Questions about Lake Manly's age, extent, and source

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ABSTRACT

In this paper, we grapple with the timing of Lake Manly, an ancient lake that inundated Death Valley in the Pleistocene epoch. The pluvial lake(s) of Death Valley are known collectively as Lake Manly (Hooke, 1999), just as the term Lake Bonneville is used for the recurring deep-water Pleistocene lake in northern Utah. As with other closed basins in the western U.S., Death Valley may have been occupied by a shallow to deep lake during marine oxygen-isotope stages II (Tioga glaciation), IV (Tenaya glaciation), and/or VI (Tahoe glaciation), as well as other times earlier in the Quaternary. Geomorphic arguments and uranium-series disequilibrium dating of lacustrine tufas suggest that most prominent high-level features of Lake Manly, such as shorelines, strandlines, spits, bars, and tufa deposits, are related to marine oxygen-isotope stage VI (OIS6, 128-180 ka), whereas other geomorphic arguments and limited radiocarbon and luminescence age determinations suggest a younger lake phase (OIS 2 or 4). In addition, the extent of constructional lacustrine features is poorly mapped, and the relationships between the lake deposits and alluvial stratigraphic units are poorly documented. Problems discussed in this paper tie directly to stratigraphic relations and possible ages for lacustrine gravel that we visit on our trip, specifically at the Beatty Junction bar complex (Stop A5), the Tea House above Furnance Creek Inn (Stop B1), and at Mormon Point (Stop C1).

As with many geologic controversies, Lake Manly's history is more unsettled than resolved. And like Lake Bonneville, which saw its purported history go from a relatively simple rise and fall to complicated oscillations based on complex interpretations, the history of Lake Manly has suffered from broad interpretations based on limited data. In this paper, we assess the merits and flaws of the various time histories proposed for Lake Manly.

INTRODUCTION

Late 19th-century surveys of the Great Basin indicated widespread lacustrine deposits related to ancient Pleistocene lakes. Benchmark papers by Russell (1885, 1889) and Gilbert (1890) established the basic framework for Lake Lahontan in northern Nevada and Lake Bonneville in northern Utah. Both of these lakes occupied large closed basins, themselves the products of Pliocene to Pleistocene basin-and-Range extension (see Gilbert, 1928). Both Russell and Gilbert referred to a former lake in Death Valley, but Gale (1902) was the first to apply a name—Death Valley Lake. Gale, however, failed to recognize the immensity and importance of this lake, stating:

> *"In spite of the immense drainage territory [that is] tributary to Death Valley there is no evidence that the waters from these streams ever accumulated in it to sufficient extent to form more than a shallow inconstant lake. A search for traces of any upper lines [shorelines] around the slopes leading into Death Valley has failed to reveal evidence that any considerable lake has ever existed there." (Gale, 1914, p. 401, as cited in Hunt and Mabey, 1966, p. A69.)*

So, almost 20 years after Russell's inference of a lake in Death Valley, the pot was just starting to simmer.

RECOGNITION AND NAMING OF LAKE MANLY

In 1924, Levi Noble—who would go on to have a long and distinguished career in Death Valley—discovered the first evidence for a large lake with his companions W.M. Davis and H.E. Gregory. Noble (1926) identified strandlines on a prominent basalt hill at the south end of Death Valley, which would later become known as Shoreline [*sic* Shore Line] Butte. By 1925, he found strandlines in the north-facing embayment east of Mormon Point (Noble, 1926, p. 69) that would later become a cornerstone of the lake's geomorphology and stratigraphy (Chapter C, Stop C1 in this volume). Soon thereafter, Means (1932) named the lake "Lake Manly," in honor of William Manly, one of the two men who lead the first pioneers out of the valley. Blackwelder (1933, 1954) conducted the first systematic studies of the lake's surficial deposits and geomorphology and used the term widely in his work. On the basis of mostly observational geology, Blackwelder (1933) speculated on the existence of Lake Manly, as well as its source areas, age, and predecessors. In one of the first papers documenting archaeological evidence for early man in Death Valley, Clements and Clements (1953) outlined the history of Lake Manly as it was then understood and described the locations of many newly recognized constructional landforms associated with the lake.

