and risers (scarps) (1) correspond to underlying structure, (2) are not associated with clastic lacustrine deposits, and (3) the base of the riser may or may not be horizontal. At Mormon Point, determining the deviation of the riser base from the horizontal is obscured, in most cases, by local erosion and deposition. However, excellent exposures in canyons to either side make application of the other criteria optimal.

Longitudinal profiles of geomorphic surfaces were drawn to supplement geologic mapping and Gilbert's field criteria. Longitudinal profiles of streams can be sensitive tectonic indicators when other geomorphic processes are relatively constant and if one assumes that the original gradient of the terrace was similar to the modern stream gradient (Bull and McFadden, 1977; Wells *et al.*, 1988). Along uplifting mountain fronts, the gradient of progressively older terraces may change over time; however, the gradient of these terraces tends to remain subparallel to the modern stream. At Mormon Point, longitudinal profiles were drawn along the modern channel, and the geomorphic surfaces just east of Mormon Point where the benches are best developed (Fig. 2) and where Dorn *et al.* (1989, 1990) sampled for varnish ages and Trull *et al.* (1995) collected samples for surface-exposure dating. Profiles were drawn from 1 : 24,000 topographic maps with a 12-m (40 foot) contour interval.

RESULTS

Mapping at Mormon Point (Fig. 3) shows that the OIS-5e/6 conglomerate mantles the southwestern and eastern areas of Mormon Point. Much of the southern contact of this well-sorted conglomerate is along a set of triangular facets cut into north–south trending spur ridges, with scattered outcrops found in several of the canyons between the spur ridges (Fig. 3). The maximum thickness (∼15 m) of the well-sorted conglomerate is found southwest of Mormon Point where cross beds dip to the south. Silicic clasts on the surface are commonly varnished, while carbonate clasts are deeply pitted. Well-developed desert pavements are sparsely preserved due to local erosion and deposition.

Geologic mapping, sedimentary facies, and geomorphology indicate that the sediments at the mouth of Willow Wash and Mormon Point Canyon (Qg_2) were deposited as alluvial fans. Facies exposed in the canyon walls are angular, poorly sorted, thick bedded, matrix-supported gravels and cobbles interbedded with clast-supported angular gravels, which are typical facies of alluvial fan deposits (Bull, 1977). The conical outcrop pattern, radiating from the active channels (Fig. 3) is also indicative of an alluvial fan (Bull, 1977). Lacustrine deposits (e.g., laminated silts), as expected in the lake bottom proposed by Trull *et al.* (1995), were not observed. In addition, the longitudinal profile of the Qg_2 surface is subparallel to the active alluvial fan and channel, suggesting that Qg_2 is an abandoned alluvial fan/channel system (Fig. 5). These data support the interpretation that the angular gravels at the mouths of Mormon Point Canyon and Willow Wash were deposited as alluvial fans.

The surface of Qg_2 is composed of well-varnished, angular to subangular clasts in a well-developed desert pavement, which

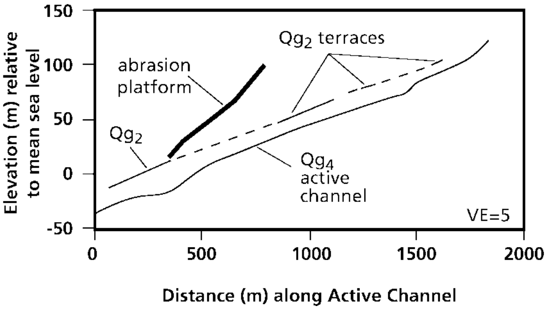

FIG. 5. Longitudinal profiles of active channel of Mormon Point Canyon, Qg$_2$ surface, and abrasion platform just east of Mormon Point Canyon showing the subparallel gradient of the active channel and Qg$_2$ surface. See Figure 2 for the locations of the profiles.

is consistent with the Qg$_2$ of Hunt and Mabey (1966). The Qg$_2$ surface is estimated to be 35 m above the active channel at the mouth of Mormon Point Canyon. Upstream, the profile formed by terraces and Qg$_2$ converges toward the active channel, as expected with uplift along a frontal fault (e.g., Wells *et al.*, 1988). Facies (e.g., well-sorted, imbricate gravels) consistent with a "beach ridge" on the Qg$_2$ surface, as described by Dorn *et al.* (1989, 1990), were not observed.

