Quaternary Stratigraphy and Geomorphology of Death Valley

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INTRODUCTION

Quaternary stratigraphy and geomorphology are two of the more scrutinized, and yet probably the least understood aspects of Death Valley geology. Sparsity of datable material and discontinuity of outcrops are only two of the many hurdles that Quaternary geologists have had to overcome. In recent years, however, several independent studies have added greatly to the knowledge of the late Cenozoic rocks of Death Valley. Detailed stratigraphic descriptions combined with tephrochronology, paleomagnetism, and radiometric age determinations have resulted in a better definition of the upper Pliocene to lower Pleistocene Funeral Formation, Pliocene Nova Formation, and the addition of a new formation, the upper Pliocene to lower Pleistocene Confidence Hills Formation. Tephrochronologic correlation of lower to middle Pleistocene tephra beds at Mormon Point, Natural Bridge, and the Kit Fox Hills has provided previously unobtainable age control in these areas and enabled the introduction of the Mormon Point formation. The greater age control allows for insights into the paleogeography and geomorphic development of Death Valley. The purpose of this paper is to provide a review of the changes to the Quaternary stratigraphic framework, and then briefly illustrate how this knowledge has been applied to the spatial and temporal geomorphic development of the Death Valley fault zone and the Black Mountains.

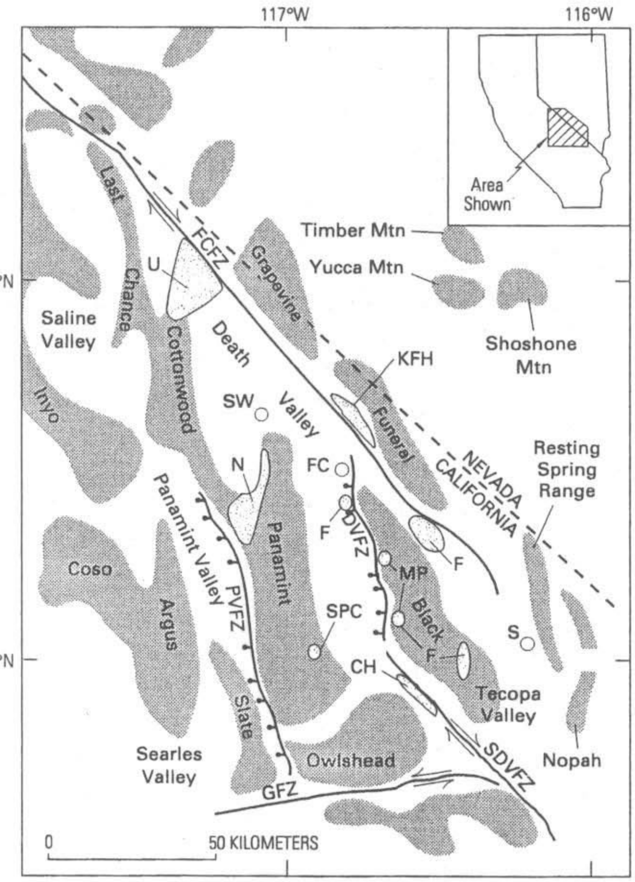

Figure 21. Death Valley and surrounding region showing major geographic features and fault systems. Light shade, mountain ranges; white areas, basins. Arrows, dominant motion of strike-slip faults; bar and ball on relatively downthrown side of normal faults. Areas with stipple pattern, locations of sedimentary basins: F, Funeral; N, Nova; U, Ubehebe; MP, Mormon Point; CH, Confidence Hills; SPC, Six Springs Canyon. Fault zones: DVFZ, Death Valley fault zone; FCFZ, Furnace Creek fault zone; SDVFZ, Southern Death Valley fault zone; PVFZ, Panamint Valley fault zone; GFZ, Garlock fault zone. Towns shown by circles: S, Shoshone; FC, Furnace Creek; SW, Stovepipe Wells.