In 1966, Charlie Hunt and Don Mabey published the first comprehensive geologic map (1:96,000 scale) of the Death Valley area (Hunt and Mabey, 1966, plate 1). Hunt's mapping of the Quaternary deposits established a four-fold division of alluvial units, and related lacustrine deposits of Lake Manly to his alluvial stratigraphy (see discussions of Quaternary stratigraphy in Chapter H in this volume).

Most of the early studies of Lake Manly (see table G-1) involved comparative geomorphology, relative stratigraphic positions, and correlations of lake deposits (and history) to other well-studied lakes in the Basin and Range, such as Lakes Bonneville and Lahontan.

THE AGE OF LAKE MANLY

With the advent of numerical dating techniques, chronologic studies sought to determine the age of Lake Manly—a few of which we summarize here (see table G-1).

In 1972, Roger Hooke reported ages between 11 and 26 ka based on the radiocarbon analysis of lake deposits from several cores near Badwater. He also mapped lacustrine deposits at several locations in central Death Valley (table G-1) and hypothesized that the prominent lacustrine deposits that extend to about +90 m elevation were related to the 11->26 ka sediments. He named this the Blackwelder stand of Lake Manly.

Subsequently, Hooke and Lively (1979; as cited in Hooke and Dorn, 1992) determined an age range of 60 to 225 ka using uranium-series disequilibrium dating; however, they recognized inconsistencies in their ages caused by open-system migration of daughter products of uranium. Consequently, Hooke and Dorn (1992) redefined the Blackwelder stand of Lake Manly as the one that left tufa at +90 m on the Black Mountains. These tufa deposits are now considered to have formed during marine oxygen-isotope stage VI (OIS6) (Ku and others, 1998).

Based on results from a series of shallow (up to 26 m deep) cores south of Badwater, Anderson and Wells (1996, 1997) proposed that numerous lakes occupied Death Valley in the latest Pleistocene (10-35 ka) and that they were relatively small, shallow, and separate from each other. Soon thereafter, Lowenstein and others (1999) analyzed a 126-m-long core from near Badwater and recognized two major lacustrine periods—an older lake at 120-186 ka (OIS6) and a younger lake at 10-35 ka (OIS2). A parallel study by Ku and others (1998) determined ages ranging from 18 to 216 ka on tufa along the Black Mountains from Badwater to Mormon Point. Both of these latter studies used uranium-series disequilibrium dating methods.

A selection of the chronologic studies on Lake Manly (table G-1) provides a broad context on the state and evolution of knowledge of the lake, with an emphasis on age and elevation of deposits. This compilation shows a significant range in the age estimates of Lake Manly deposits and that the dates of some shoreline features have also changed significantly over the last several years. Additionally, most of the data suggests that the +90 m shoreline is associated with an OIS6 highstand, but there also is a wide range in ages (18 to 216 ka) for the +90 m shoreline deposits. Dates coupled with careful stratigraphic studies and detailed mapping are needed to refine our understanding of the lake history and location of shoreline deposits.

