Isotopic evidence for climatic influence on alluvial-fan development in Death Valley, California

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ABSTRACT

At least three semiarid to arid cycles are recorded by $\delta^{13}C$ values of organic matter in layers of rock varnishes on surfaces of Hanaupah Canyon and Johnson Canyon alluvial fans, Death Valley, California. These isotopic paleoenvironmental signals are interpreted as indicating major periods of fan aggradation during relatively more humid periods and fan entrenchment during subsequent lengthy arid periods.

INTRODUCTION

The history and mechanisms of alluvial-fan development are some of the more controversial topics in desert geomorphology. Tectonics (Hooke, 1972; Bull, 1977), climate (Bull, 1964, 1986; Lustig, 1965; Melton, 1965; Mayer et al., 1984), dynamic equilibrium (Denny, 1965, 1967), steady-state (Hooke, 1968), process-response (Weaver, 1984), or a combination of these (Hunt and Mabey, 1966; Bull, 1979) have been invoked to explain alternating aggradation and incision events resulting in the segmentation of alluvial fans into distinct surfaces. A major difficulty in identifying the correct models has been a lack of evidence on the ages of alluvial-fan surfaces and the environments in which they formed.

Some paleoenvironmental information has been obtained in the southwest from analysis of particle-size distributions (Mayer et al., 1984), soils (McFadden et al., 1984), and fan-surface morphologies (Hunt and Mabey, 1966; Hooke, 1972). Here, we use stable carbon isotopic analysis of organic matter in rock varnishes to provide new and direct evidence about the influence of environmental change on the morphogenesis of arid-region alluvial fans.

Rock varnish is a ubiquitous coating on gravel on arid-region fans. It is composed of clay minerals, manganese and iron oxides, and a variety of minor and trace constituents, including organic matter (Potter and Rossman, 1977; Dorn and Oberlander, 1982). Our approach is based on a previous study (Dorn and DeNiro, 1985) in which we sampled contemporary varnishes from humid and arid environments and found an excellent correlation between the $\delta^{13}C$ values (see next section for definition) of organic matter in surficial varnish and aridity of the environment in which the varnish formed. Values for $\delta^{13}C$ from $-22‰$ to $-24‰$ were observed for varnish samples from semiarid to humid environments. Less negative $\delta^{13}C$ values from $-11‰$ to $-19‰$ were found in arid areas. Dorn and DeNiro (1985) correlated these $\delta^{13}C$ values with the photosynthetic pathways of adjacent vegetation. As the photosynthetic pathways shift along climatic gradients, the $\delta^{13}C$ input to the varnish changes. Thus, the stable carbon isotopic composition of the varnish organic matter reflects the relative aridity of the adjacent environment, with few exceptions. We used sites that had good age control and demonstrated that $\delta^{13}C$ values of organic matter in fossil layers of varnishes contain a paleoenvironmental signal.

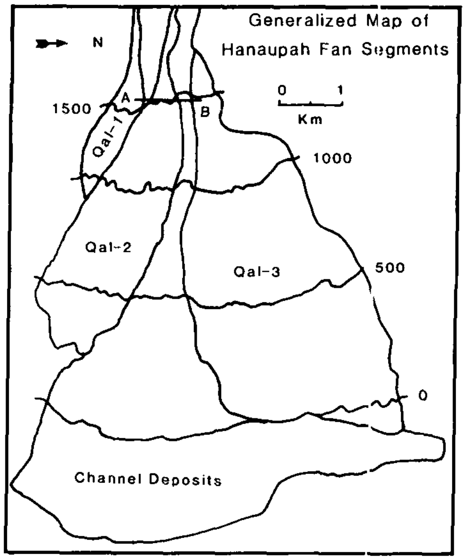

Figure 1. Generalized map of surface and channel deposits of Hanaupah Canyon alluvial fan. Qal-1, Qal-2, and Qal-3 surfaces presented here are incorporated into Hunt and Mabey's (1966) Qg-2 unit. Channel deposits include many subdivisions (cf. Hunt and Mabey, 1966; Hooke, 1972) that cannot be distinguished by $\delta^{13}C$ analyses of rock varnish. Line A-B locates cross-fan profile in Figure 2.

STUDY SITES AND METHODS

Death Valley is a classic area for the study of alluvial fans. Denny (1965), Hunt and Mabey (1966), Hooke (1972), Hunt (1975), Bull (1977), and many others have used the fans on the west side of southern Death Valley that debouch from the Panamint Range as examples of complex fan morphogenesis.

