

Letter to the Editor

Reply to Hooke (2004)

Hooke's (2004) comments pertaining to Knott et al. (2002) focus on (1) Lake Manly's maximum stand during marine oxygen isotope stage 2 (OIS-2), (2) the stratigraphic and geomorphic relations between alluvial-fan deposits (the No. 2 gravel of Hunt and Mabey (1966) and OIS 5e/6 age lacustrine deposits of Lake Manly), and (3) the criteria for distinguishing strandlines vs. fault scarps. These comments offer an opportunity to elaborate on our field studies and to clarify the data upon which we based our stratigraphic, tectonic, and geomorphic interpretations of Death Valley. Our interpretations (1) build upon the work of Quade et al. (1998) and exclude data derived from sediments near spring-fed environments, (2) rely only on numerical ages of samples that are unequivocally in situ and occur in landscape-stratigraphic context, (3) rely upon detailed local stratigraphic and geomorphic relations in order to correlate alluvial-fan and lacustrine deposits, rather than utilizing regional landform morphology for correlation purposes, and (4) build upon the work of Drewes (1963) and Burchfiel et al. (1995) to link key structural features with geomorphic features physically, stratigraphically, and kinematically.

Maximum elevation of OIS-2 lake stands

Knott et al. (2002) concluded that the maximum elevations of the OIS-2 (10,000–30,000 yr) lake stands were significantly lower than previously interpreted (Dorn et al., 1990; Hooke, 1972) and therefore did not cut shorelines near sea level at Mormon Point. Hooke (2004) does not refute this conclusion, but offers a different interpretation of the core data in which a significantly lower Lake Manly existed and receded much later (after 12,980 ¹⁴C yr B.P.) than in our interpretation. We believe that the primary difference in these two interpretations rests upon the ability to distinguish lacustrine sediments from spring-fed deposits, a key problem recognized in the southern Great Basin by Quade et al. (1998).

Hooke (2004) suggests that our OIS-2 lake reconstruction should place greater reliance on data from core 68-7 of Hooke (1972). Core 68-7 was drilled ~600 m east of perennial Tule Spring (Hunt et al., 1966), while other cores described by Hooke (1972) do not appear to have the same relative position to a spring. We believed at the time of our original paper that the depositional environments around

Tule Spring are influenced by spring discharge and therefore data from this area should be conservatively interpreted. Thus, our original interpretations of lacustrine sediments and the relative depth of the associated lake were based, in part, on depositional units described by Hooke (1972) and Anderson (1999) and interpreted by them as unequivocally lacustrine.

Our interpretation is supported by core 9 of Anderson and Wells (2003), which was drilled near Hooke's (1972) core 68-7. Anderson and Wells interpreted framboidal pyrite root tubes within the black silts and clays as wetland-marsh deposits with an age of 9780 ± 60 ¹⁴C yr B.P. This age is significantly less than the $11,900 \pm 200$ ¹⁴C yr B.P. age of lacustrine sediments reported by Hooke (1972) near Badwater, in the lowest part of the basin. These data support the interpretation of Knott et al. (2002) that the elevation of Lake Manly was much lower during the late OIS-2 and that spring activity kept the topographically higher Tule Spring area relatively wet after the lake surface receded.

Hooke's (2004) interpretation of OIS-2 lake depths uses uranium-series ages on tufa (18.0 ± 1.6 and $24.7 \pm 1.6 \times 10^3$ yr, samples 94-17 and 94-18, respectively) from the 3- to 4-m-diameter "Badwater Big Rock" of Ku et al. (1998) along Highway 190. Relying upon these dates, Hooke infers an OIS-2 lake depth between 64 and 56 m. Although we were aware of these dates, we discounted results from this specific sample site because the boulder is not unequivocally in situ, is not associated with any geomorphic or stratigraphic shoreline features, and a third sample collected from this same boulder (94-16 of Ku et al., 1998) was not in secular equilibrium, indicating weathering of the tufa. It is important to note that none of the other sample locations from Ku et al. (1998) are taken from boulders, either along the road or on the alluvial fans.