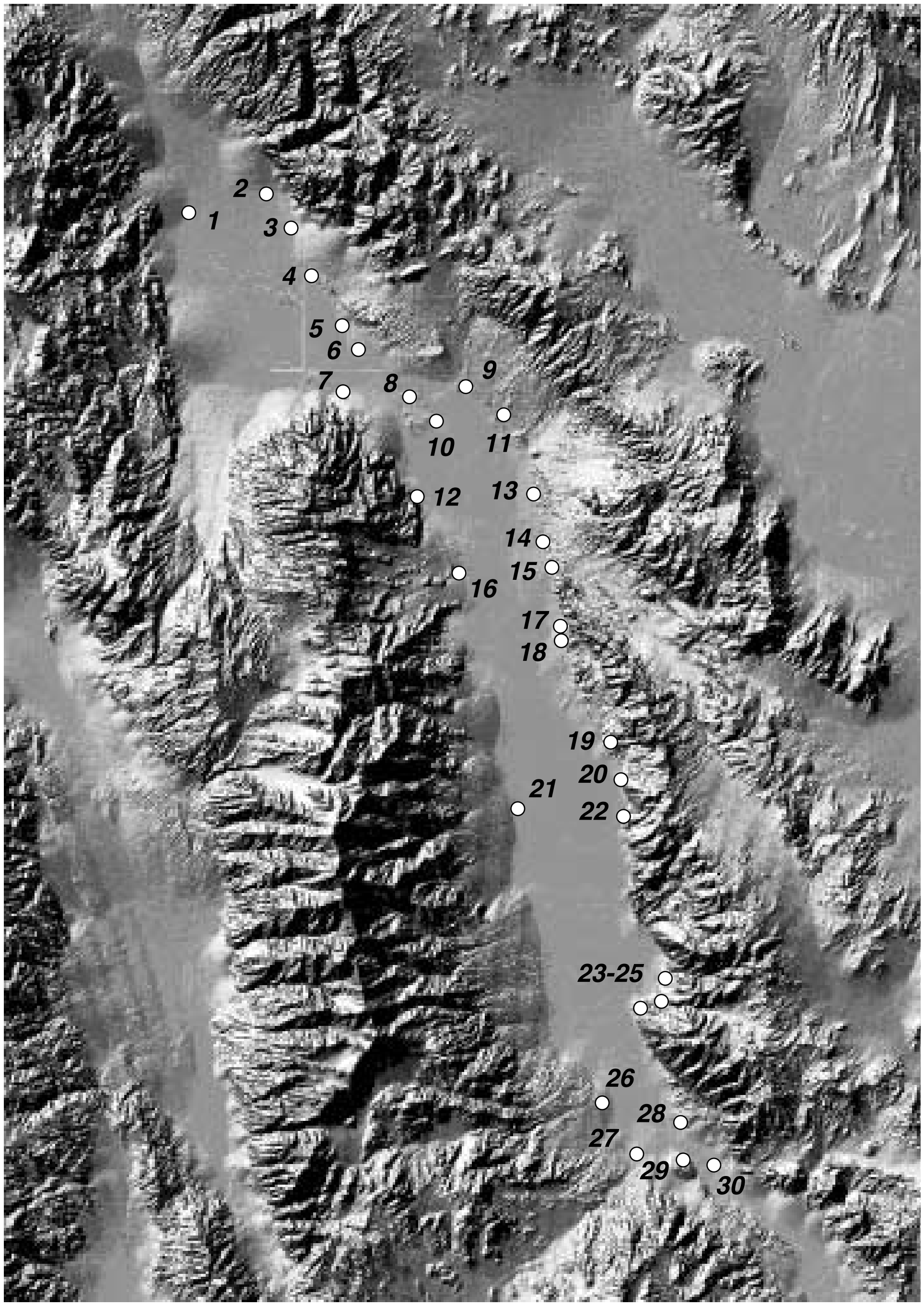
In the past 30 years, most geologic research on Lake Manly has involved local mapping, topical studies, and numerical dating, first using radiocarbon techniques and then uranium-series disequilibrium analyses (table G-1). More recently, researchers have attempted to date near-shore lake sediment by thermoluminescence techniques (TL, table G-1) and gravelly shoreline deposits by cosmogenic dating techniques (primarily ^{10}Be and ^{36}Cl, table G-1). No new systematic effort, however, has been undertaken to map the surficial deposits related to Lake Manly in a modern context and tie these deposits, their stratigraphic relations, and positions relative to the Death Valley fault system to the ever-increasing catalog of numerical ages. Therefore, we have initiated several separate studies to examine the age and distribution of Lake Manly deposits using cosmogenic- and luminescence-dating techniques coupled with geologic mapping. In addition, the continued compilation and updating of a catalog of all such significant deposits related to Lake Manly will provide a spatial and temporal framework for assessing existing and new age determinations.