STRATIGRAPHY

FUNERAL FORMATION

Thayer named the coarse conglomerates with interbedded basalts and basaltic agglomerates of the eastern Furnace Creek basin, the Funeral Formation in 1897 (cited in Noble, 1941). In the Furnace Creek basin, the Funeral Formation overlies the upper Miocene Furnace Creek Formation and is distinguished from younger deposits by its greater cementation and tilting. Consequently, similar deposits throughout the Black Mountains and southern Panamint Mountains (fig. 21) were mapped as Funeral Formation (Noble and Wright, 1954; Hunt and Mabey, 1966; McAllister, 1973). The facies of the Funeral Formation were interpreted to represent an alluvial fan depositional environment with a Pliocene to Pleistocene age (Noble, 1941); however, Noble also postulated that variability and discontinuous exposure prevent actual correlation of the isolated outcrops of the Funeral Formation. Hunt and Mabey (1966) also recognized these correlation problems and further went on to state that there is no evidence that all outcrops of the Funeral Formation are the same age.

Early age determinations of the Funeral Formation focused first on the interbedded basalts, then later on tuff beds. McAllister (1973) dated a basalt flow near the type locality at 4.0 Ma using conventional whole rock K/Ar. Wright and others (1991) stated that the basaltic rock that composes Shoreline Butte in the northern Confidence Hills is 1.7 Ma (conventional K/Ar). Topping (1993) obtained a 5.2-Ma age on a tuff below the basalt dated by McAllister using zircon fission-track dating. Holm and others (1994) dated a tuff in the Funeral Formation of Copper Canyon, central Black Mountains, at 3.1 ± 0.2 Ma ($^{40}Ar/^{39}Ar$ on biotites).

Recent tephrochronologic studies and mapping in the Black Mountains area have identified a number of other tuff beds within the Funeral Formation (fig. 22). Knott (1998) collected geochemical data on seven tuffs at Artists Drive, correlating or naming the following: (1) lower Nomlaki tuff (est. >3.58 Ma), (2) the tuff of Curry Canyon (>3.35 Ma), (3) the lower Mesquite Spring tuff (3.35 Ma), (4) the Nomlaki Tuff (3.28 Ma), (5) the upper Mesquite Spring tuff (3.1–3.28 Ma?), (6) the tuff of Clayton Valley (~2.5 Ma), and (7) a lower Glass Mountain tuff (1.98–2.09 Ma). Correlation of these tuffs and their estimated ages are based on the chemical composition of the volcanic glass, paleomagnetism, and relative stratigraphic position (Knott, 1998). The lower and upper Mesquite Spring tuffs are both normally polarized and chemically indistinguishable; they are similar to tephra from the Long Valley volcanic field. The 3.1-Ma tuff of Holm and others (1994) is a Mesquite Spring tuff that is correlative with either of the Mesquite Spring tuff beds at Artists Drive (similarity coefficient = 0.97). Similarity coefficients listed in this paper are calculated using the methods outlined by Sarna-Wojcicki and Davis (1991) using elements La, Ce, Nd, Sm, Tb, Dy, Lu, Sc, Mn, Fe, Rb, Cs, Hf, Th, and U, which were measured by solution ICP-MS analysis of volcanic glass.

Morphologically, the Funeral Formation is faulted and tilted such that it no longer retains alluvial fan morphology. At Artists Drive, below an elevation of +90 m, the Funeral Formation is cut by shorelines or overlain by deposits from late Pleistocene lake deposits dated at 160–185 ka by Ku and others (1998).