Our field observations are that Badwater Big Rock rests on an alluvial fan that we interpret as Holocene (unvarnished clasts with bar-and-swale topography) and thus the boulder was probably not at this location 18,000 years ago when the tufa was deposited. Knott et al. (2002) relied less on the Badwater Big Rock results than Hooke (2004) apparently believes is warranted. Instead, they relied on the 17 other age determinations of Ku et al. (1998), ages between $132,000 \pm 5000$ and $216,000 \pm 15,000$ yr for samples that were from a shoreline context, unequivocally in situ, and at topographically higher elevations. We are uncertain of Badwater Big Rock's geo-

morphic or stratigraphic context and we question the origin of the tufa.

Relative age of alluvial-fan and lacustrine deposits (No. 2 gravel) at Mormon Point

Hooke's (2004) comments regarding the relations between the No. 2 gravel (map symbol Qg_2 in Hunt and Mabey, 1966) and Lake Manly deposits do not accurately reflect the findings of Knott et al. (2002). We did not state or imply that Qg_2 has the same numerical age throughout Death Valley. Our observations at Mormon Point are related to the relative age relations between Qg_2 and Lake Manly deposits. These relations were, in general, a paradox to Hunt and Mabey (1966).

Hunt and Mabey (1966, p. A71) explicitly noted that the Qg_2 was apparently younger than the Lake Manly deposits everywhere except at Mormon Point, Tucki Wash, and North Side Borax Camp, where the stratigraphic relations are reversed. Our observations are limited to Mormon Point and thus reflect stratigraphic and geomorphic relations there, and not at Tucki Wash and North Side Borax Camp on the eastern Panamint Mountains piedmont.

At Mormon Point, however, our mapping and observations showed that an alluvial-fan unit whose geomorphic characteristics are similar to the Qg_2 of Hunt and Mabey (1966) is present and is unequivocally younger than the OIS 5e/6 Lake Manly deposits (Fig. 3 in Knott et al., 2002). Our conclusions and observations are similar to those of Drewes (1963), who mapped OIS 5e/6 Lake Manly deposits overlying one alluvial-fan unit (moderately well-indurated gravels), but not another (poorly indurated gravels). Drewes (1963) inferred that the moderately indurated gravels were equivalent to Qg_2 . Both Drewes (1963) and later Burchfiel et al. (1995) observed that the poorly indurated gravels (Qoc_2 of Burchfiel et al., 1995) were younger than the OIS 5e/6 deposits and had a well-developed desert pavement surface composed of highly varnished clasts. Hunt and Mabey's (1966) paradox begins when, because of the smaller scale of their mapping, they quite appropriately grouped both the well-indurated and poorly indurated units of Drewes (1963) as Qg_2 at Mormon Point.

The gravels of Drewes (1963)

The moderately well-indurated gravels of Drewes (1963) were renamed the Mormon Point Formation (Knott et al., 1999). The Mormon Point Formation has an unequivocal age of ~ 0.5 to ≤ 1.2 myr (Knott et al., 1999). Key marker beds and tephra beds of the Mormon Point Formation do not extend into the poorly indurated gravels of Drewes (1963), clearly distinguishing these two units. Based on the well-developed desert pavement and highly varnished clasts observed by both Drewes (1963) and Burchfiel et al.

(1995), attributes that are characteristic of Hunt and Mabey's Qg_2 deposits, we interpreted the poorly indurated gravels of Drewes (1963) as Qg_2 -equivalent owing to this characteristic surface morphology. Thus, at Mormon Point Knott et al. (2002) demonstrated that Qg_2 is younger than the OIS 5e/6 Lake Manly deposits, and although this differs from Hunt and Mabey's (1966) original interpretation at this site, our interpretation is consistent with their observations elsewhere in Death Valley, except perhaps at Tucki Wash and North Side Borax Camp.

We believe that the relations between alluvial-fan deposits and Lake Manly on the Panamint piedmont remain unresolved because of the contentious varnish-age chronology (Watchman, 2000) compiled by Hooke and Dorn (1992). As we outlined in our original paper, the lack of clarity regarding the relations between Lake Manly and alluvial-fan deposits motivated our study.