DISTRIBUTION OF CONSTRUCTIONAL DEPOSITS OF LAKE MANLY

Clearly recognizable lacustrine deposits are sparse but present throughout Death Valley, mainly at elevations below +90 m (<300 ft), although Hunt and Mabey (1966) suggested even higher deposits at several locations such as Shoreline Butte (fig. G-1, no. 29). and Dinosaur Ridge (fig. G-1, no. 16). Lake Manly deposits extend from Shoreline Butte, on the south, to as far north as the Mesquite Flat basin (fig. G-1, no. 2). At a hypothetical level of +30 m (+100 ft msl), Lake Manly would have been about 140 km long from north to south and 10-15 km at its widest.

The majority of the deposits are preserved along the eastern margin of the valley, mainly as a result of their preferential formation of the prevailing wind (west to east); this places the shoreline deposits close to the majority of active faults in the valley. Figure G-1 shows the approximate location of these deposits, and the associated table (table G-2) lists their attributes.

Notwithstanding the lake's long (north to south) fetch, the rather limited preservation of the deposits on the west side of the valley is somewhat surprising. This side of the valley is marked by very large alluvial fans, many of which are old enough (unit Qg2 of Hunt and Mabey, 1966) to have preserved shorelines and deposits of an OIS 2 or 4 lake. In fact, Blackwelder recognized this anomaly and said that the shorelines of Lake Bonneville and the expanded (deeper) stage of Mono Lake are *"…much more continuous and distinct than those of Lake Manly—an indication that they are younger"* (Blackwelder, 1933, p. 469). Blackwelder suspected, as we now know, that the prominent shoreline features of Lakes Bonneville



Localities shown above:
1. Niter beds
2. Titus Canyon (Stop A4)
3. Eastern Mesquite Flat
4. Triangle Springs
5. Mud Canyon
6. NPS Route5 at Hwy 190
7. Stovepipe Wells
8. Salt Creek Hills Anticline
9. Beatty Junction (Stop A5)
10. Salt Creek
11. Three Bare Hills
12. North of Salt Spring
13. Park Village Ridge
14. Road to NPS landfill
15. Tea House (Stop B1)
16. Unnamed ridge
17. Desolation Canyon (Stop C4)
18. Manly Terraces/Artists Drive
19. Natural Bridge
20. Nose Canyon
21. Tule Springs, Hanaupah Canyon
22. Badwater
23. Sheep Canyon
24. Willow Wash
25. Mormon Point (Stop C1)
26. Warm Springs Canyon
27. Wingate Delta (?)
28. East of Cinder Hill
29. Shoreline Butte
30. East of Ashford Mill

Figure G-1 Index map of Death Valley showing selected locations of Lake Manly deposits. Information for localities are shown in table G-2. Base map modified from figure M-1 in this volume. North-south banding is an artifact of processing the DEM data.

Table G-1. Selected compilation of Lake Manly chronologic studies

[Abbreviations: NA, not applicable; ka, thousands of years ago; msl, mean sea level, ^{14}C, radiocarbon analysis; U-series, uranium-series disequilibrium analysis of calcium carbonate; TL, thermoluminescence; OSL, optically stimulated luminescence]