Thus, the Funeral Formation remains the coarse conglomerate with interbedded basalt, basaltic agglomerates, and tuffs deposited in an alluvial fan depositional environment. Radiometric ages and tephrochronologic correlations

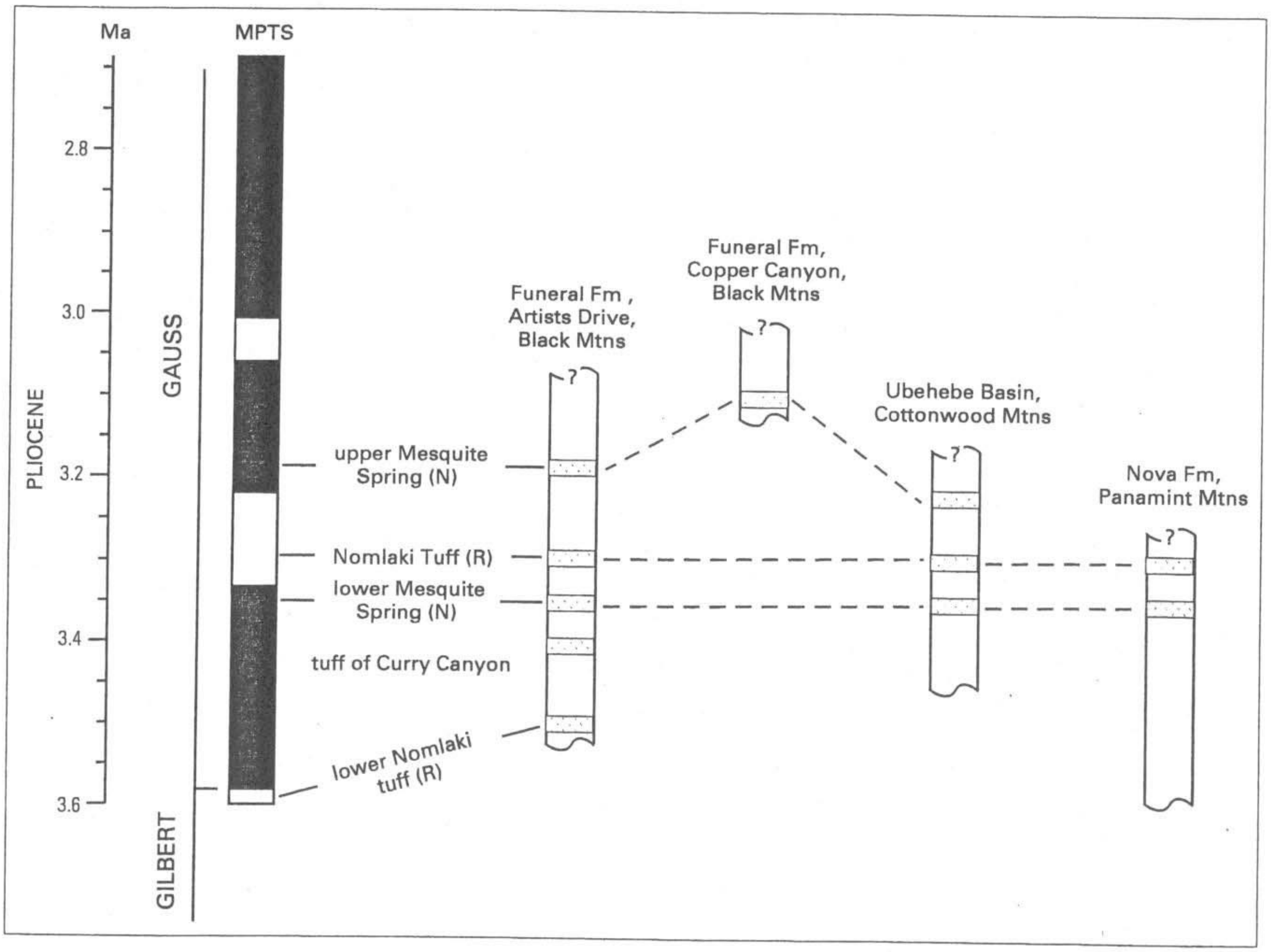

Figure 22. Correlation diagram for Pliocene tuffs of Death Valley. Correlation to the magnetic polarity time scale (MPTS) is signified by N or R, which indicates normal and reverse polarity, respectively. Solid lines, reliable correlation; dashed lines, tentative correlation. Age of the Nomlaki Tuff from A. Deino (personal commun., 1997).

bracket the majority of the Funeral Formation to the Pliocene (5.2 and 1.98 Ma). A 1.7-Ma age on the Shoreline Butte basalt in the northern Confidence Hills, included in the Funeral Formation by Wright and Troxel (1984) and omitted as part of the Confidence Hills Formation (Beratan and Murray, 1992), is the lone Pleistocene age determination.