Geomorphology of the Mormon Point Benches

As described in several earlier studies, the surface of the OIS-5e/6 conglomerate at Mormon Point is interrupted by a series of benches interpreted as lacustrine strandlines (Noble, 1926). A bench consists of two relatively flat surfaces (treads) separated by a comparatively steep slope (riser). The benches and risers at Mormon Point are best developed east of Mormon Point Canyon (Fig. 2), where the risers trend nearly east–west.

The benches at Mormon Point do not correspond to a lithologic change and thus are not formed by differential erosion. In the past, Mormon Point turtlebacks were thought to have formed by gravitational unroofing (Sears, 1953; Drewes, 1963). However, Wernicke (1981) has argued that tectonics is the main driving force in Death Valley low-angle normal fault systems. A tectonic origin is consistent with kinematic slip indicators on the Mormon Point turtleback fault, which are oblique to the maximum gradient, indicating forces other than solely gravitational (Keener *et al.*, 1993). Geophysical data show that the turtleback surfaces extend to depths of 2–3 km below the salt pan (Keener *et al.*, 1993); landslides, being surficial phenomena, do not extend to such depths into the crust. Finally, if the benches at Mormon Point were landslide headscarps, it is difficult to imagine the landslide mass moving because the valley fill deposits would buttress the slide mass. Thus, from the preponderance of data and observations, we conclude that the benches are not the result of landsliding. The benches are perpendicular to the trend of the present channels and, thus, are not fluvial terraces.

Therefore, according to Gilbert (1890), the two remaining bench-forming processes are faulting and wave action. To determine if faulting or wave action formed the benches, the canyon walls at either end of each riser were examined. The topographically highest bench and riser are found at the base of a set of triangular facets, called beach cliffs by Hooke (1972), formed on the N–S trending spur ridges near 90 m above mean sea level (msl) (Fig. 2). The canyon walls at the base of the facets consist of thickly bedded Mormon Point formation conglomerate that dip gently south and are overlain by well-sorted conglomerate. No faults were observed in the canyon walls at the base of the facets during this study or mapped by Burchfiel *et al.* (1995). As described above, deposits of the well-sorted conglomerate (Ql) extend south from the highest bench up the N–S trending canyons south (Fig. 3). These extensions of clastic sediments from stable headlands are interpreted as spits. Thus, the upper bench is independent of underlying structure and is associated with clastic lacustrine deposition (spits). Therefore, the bench located at the base of the faceted spur ridges (Fig. 2) at ~90 m msl is inferred to have formed by wave action and interpreted to be a lacustrine strandline. We concur with Hooke (1972) that the facets are beach cliffs, and we infer that the north-descending slope is an abrasion platform. The profile of the well-sorted conglomerate surface, which is steeper than both the active channel and the uplifted alluvial fan (Figs. 2 and 5), has a gradient similar to coarse sand beaches (Bascom, 1951).

We observed five other continuous and mappable risers cut into the abrasion platform east of Mormon Point Canyon (Fig. 2). Where each of these risers intersects the canyons, the Mormon Point formation conglomerate exposed in the canyon walls is offset by north-dipping normal faults (Fig. 6). In some places, these faults are exposed, cutting through the well-sorted conglomerate offsetting the unconformity at the base and forming risers on the ground surface (this study; Burchfiel *et al.*, 1995, p. 210). In many cases, the upper few meters of these faults are covered by colluvium; however, the faults all project upward to risers (Fig. 6). Risers independent of faults were not observed below the ~+90-m msl strandline. No spits or bars are found with respect to these risers. Thus, these risers, and associated benches, are (1) dependent on structure and (2) not associated with clastic lacustrine deposits. Therefore, according to Gilbert's criteria, these benches are inferred to be fault scarps and not strandlines. The bench that Trull *et al.* (1995) described as a lake terrace at +158 m msl appears to be a colluvial covered ridge with no evidence of lacustrine deposits or strandlines.