Study	**Observations/Contributions (no. is location on figure G-1)**	**Age and Elevation (msl)**	**Basis for Age**
Noble (1926)	Recognized lake strandlines at Shoreline Butte (**29**) and Mormon Pt. (**25**).	NA	NA
Blackwelder (1933)	Described lake deposits at seven locations, Panamint Valley overflow at Wingate Pass	Tahoe glaciation (late Pleistocene)	Morphology
Clements and Clements (1953)	Described lake deposits at a number of locations throughout Death Valley	Tioga glaciation (latest Pleistocene)	Archaeology
Drewes (1963)	Mapped lake deposits at Mormon Point (**25**)	NA	NA
Hunt and Mabey (1966)	Mapped and described lake deposits at numerous locations throughout Death Valley	Late Pleistocene, older than Qg2	Superposition of deposits
Hooke (1972)	Mapped and described lake deposits in central Death Valley and deltaic deposits of Wingate Wash (2**7**); dated sediment at 11-26 ka from core; named +90 m shoreline Blackwelder stand (**25**)	11-26 ka at +90 m	^{14}C
Hooke and Lively (1979)	Dated tufa at Goblet Canyon	60-225 ka	U-series
Dorn (1988)	Dated rock varnish on shoreline features and deposits near sea level (**25**); speculated on deep lake during middle Pleistocene (oxygen-isotope stage 16)	12 ka at 0 m; 665 ka	^{14}C
Dorn and others (1989)	Dated rock varnish on shoreline features	12 ka at +3 m	^{14}C
Dorn and others (1990)	Dated rock varnish on shoreline features	12 ka at 0 m; 120-130 ka at +90 m	^{14}C and cation ratios
Hooke and Dorn (1992)	Dated rock vanish on shoreline features on Hanaupah fan (**21**)	180 ka at +90 m	Cation ratios
Trull and others (1995)	Dated clasts from shoreline(?) deposits at Mormon Point (**25**), new locality near Tule Springs	40 ka at 0 m; 135 ka at 158 m	Cosmogenic ^{10}Be
Anderson and Wells (1996, 1997)	Dated organic sediment from cores	10-26 ka at -70 m	^{14}C
Knott, cited in Anderson (1998)	Dated silt from fine-grained deposit behind Beatty Junction bar complex (**9**; Stop A5 in this volume)	24.0±2.5 ka at +45 m	TL
Knott (unpubl. data, 1998)	Dated silt from fine-grained deposit behind Beatty Junction bar complex (**9**; Stop A5 in this volume)	68 ka @ +45 m	OSL
Ku and others (1998)	Dated tufa along the Black Mountains (**22-25**)	185±15 ka at 90 m	U-series
Lowenstein and others (1999)	Dated deposits in core 3.2 km northwest of Badwater Springs	10-35 ka at 10-18 m; 120-186 ka at 110-160 m	U-series
Hooke (1999)	Describes observations of deposits in the region	180 ka at +90 m	NA
Phillips and Zreda (cited in Orme and Orme, 1991)	Dated lacustrine gravel clasts from crest of Beatty Junction bar complex (**9**; Stop A5 in this volume)	154±13 ka at +46 m	Cosmogenic ^{36}Cl
Phillips and Zreda (1999)	Dated lacustrine gravel profile from crest of Beatty Junction bar complex (**9**; Stop A5 in this volume)	20-85 ka at +46 m	Cosmogenic ^{36}Cl
Klinger (Chapter A, this volume)	Dated tufa deposit along shoreline, north edge of Mesquite Flats (**2**)	~16 ka at +37 m	^{14}C

Table G-2. List of selected locations of Lake Manly deposits

[Abbreviations: Elev., elevation relative to sea level; Position relative to Death Valley fault system: U, upthrown side; D, downdropped side; H, above Hanaupah fault scarp; F, on the limb of fold; W, west side of valley]