NOVA FORMATION

The Nova Formation was named for coarse conglomerates and interbedded basalts located along the northwestern flank of the Panamint Mountains (fig. 21). Hunt and Mabey (1966) suggested that the Nova Formation is also Pliocene to lower Pleistocene, and thus so similar to the Funeral Formation that the name Nova Formation should be dropped. Hodges and others (1989), however, argued that Nova Formation be continued, because this name distinguished an important Miocene to Pliocene depocenter; they compiled a stratigraphic section that shows deposition occurred between 5.4 ± 0.4 and 3.7 ± 0.2 Ma (whole rock K/Ar). Snow (1990) dated a 10-m-thick tuff in the upper Nova Formation at 3.35 ± 0.13 Ma ($^{40}Ar/^{39}Ar$ sanidine) and correlated this with the Mesquite Spring tuff in the Ubehebe basin. Using the composition of volcanic glass, Knott and others (1997a) correlated this tuff to the normally magnetized lower Mesquite Spring tuff that underlies the 3.28-Ma Nomlaki Tuff at Artists Drive. Thus, the upper age range of the upper Nova Formation is extended to 3.35 Ma, but does not extend to ~2 Ma as the Funeral Formation does (fig. 22). This adds some support to Hodges and others' (1989) assertion for the continued separation of the Nova and Funeral Formations.

UBEHEBE BASIN

The Ubehebe basin of Snow (1990) is located in the northern Cottonwood Mountains of Death Valley (fig. 21). The Ubehebe basin consists of five sedimentary sequences composed of a variety of rock types from conglomerates to basalts to tuffs (Snow, 1990). Based on radiometric dates, Snow (1990) showed that the age of the Ubehebe basin is Miocene to Pliocene (23.87 ± 0.23 to 3.28 ± 0.07 Ma). Knott (1998) sampled the type locality of the Mesquite Spring tuff (3.28 Ma) and determined that the major-element composition of volcanic glass is very similar to that of the Bishop ash bed (SC = 0.97). The major-element composition of volcanic glass from another tephra bed in the Ubehebe basin is similar to that of either the Nomlaki Tuff (3.28 Ma) or the lower Nomlaki tuff (est. >3.58 Ma) (Knott, 1998). Klinger and Piety (1996), working in the eastern Ubehebe basin, correlated the Bishop ash bed (0.76 Ma) using major-element composition of volcanic glass. Thus, the Ubehebe basin is composed of conglomerates to basalts with an age range of Miocene to middle Pleistocene.

CONFIDENCE HILLS FORMATION

The sequence of tilted conglomerate, mudstone, breccia, and evaporite that composes the Confidence Hills in southern Death Valley has been named the Confidence Hills Formation (Beratan and Murray, 1992). Mapped as Funeral Formation by Wright and Troxel (1984), a late Pliocene age was established by the correlation of the 2.09-Ma Huckleberry Ridge ash bed (Troxel and others, 1986). Later, Beratan and Murray (1992) described the stratigraphy and depositional environments of the exposed section and named these rocks the Confidence Hills Formation. The depositional environment of the Confidence Hills Formation ranges from alluvial fan to playa lake. Pluhar and others (1992) used paleomagnetism to determine that the Confidence Hills Formation ranged in age from >2.15 to <1.79 Ma (fig. 23). Sarna-Wojcicki and others (unpublished data) correlated a number of tuffs and tephra beds within the Confidence Hills Formation with ages ranging from 2.2 Ma to the 1.78–2.09 Ma tuffs of lower Glass Mountain. Thus, the Confidence Hills Formation consists of conglomerate to evaporite that record alluvial fan to playa lake depositional environments in the upper Pliocene to lower Pleistocene (2.2 and 1.78 Ma). The Confidence Hills Formation has not been extended beyond the type locality, and it may be difficult to distinguish from the Funeral Formation, which records similar depositional environments in the same age range.