Interpretation of strandlines vs. fault scarps

Knott et al. (2002) concluded that many of the risers cut on the landscape at Mormon Point are created by faulting and not wave action during stands of Lake Manly. Hooke (2004) suggested several lines of evidence in an attempt to refute our interpretation. We stand by our interpretations on the basis of our detailed mapping that shows (1) the relations between lacustrine facies and the strandline near +88 m amsl, (2) reactivation of faults over time, (3) the complex relations between the surface and subsurface geology, (4) the kinematic relations between deeper structures and complex fault trends (Burchfiel et al., 1995; Knott et al., 1999, 2002; Hayman et al., 2003), and (5) the consistency between our mapping and detailed mapping by Drewes (1963) and Burchfiel et al. (1995) that supports the relations between surficial scarps and subsurface faults.

Hooke (2004) conducted two topographic surveys in 1969 and 2001 and identified a variation in the upper riser of <3 m over a 200-m distance, which he attributes to tectonic tilting. There are two other hypotheses that explain the elevation difference of the upper riser, which Hooke (2004) does not consider: (1) the upper riser is not horizontal, and (2) differential erosion has changed the elevation of the upper riser. A nonhorizontal riser is consistent with a fault-scarp origin but not a shoreline feature (Gilbert, 1890, p. 84). Knott et al. (2002) asserted that differential erosion on the abrasion platform and across the fault scarps has altered the elevation of the upper riser's top, which may also account for the elevation differences. The available data are consistent with any of these three hypotheses. In our judgment, and in accord with Gilbert's (1890) criteria, the field association of the risers with underlying faults favors a fault-scarp origin.

If Hooke's (2004) hypothesis is correct, and all risers in both surveys are shoreline features, and if the elevation of

the highest riser in the second profile has been lowered by ~3 m owing to tectonic tilting, then after the normalization to +88 m amsl, the elevations of the risers in the two profiles should be the same. However, the lower risers plot at different elevations (Hooke, 2004, Fig. 2a), which is inconsistent with their interpretation as shoreline features but consistent with their interpretation as fault scarps (Gilbert, 1890) and supports the interpretation of Knott et al. (2002).

Hooke (2004) questions our conclusion because there are (1) differences between the measured trends of risers and the strikes of faults measured in outcrop, (2) a greater number of faults than risers exposed in the canyon walls, and (3) south-side-down faults that should result in south-facing scarps. Mapping by Drewes (1963), Burchfiel et al. (1995), and Knott et al. (2002, Fig. 3) shows that the anastomosing high-angle hanging-wall faults that offset the OIS 5e/6 deposits range in strike from N5E to N75E within a kilometer east and west of Mormon Point Canyon. Subsequently, more exhaustive structural geologic studies have shown that these faults are kinematically linked to the underlying, antiformal Mormon Point turtleback fault, thus explaining the wide range of strike (Hayman et al., 2003). Therefore, Hooke's (2004) finding that strike measured at one point along a hanging-wall fault is different from strike measured at another point is consistent with the previous mapping.

The fault and fault-line scarps that cut the Lake Manly gravels are formed by high-angle faults that sole into the low-angle Mormon Point turtleback fault. The reactivation of these faults is apparent if the separations of the OIS 5e/6 gravels (a few meters) and the middle Pleistocene tephra beds (hundreds of meters: Hayman et al., 2003) are compared, but the mapping by Knott et al. (2002) demonstrates that not all high-angle faults are reactivated. Thus, for every riser or scarp, there is a corresponding underlying fault; however, the converse relation is not true.

Hooke (2004) questions our conclusion regarding the fault scarps at Mormon Point because he observed a fault with south-side-down displacement, which should produce a south-facing scarp if reactivated. We mapped one reactivated south-side-down fault offsetting the Qg₂ deposits with <1-m separation near the northern end of Mormon Point Canyon. The correspondence between this south-side-down fault and south-facing scarp supports the conclusions of Knott et al. (2002).

We understand that from a distance these scarps at Mormon Point appear to be shorelines. We agree with the many previous studies that have found evidence of a middle Pleistocene lake. However, our detailed stratigraphic, tectonic, geomorphic, and geochronologic field data coupled with objective observations demonstrate a more complex tectonic origin for many of these features. Gilbert (1890, p. 84) described the field observations necessary to interpret these important landscape elements because risers formed by faulting and wave action may have a similar geomorphic expression. Using Gilbert's (1890) criteria, we show a co-

genetic relation among the numerous topographically lower scarps and underlying faults, and a co-genetic relation between lacustrine deposition and erosion only at the topographically highest riser at Mormon Point, allowing interpretation of these features as fault and fault-line scarps and lake strandlines, respectively.

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