The high-angle faults that form scarps on the abrasion platform are down-to-the-north normal faults dipping between 22° and 85°N (Fig. 3). Consistent with Troxel (1986) and Burchfiel *et al.* (1995), our mapping shows that the high-angle faults, where exposed, are cut or merge (e.g., the Willow Wash fault) with the Mormon Point turtleback fault. Thus, we concur that these high-angle faults probably slip sympathetically or predate the latest slip on the turtleback fault.

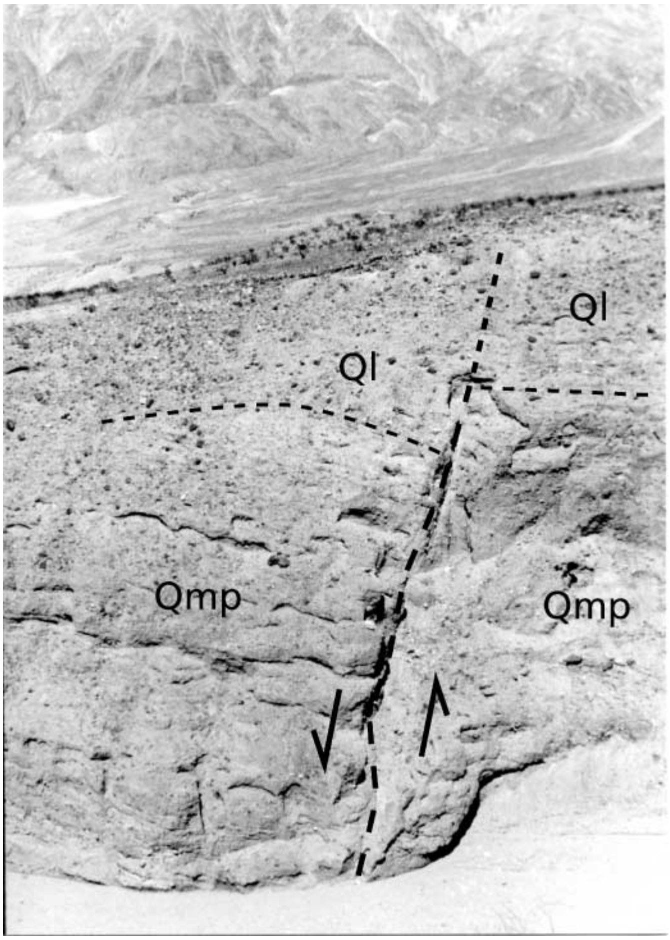

FIG. 6. View of east wall of Mormon Point Canyon showing the highest and most prominent abrasion platform fault scarp visible in Figure 2. This is a typical view for all the scarps along Mormon Point Canyon, which display the more resistant Mormon Point formation (Qmp) and overlying 120,000–186,000-yr-old well-sorted lacustrine conglomerates (Ql) cut by a north-dipping (north-side-down) normal fault. A gentle fault scarp is visible across the abrasion platform surface. Height of the canyon wall is about 30 m.

DISCUSSION

Reinterpretation of Lake Shorelines and Lake History

Gilbert's field criteria indicate that there is only one strandline at Mormon Point, which is at ∼+90 m msl (Figs. 2 and 3). The topographically lower risers examined in this study are interpreted to be fault and fault-line scarps offsetting the abrasion platform. Our new interpretation is circumstantially consistent with the earlier observations by Hooke (1972) that the upper bench and riser at Mormon Point is better developed than the lower benches and risers by showing that the upper bench formed by a different process (wave action) than the lower benches (faulting).

The reinterpretation of the lower risers at Mormon Point does not preclude the possibility that recessional strandlines are preserved elsewhere in Death Valley (e.g., Shoreline Butte). However, at Mormon Point, the lower risers below the high strandline are fault scarps. We interpret the lack of recessional strandlines to indicate that the OIS-5e/6 pluvial lake receded from its high stand at Mormon Point without significant still-stands, or more rapidly than previously thought.

The geomorphic relations indicate that the local depth of the OIS-5e/6 lake at Mormon Point was about 90 m. This is based on the elevation of the high stand (∼+90 m msl) and the elevation of the apex of the Qg_2 alluvial fan near sea level. The absence of lacustrine facies interbedded with the Qg_2 deposits indicates that Qg_2 was deposited at or near the local base level, which was unaffected by the pluvial lake. From these observations, we infer that the Qg_2 alluvial fan must have been deposited at or near the valley floor at Mormon Point. The 90-m depth is significantly less than the 335-m lake depth estimated by Lowenstein *et al.* (1999) at Badwater and indicates that the Death Valley pluvial lakes shallowed rapidly away from the lowest point near Badwater.