MORMON POINT FORMATION

The Mormon Point formation is an informally named, early to middle Pleistocene unit of conglomerate, breccia, mudstone, evaporite, and tephra beds exposed at Mormon Point in southern Death Valley (Knott and others, in press). These deposits are interpreted as alluvial fan, playa margin, and perennial to ephemeral lake depositional environments. Tephra layers within the Mormon Point formation (fig. 23), which are correlated by volcanic glass composition, relative stratigraphic position, and paleomagnetism, include several ash beds: upper Glass Mountain (0.8–1.2 Ma), Bishop (0.76 Ma), Lava Creek B (0.665 Ma), and Dibekulewe (~0.51 Ma).

Three perennial to ephemeral lake sequences are found within the Mormon Point formation. The older sequence includes upper Glass Mountain tephra beds, but not the Bishop ash bed. The middle sequence is above the Bishop ash bed and ends with the Lava Creek B ash bed. The youngest and poorly exposed lake deposits are found just below the Dibekulewe ash bed. Thus, lake deposition occurred between ~1 and >0.76 Ma, from <0.76 to ~0.665 Ma, and just prior to 0.51 Ma. The Mormon Point formation is highly faulted; thus, the middle and youngest lake sequences may be the same. Rapid facies changes from green mudstones to evaporites indicate that the lakes recorded by the Mormon Point formation quickly became saline, suggesting that, despite their apparent longevity, the lakes may have been relatively shallow. The timing of these