No.	Name of locality (informal)	Features/deposits	Position: Elev. in m (ft)	Primary reference (* means not previously reported)
1.	Niter beds	Lacustrine and playa sediment	W: 34 (110)	Blackwelder, 1933
2.	Titus Canyon (Stop A4)	Tufa, limestone	D: 37 (120)	Chapter A, this volume*
3.	Eastern Mesquite Flat	Beach shore	D: 34-37 (110-120)	Chapter A, this volume*
4.	Triangle Springs	Back bar deposit	U: 30 (100)	Machette, unpubl. data*
5.	Mud Canyon	Beach ridge	D: 50 (160)	Chapter A, this volume*
6.	NPS Route 5 at Highway 190	Spit, deltaic beds	D: 25 (80)	Machette, unpubl. data*
7.	Stovepipe Wells	Terraces	W: 0-50 (0-160)	Blackwelder, 1933; Clements and Clements, 1953
8.	Salt Creek Hills Anticline	Terraces, shoreline gravel	F: Sea Level	Chapter A, this volume*
9.	Beatty Junction (Stop A5)	Spit and bar complex	U: 46 (150)	Clements and Clements, 1953; Blackwelder, 1954
10.	Salt Creek	Shoreline gravel	F: -48 (-160)	Klinger, unpubl. data*
11.	Three Bare Hills	Deltaic gravel	U: 36 (120)	Hunt and Mabey, 1966
12.	North of Salt Spring	Shoreline gravel	W: Sea Level	Klinger, unpubl. data*
13.	Park Village Ridge	Shoreline gravel	U: 0-46 (0-150)	Hunt and Mabey, 1966
14.	Road to NPS landfill	Deltaic	U: -3 (-10)	Machette, unpubl. data*
15.	Tea House (Stop B1)	Shoreline gravel, foreset beds	U: 24-32 (80-105)	Chapter B, this volume*
16.	Unnamed ridge	Shoreline gravel, tufa	W: 48 (160)	Clements and Clements, 1953; Hunt and Mabey, 1966, Reheis, unpubl. data*
17.	Desolation Canyon (Stop C4)	Spit	D: Sea Level	Chapter C, this volume*
18.	Manly Terraces	Shoreline gravel	D: 30 (100)	Clements and Clements, 1953; Hunt and Mabey, 1966
	Artists Drive	Cross-bedded gravel	D: 8 (25)	Chapter C, this volume*
19.	Natural Bridge	Lacustrine sand	U: 73 (240)	Knott, unpublished data*
20.	Nose Canyon	Lacustrine gravel, foreset beds	U: 90 (295)	Hunt and Mabey, 1966; Knott, unpubl. data*
21.	Tule Springs	Eroded bar, deltaic gravel	W, H: 27 (90)	Hunt, 1975, fig. 155; Trull, et al., 1995; Meek, 1997, Machette,, unpubl. data*
	Hanaupah Canyon	Shorelines	W, H: 39-58 (128-190)	Hooke, 1972
22.	Badwater	Tufa-encrusted shorelines	U: 90 (295)	Hooke, 1972; Ku and others, 1998 (U/Th ages)
23.	Sheep Canyon	Spit and shoreline	U: 60 (200)	Klinger, unpubl. data*
24.	Willow Wash	Platform, bars, back bar	U: 0-92 (0-300)	Knott, unpubl. data*
25.	Mormon Point	Lacustrine gravel, platform, spit	U: 0-60 (0-200)	Chapter C, this volume
26.	Warm Springs Canyon	Lacustrine sand and gravel	U: 35-55 (115-180)	Blair, 1999, sta. 32; Machette, unpubl. data*
27.	Wingate Delta	Deltaic beds, shorelines	U: 50±15 (16050)	Hooke, 1972
28.	East of Cinder Hill	Lacustrine gravel, terraces	U: 0, 24-35 (0, 80-115)	Troxel and Butler, 1986; Knott, unpubl. data*
29.	Shoreline Butte	Shorelines (12), gravel	W: 15-125 (50-380)	Blackwelder, 1933
30.	East of Ashford Mill	Deltaic gravel	U: 50 (160)	Klinger, unpubl. data*

and Mono are related to the last major pluvial (OIS2), which is recorded by lacustrine sediment of 35-10 ka age.

TECTONICS

Considerable controversy exists regarding the timing, depth, and extent of the many phases of Lake Manly that have occupied Death Valley in the Quaternary. Different dating techniques suggest that the youngest highstand is from OIS 2, 4, or 6, yet the geomorphology and limited preservation of these features suggest (at least to us) an OIS6 lake. We briefly discuss additional and important complications in terms of tectonics and paleolake hydrology below.