Because we interpret the risers at +15 m msl and +3 m msl as fault scarps, the 12,630 ± 110 ^{14}C yr B.P. (Dorn, 1988) and 12,970 ± 185 ^{14}C yr B.P. (Dorn *et al.*, 1989, 1990) rock-varnish ages are not relevant to lake history. Dorn's (1988) and Dorn *et al.*'s (1989, 1990) descriptions (e.g., beach ridge) imply that the rock-varnish samples were collected on the risers or fault scarps. Thus, in addition to possible analytical problems associated with both the cation-ratio and radiocarbon varnish-dating techniques (e.g., Watchman, 2000; Beck *et al.*, 1998), the rock-varnish ages measured on clasts from Mormon Point do not date lake strandlines. Based on the sample location description provided by Dorn *et al.* (1990), we cannot determine the geomorphic context (riser or bench) of the 120,000–130,000 yr B.P. cation-ratio varnish date as well. With this combined sampling uncertainty and analytical problems, we find that the cation-ratio date is not interpretable with respect to lake history.

We have interpreted the lake terraces dated by Trull *et al.* (1995) using ^{10}Be to be a faulted abrasion platform and an alluvial fan (Qg_2) surface. Even though the ages are not inconsistent with morphologically similar alluvial fan surfaces to the south, the wide range of age, and the lack of detailed sampling locations, we find it difficult to interpret the exposure ages of the abrasion platform and alluvial fan surfaces, especially in light of our new geomorphic interpretation. Based on its geomorphic position inset below the 120,000–186,000 yr B.P. well-sorted conglomerate dated by Ku *et al.* (1998) (Fig. 2), at this time, we interpret the age of the Qg_2 deposit and surface to be less than 120,000–186,000 yr B.P. (OIS-5e/6). Comparing the surface morphology with those described by McFadden *et al.* (1989) indicates that Qg_2 is Pleistocene in age (i.e., not Holocene) and therefore was most likely present during OIS-2.

The absence of OIS-2 strandlines at Mormon Point is consistent with the studies of drill cores in the lowest parts of Death Valley. Hooke (1972) showed that lacustrine (unoxidized) sedimentation receded below −89 m msl by 17,440 ^{14}C yr B.P. Consistent with this result, Anderson and Wells (1996) showed that the pluvial lake receded below −84 m msl by 17,550 ± 80 ^{14}C yr B.P. In both studies, lacustrine sediments ∼12,000 yr old are found only near Badwater, thereby indicating that by 12,000 yr B.P., the pluvial lake covered only the lowest part of the Death Valley salt pan. Thus, two independent coring studies indicate that the OIS-2 lake could not have cut shoreline features at or above sea level ~12,000 yr ago.

On the basis of the rock-varnish dated beach ridge at Mormon Point, Li *et al.* (1996) inferred a depth of ~90 m for the OIS-2 lake. Our interpretation indicates that these beach ridges are fault scarps, which raises the question: what was the elevation of the OIS-2 lake? Because the Qg_2 shows no evidence of lacustrine erosion or deposition, we infer that the maximum surface elevation of the OIS-2 lake is −30 m msl, or a maximum depth of 60 m. This lake surface elevation and lake depth are probably overestimated considering that the core data indicate that the OIS-2 lake was ~2 m deep after ~17,000 yr B.P. (Hooke, 1972; Anderson and Wells, 1996). The shallower OIS-2 lake indicates that effective precipitation during OIS-2 was significantly less than during OIS-5e/6, at least in the Death Valley drainage basin, which is consistent with other pluvial lake records in the region (Smith, 1984).