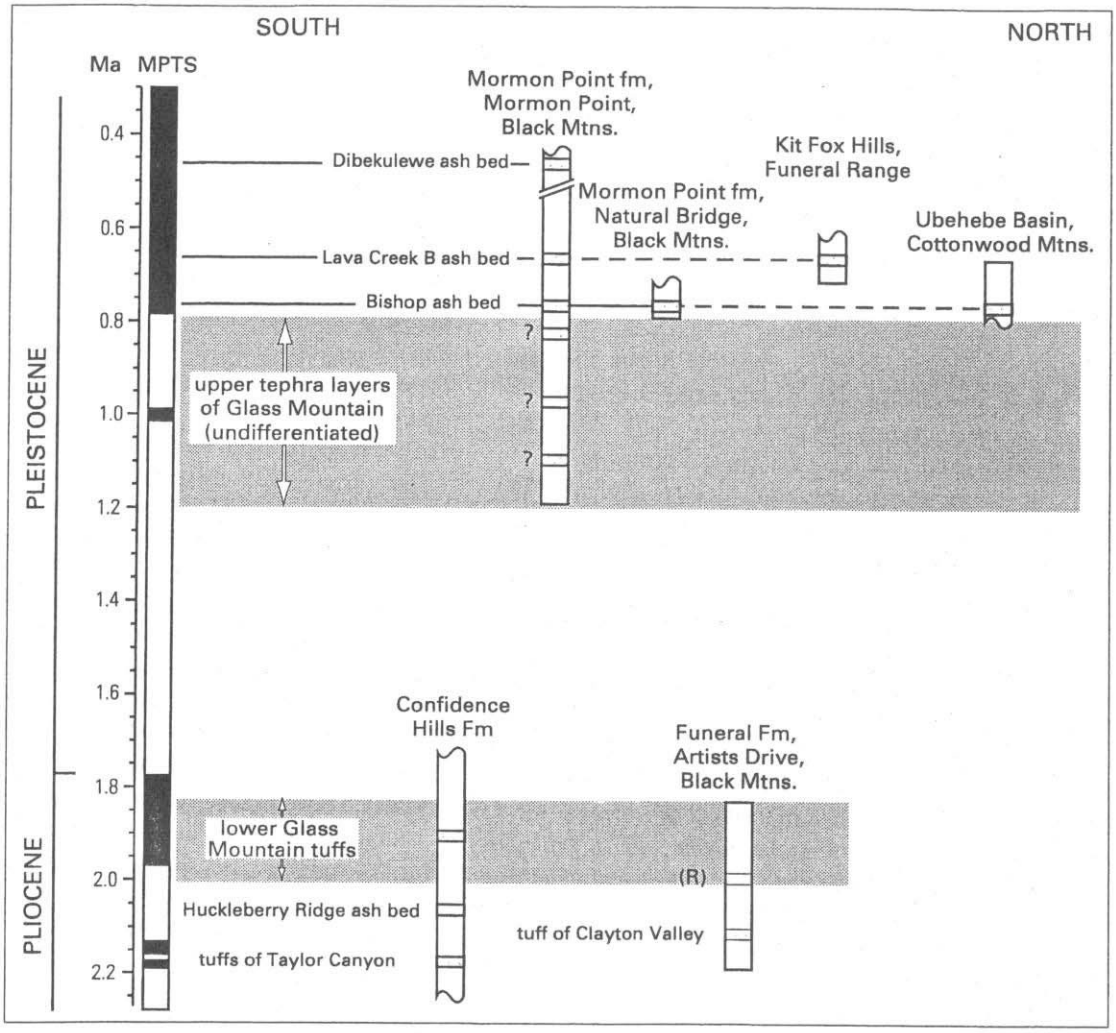

Figure 23. Correlation diagram for upper Pliocene to middle Pleistocene tuffs and tephra beds of Death Valley. Shaded areas, range of ages for upper and lower Glass Mountain families of tephra beds and tuffs. Solid lines, reliable correlation; dashed lines, tentative correlation. Question marks by upper Glass Mountain tephra layers found at Mormon Point indicate that exact age of these tephra beds is not established. Lower Glass Mountain tuff at Artists Drive has reverse paleomagnetic declination, limiting its age to between 1.98 and the age of the Huckleberry Ridge ash bed (2.09 Ma).

lakes is coincident with wetter climatic conditions in Searles Lake to the west (Smith, 1984).

The coarse conglomerate at Natural Bridge, just north of Badwater, contains the Bishop ash bed and thus is included as part of the Mormon Point formation. Klinger (unpublished data) correlated the Lava Creek B ash bed in the southwestern Kit Fox Hills. This area is tentatively considered part of the Mormon Point formation; however, further investigation should be completed to confirm the correlation of Lava Creek B. Like the Funeral Formation, the Mormon Point formation does not have alluvial fan morphology. In the absence of tuffs, the Mormon Point formation is distinguishable from the Funeral Formation because it is generally less indurated and less tilted.

Geologic and geomorphic mapping at Mormon Point and the discrimination of the Mormon Point formation settles an unresolved stratigraphic conflict described by Hunt and Mabey (1966). In most locations in Death Valley, they determined the relative geomorphic relationships to show that the prominent late Pleistocene (160–185 ka) lake strandline was older than their Qg_2, except, and most prominently, at Mormon Point. Knott and others (1997b) showed that the Mormon Point formation and not the Qg_2 are cut by the late Pleistocene strandlines. An alluvial fan, morphologically equivalent to the Qg_2 unit, is inset below the late Pleistocene lake deposits (Knott, 1998).

ALLUVIAL FANS

Some of the more dramatic features of Death Valley are the alluvial fans that are found between the mountain front and the salt pan. Many studies have been made of the alluvial fan deposits; however, the observations of Denny, Hunt, and Hooke have guided the study of alluvial fans in Death Valley, and many other places, for more than 40 years.

Denny (1965) described the morphology of the alluvial fans in central Death Valley. In his study, Denny noted the contrast between the elongate, areally extensive fans and adjoining drainage basins of the Panamint Mountains with the relatively smaller fans and basins of the Black Mountains. Denny suggested that mathematical relationships existed among drainage-basin size, size of active fan, channel width, and clast size. Denny hypothesized that the differences among these and other variables were related to bedrock composing the drainage basin, elevation of the mountain range, which affected precipitation, and locus of tectonic activity.