Hunt and Mabey (1966) suggested that the lake basin has tilted eastward about 6 m (20 ft) in the past 2,000 years (as dated by archaeology), which implies a 3 mm/yr slip rate on the Black Mountains fault zone (BMFZ) since 2,000 years ago. This rate, although indirectly derived, suggests that the BMFZ is a very active structure (see Chapter J and L in this volume). This bears on the issue of lake depths in tectonic areas. If a long-term slip rate of 1-3 mm/yr is reasonable for the BMFZ (see Chapter L in this volume), then in 186 k.y. the fault could generate 186 m to 558 m of tectonic displacement. Lowenstein and others' (1999) 120-186 ka sediments were reached at 130-160 m below the surface. Their drill rig started at about -85 m (-280 ft) elevation; so the OIS6 deposits are at about -215 m to -245 m elevation (msl) beneath Badwater, whereas Ku and others (1998) 186-ka tufas are at +90 m msl at Badwater (table G-1; fig. G-1, no. 22). Thus, the net relief between these two areas, which are only about 3 km apart but on different sides of the BMFZ, is 305-335 m. Therefore, one half to more than all the net relief may be accounted for by 1-3 mm/yr of slip on the BMFZ, so it's anyone's guess as to the depth of the OIS6 Lake Manly. Similar tectonic problems exist all along the eastern margin of Death Valley. Many of the most important deposits straddle the Death Valley fault system, or are close to its modern trace. Table G-2 lists many of these deposits and shows their relation to the fault system, specifically whether they exist on the upthown (U) or downdropped (D) block.

Considering the long history of searching for lacustine deposits by very capable geologists (such as Noble, Blackwelder, Hunt, Hooke, and others), our recent discoveries are surprising (see table G-2). One of the most important new localities of Lake Manly deposits that we have found is on the upthrown side of the Hanaupah Canyon fault (fig. G-1, no. 21) about 12 km west of Badwater. These deposits form an elongate east-west bluff that is composed of a series of climbing bars, from about -15 m (-50 ft) elevation to about +27 m (+90 ft) elevation as determined from the Hanaupah Canyon 7.5' topographic map. On the north side of the bluff (away from the Hanaupah Canyon road), pebble- to small cobble-size gravelly foreset beds are clearly visible. The lacustrine bar(s) have been extensively eroded, with Q2-like gravels (probably units Q2c and Q2b, see Chapter H in this volume) inset at lower elevations to the south and Q3 and Q4 gravel inset at lower elevations to the north. Cosmogenic and luminescence dating is underway, but the results are still pending at the time of our FOP trip. Gravel from the highest of the Hanaupah Canyon bars has been sampled for cosmogenic ^{36}Cl dating and a fine-grained lacustrine sand from this same bar has been sampled for luminescence dating. These age determinations may prove piviotal in answering the question of the age of Lake Manly, inasmuch as this is one of the few well-exposed lacustrine deposits on the west side of Death Valley, well away from the Death Valley fault system.

PALEOHYDROLOGY

Some main concerns in terms of paleolake hydrology are the source(s), flow-paths, and volumes of water for the lakes and southward closure of the lake basin. Many authors including Blackwelder (1933) suggested that the major water source for the lake was distant flow from the Sierra Nevada, ultimately entering the valley via Wingate Pass from southern Panamint Valley. Few researchers, however, have been able to find, or looked for stratigraphic records for this overflow, with the exception of Hooke's (1972) reported deltaic deposits in Anvil Spring Canyon. Similarly, the Mojave River drainage has been considered a possible southern source, but it probably was not intregrated into the Death Valley system until the latest Pleistocene. Li and others (1997) examined the geochemistry of the source waters feeding Death Valley and compared it to the evaporite mineralogy from Badwater basin. They concluded that over the past 100 k.y. the brines and evaporite minerals were produced by the mixing of meteoric water primarily from the Amargosa system and local spring water. Ancient overflow from Lake Manly may have reached the Colorado River as suggested by Blackwelder (1933). This hypothesis seemed to be supported by faunal evidence in the classic paper by Hubbs and Miller (1948) where they used fossil cyprinodonts (pupfish) to reconstruct the past hydrography of the region. Hooke (1999) speculated that Lake Manly may have extended south into the Mojave. This hypothesis is based on high-level lacustrine deposits in the northern Mojave that he believes could correlate with the Blackwelder stand of Lake Manly. This connection, however, requires several hundred meters of vertical movement related to transpression along the Southern Death Valley and Garlock fault zones.

CONCLUSIONS

Much remains to be discovered and resolved concerning Lake Manly. Continued dating by conventional, experimental, and yet-to-be discovered techniques will help to resolve the age of individual deposits, but further reconnaissance, geologic mapping, and a basinwide inventory of constructional lacustrine deposits will be needed to determine when, where, and how Lake Manly was created.

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