Quaternary Low-Angle Faulting

Outcrops, structural relations, and geophysical data suggest that high-angle faults south of the mountain front merge into and thus slip sympathetically with slip on the Mormon Point turtleback fault (Troxel, 1986; Keener *et al.*, 1993; Burchfiel *et al.*, 1995; Fig. 3). This is consistent with upper-plate fault geometries observed above low-angle normal faults elsewhere (Axen *et al.*, 1999). Assuming that the high-angle faults that offset the abrasion platform have this same behavior, then the scarps that offset the 120,000 to 186,000-yr-old well-sorted conglomerate imply that slip on the low-angle normal Mormon Point turtleback fault postdates 120,000–186,000 yr B.P. However, an outcrop south of Mormon Point also shows that the well-sorted conglomerate is not offset by the turtleback fault (Fig. 3). These differences in slip history suggest that the turtleback fault is segmented with slip on the segment south of the unnamed northeast trending fault older than the north segment. Alternatively, the high-angle faults that offset the abrasion platform may offset the turtleback at depth as suggested by Keener *et al.* (1993), yet may not be detectable using geophysical techniques. However, such offsets would be inconsistent with the outcrop data.

Solving a Death Valley Paradox

In 1966, Hunt and Mabey showed that the lake deposits (Ql) at Mormon Point rest on the Qg_2 gravels. This was inconsistent with their observations elsewhere in Death Valley that the Qg_2 did not have strandlines on its surface, and caused them some concern (Hunt and Mabey, 1966, p. A71). Our geologic mapping (Fig. 3) shows that the 120,000–186,000 yr-old lake deposits overlie the Mormon Point formation and that a Qg_2 fan unit is found inset below the lake deposits at the mouths of Mormon Point Canyon and Willow Wash (Fig. 2). This is consistent with the observations of Hunt and Mabey throughout Death Valley and shows that the Qg_2 fan deposits are younger than the prominent OIS-5e/6 lake deposits.

SUMMARY

The abrasion platform composed of the 120,000–186,000-yr-old, well-sorted conglomerate with interbedded tufa deposits at Mormon Point is divided into a series of benches and risers. Based on geologic and geomorphic relations, only the bench at ~+90 m msl is interpreted as a lake strandline. From the correspondence of risers to faults exposed in the canyon walls and lack of associated clastic deposits, we infer that the remaining risers at Mormon Point are fault scarps. We consider the exposure dates on the fault scarps as not relevant to lake history (Dorn, 1988; Dorn *et al.*, 1989, 1990; Trull *et al.*, 1995). As a result, we infer that the OIS 6 pluvial lake receded more rapidly than previously thought and the lake depth at Mormon Point was ~90 m. Consistent with the core data of Hooke (1972) and Anderson and Wells (1996), no evidence of OIS-2 shorelines was found at Mormon Point.

The Mormon Point turtleback fault is the only low-angle normal fault that we are aware of where Quaternary faulting (in this case <760,000 yr B.P.) is clearly observed in outcrop (Fig. 3; Knott *et al.*, 1999). The faults that offset the OIS-5e/6 abrasion platform are most likely consistent with upper-plate fault geometries observed elsewhere (e.g., Axen *et al.*, 1999) in that the high-angle faults merge into and slip sympathetically with the low-angle Mormon Point turtleback fault. As a result, this study shows that the Mormon Point turtleback fault was active into the late Pleistocene.

For the past three decades, the volumes of the OIS-5e/6 and OIS-2 lakes in Death Valley, and consequently the effective precipitation during these two pluvial periods, were implied to be similar. This implication was based in part on the dated shorelines at Mormon Point and is inconsistent with other studies in the region, which indicate that effective precipitation was not as high during OIS-2 (Smith, 1984; Jannik *et al.*, 1991). Our study demonstrates that the surface elevation of the OIS-5e/6 lake was ~+90 m msl and the risers thought to be OIS-2 wave cut strandlines are fault scarps. Our geomorphic interpretation indicates that the OIS-2 lake never rose above −30 m msl elevation and was likely only a few meters deep, which is consistent with the core data (Hooke, 1972; Anderson and Wells, 1996). Thus, we infer that the effective precipitation in Death Valley during OIS-2 was a significantly less than during OIS-5e/6 and resulted in only shallow perennial lakes in Death Valley. Enzel *et al.* (1992) inferred that persistent shifts in atmospheric circulation patterns over the North Pacific are what sustain perennial lakes in western North America. Our interpretation of lake shorelines supports the hypothesis that these alterations in western North American–North Pacific atmospheric circulation patterns were only episodic during OIS-2, similar to those inferred by Enzel *et al.* (1992) during the Holocene.

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