Hunt and Mabey (1966) followed with detailed maps of Death Valley alluvial fans, including those described by Denny. Building on the observations of Denny, that degree of desert pavement formation and varnish covering of clasts were age dependent, Hunt and Mabey divided the alluvial fans into four units. The oldest alluvial fan unit (g_1) has gone through several revisions. Originally, Hunt and Mabey (1966) designated the Funeral Formation as the first gravel with a map symbol of QTg_1. Wright and Troxel (1984) dropped this awkward dual usage, preferring to use Qg exclusively for units that maintain alluvial fan morphology. As a result, they designated uplifted conglomerates with alluvial fan morphology and an ancient shoreline cut into the surface in southern Death Valley as Qg_1. Subsequently, Knott (1998) found tephra beds within the Qg_1 unit of Wright and Troxel with volcanic glass composition similar to the lower Glass Mountain family of tephra beds (1.7–2.09 Ma), making this unit equivalent to the upper Funeral and Confidence Hills Formations. Thus, I recommend that Qg_1 as used by Wright and Troxel (1984) be discontinued. Dorn (1988) has also used Qg_1 for the older surface facies of Hooke (1972), about 60 m above the channel at Hanaupah fan.

The next oldest unit (Qg_2) of Hunt and Mabey (1966) has a well-developed desert pavement surface, and most clasts are coated with desert varnish. Gravels with Qg_2 surface morphology cover large areas of the alluvial fans in Death Valley. As described above, the relative stratigraphic relations between Qg_2 and the 160–185 ka lake deposits at Mormon Point suggest that Qg_2 is younger than 160–185 ka (Knott and others, 1997b).

The next geomorphic unit (Qg_3) is generally a few meters or less above the active channel and has a remnant bar-and-swale topography; clasts are only partially coated with desert varnish. Based on archeological data, Hunt and Mabey (1966) estimated the age of Qg_3 between 10,000 and 2,000 yr. The youngest alluvial fan unit (Qg_4) occupies the active channels of washes and has prominent bar-and-swale topography and very few varnish-coated clasts.

GEOMORPHOLOGY

WESTERN BLACK MOUNTAINS PIEDMONT

The paradigms that dominate Death Valley geomorphology were established through the work and observations of Hunt, Denny, and Hooke. Denny (1965) observed and measured elements of alluvial fans and drainage basins on both sides of Death Valley between Artists Drive on the north and Mormon Point on the south. One of many important observations in Denny's study was that there appeared to be a numerical relationship between the area of the drainage basin and the area of the alluvial fan. He concurred with Hunt that eastward tectonic tilting of Death Valley by normal slip on the Death Valley fault zone restricts the areal extent of alluvial fans on the east side to about 1/10 the area of their respective basins. In contrast, fans on the west side of Death Valley, which emanate from the Panamint Mountains, are unconfined by tectonic activity, and thus the area covered by the alluvial fans is 1/3 to 1/2 the area of their drainage basins. Hunt and Mabey (1966) also suggested that greater incision of older fan deposits toward the north, along the Panamint Mountain piedmont, indicated a general northward tilting of the range. Hooke (1972) noted that this eastward tilting of Death Valley caused the locus of deposition on east side fans to be nearer the mountain front than on west side fans. In addition, he measured longitudinal profiles along Panamint Mountain alluvial fan surfaces which suggested that the eastward tilting caused burial of older alluvial fan surfaces by younger fan deposits.

Knott (1998) examined drainage basin and alluvial fan morphology along the entire length of the Black Mountains. He found that, although basins and fans along the mountain front from Badwater to Copper Canyon fit the model of an east-tilting basin bound by a single-strand normal fault, other reaches of the mountain front do not fit this model. In the Artists Drive fault block of Hunt and Mabey (1966), just north of Badwater, the Death Valley fault zone is currently expressed as a broad graben with an east-dipping antithetic fault. Alluvial fans at Artists Drive are large, relative to fans to the south, and incision across the uplifting Artists Drive block has resulted in the location of fan apexes and basin mouths away from the mountain front and out on the piedmont, rather than at the mountain front. The incorporation of piedmont areas into the drainage basin makes the balance between alluvial fan and basin area more similar to the Panamint Mountain system of Denny (1965) than to the Black Mountains.

The mountain front along Artists Drive was not always a graben with an antithetic fault, however. The ~3.5–2-Ma alluvial fan deposits of the Funeral Formation, presently uplifting in the Artists Drive block, were most likely deposited along a single-strand normal fault that records the northward propagation of the Death Valley fault zone (Knott and others, in press). This is consistent with the ~4-Ma age of cessation of deposition of the Furnace Creek Formation (Hunt and Mabey, 1966). The youthfulness of the Black Mountains north of Badwater is expressed by smaller drainage basins and a lower mountain crest elevation compared to the remainder of the range (Knott, 1998). This northward growth of the Death Valley fault zone and other normal faults in Death Valley (Knott and others, this volume) may also explain Hunt's hypothesis that the Death Valley region has a slight northward tilt.

At Mormon Point, just south of the area studied by Denny and Hooke, the north-south-trending segments of the Death Valley fault zone are linked by an east-west-trending, north-dipping normal fault. This sequence of faults defines a 5-km right-step in the Death Valley fault zone at the Mormon Point Turtleback. Geologic mapping and tephrochronologic studies that have defined the Mormon Point formation (described previously) show that the east-west-trending segment of the Death Valley fault zone stepped about 1 km northward since the early Pleistocene (Knott and others, in press). The northward stepping of the east-west-trending fault is likely driven by along-strike (northward) propagation of the westerly north-south-trending segment. Geologic relations suggest that the western segment of the Death Valley fault zone is propagating northward at a rate of 1 km/m.y.

This northward propagation is expressed morphologically by a relatively small alluvial fan at the mouth of the Willow Creek basin. Denny (1965) explained the discrepancy between basin and fan area as a result of less resistant bedrock in the basin. Although more erosive bedrock may very likely remain a factor, the evidence of incorporation of Pleistocene fan deposits by northward stepping of the Death Valley fault zone must be considered a significant—and most likely the main—cause for a smaller alluvial fan at Willow Creek. Leeder and Jackson (1993) described mountain front morphology similar to Mormon Point, in central Nevada, suggesting there that, even with consistent underlying bedrock, a long-lived step and along-strike propagation were main elements in the geomorphic expression of the mountain front.

SUMMARY

A number of recent studies have added significantly to the Quaternary stratigraphy of Death Valley. Dating and correlation of tuffs within the Funeral Formation provide reliable bracketing ages between 5.2 and 1.98 Ma. Similarly, the age range of the Nova Formation is between 5.4 and 3.35 Ma, suggesting that deposition in the Nova basin ceased earlier. Speculation had been that both the Funeral and Nova Formations extended into the Pleistocene (<1.79 Ma); the available data, however, do not support this idea. The Ubehebe basin in the northern Cottonwood Mountains records deposition between ~3.28 and 0.76 Ma; more extensive work is ongoing in this area (R.E. Klinger, personal commun., 1999).

Two new Quaternary formations have been established in Death Valley: the Confidence Hills Formation and the Mormon Point formation. The Confidence Hills Formation of Beratan and Murray (1992) is found only in the Confidence Hills and records deposition from 2.2 to 1.7 Ma. The Mormon Point formation is found in central Death Valley at Mormon Point, Natural Bridge, and the Kit Fox Hills, and is lower to middle Pleistocene in age. Tephrochronology has been shown to be a useful tool in deciphering the Pliocene-Pleistocene stratigraphy.

Application of the recently revised and more reliable stratigraphy to resolve geomorphic issues in Death Valley has been limited. Studies along the western Black Mountains indicate that spatial and temporal variations in the behavior and location of the Death Valley fault zone affect the alluvial fan and drainage basin morphology.

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