Surfaces of four different ages were sampled from Hanaupah Canyon and Johnson Canyon fans. The spatial relation among these surfaces is portrayed for Hanaupah Canyon fan in Figures 1, 2, and 3. The oldest surface on the two fans (Qal-1) is characterized by gullies that incise rounded ballenas. The surface of Qal-1 is covered with calcrete rubble and isolated patches of preserved desert pavement. Qal-2 is lower and younger than Qal-1; it maintains a larger area of well-varnished pavement and is less incised. Qal-3 is still lower and younger than Qal-2, has the largest area of smooth desert pavement and limited gully development, and in contrast to the older surfaces, has no calcrete rubble incorporated into the pavement. These three surfaces correspond to the Qg-2 unit of Hunt and Mabey (1966).

Three to four sets of channel units are incised into Qal-3 fan surfaces. The oldest of these, Qal-4, is quite extensive at the toe of the fans. Because of the paucity of varnish on these younger deposits, only varnish on the Qal-4 surface was sampled here. Qal-4, the youngest alluvial-fan surface studied, consists of irregular desert

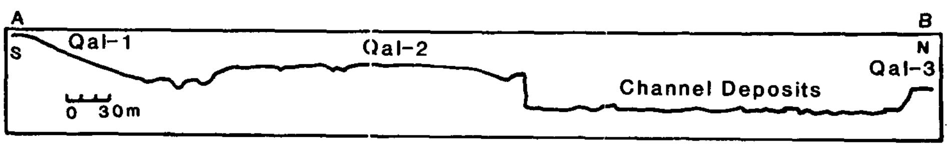

Figure 2. Cross-fan profile at head of Hanaupah Canyon fan showing positions of broad-fan surfaces relative to channel deposits.

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pavement that still preserves some bar and wash topography. It is roughly equivalent to the Qg-3 unit mapped by Hunt and Mabey (1966).

Varnished pieces from the largest boulders and larger cobbles in the desert pavements of Qal-1 through Qal-4 were sampled away from lichens and away from the calcrete rubble on the Qal-1 and Qal-2 surfaces. The varnish was scraped off in about 10-μm layers by using a tungsten-carbide needle under 45× magnification until the underlying rock was reached. This scraping depth was checked by random scanning electron microscope (SEM) analysis of the specimens and has an uncertainty of 5–10 μm. The 10-μm depth was chosen because other types of paleoenvironmental signals (cf. Dorn, 1984, 1986) in these Death Valley varnishes display fluctuations at about 10-μm intervals (Dorn, in prep.).

After each 10-μm layer was scraped off, it was processed by the methods described in Dorn and DeNiro (1985). Organic matter is concentrated by dissolution of the other varnish constituents, freeze dried, and combusted. Ratios of $^{13}C/^{12}C$ of the resulting CO_2 are determined by mass spectrometry. About 15 mg of organic matter are obtained by this extraction method. The results are given in the usual δ notation, where

$$\delta^{13}C = \frac{(^{13}C/^{12}C)\,\text{sample} - (^{13}C/^{12}C)\,\text{standard}}{(^{13}C/^{12}C)\,\text{standard}} \times 1000‰.$$

More than 1000 cm^2 of varnish was sampled from each fan surface. SEM analysis assisted in the selection of varnishes that have a fairly uniform thickness for a given fan surface. The scraping method is subject to the uncertainty of the uniformity of the thickness of the layer that is sampled, and it depends on the skill of the operator; however, currently it remains the only method of obtaining enough carbon from varnish layers for $\delta^{13}C$ analysis.

RESULTS AND DISCUSSION

As shown in Tables 1 and 2, the sequences of stable carbon isotope fluctuations are remarkably similar for Johnson Canyon and Hanaupah Canyon alluvial fans. On the youngest surface sampled, Qal-4, the organic matter extracted is derived from the entire varnish coating, because these varnishes are typically less than 10 μm thick. Values of −14.7‰ and −15.1‰ record an arid signal (Tables 1 and 2). Preliminary cation-ratio analysis (Dorn, in prep.) suggests that the Qal-4 surfaces are middle to early Holocene in age. These arid isotope signals are consistent with the *Neotoma* plant macrofossil record for the Holocene in Death Valley (Wells and Woodcock, 1985).

The $\delta^{13}C$ values of varnish on the Qal-3 surfaces record a relatively semiarid (to humid) period followed by an arid period. It is likely that the middle layer in Johnson Canyon (Table 2) represents a transition between the upper and lower layers and thus reflects the inexact depth resolution of the scraping technique. Preliminary radiocarbon and cation-ratio analysis suggests that the Qal-3 surfaces are late Wisconsin in age (Dorn, in prep.). The more humid isotopic signal for the basal layers is consistent with the *Neotoma* plant macrofossil record for the late Wisconsin (Wells and Woodcock, 1985).

The stable carbon isotopic sequences reflect the relative ages of the two oldest surfaces. The paleoenvironmental sequence for Qal-2 is semiarid, arid, semiarid, arid. Varnishes on the oldest Qal-1 surface record a basal semiarid period followed by arid, semiarid, arid, semiarid, and at the surface, an arid period.

The paleoenvironmental interpretation of these measurements requires some assumptions. (1) The environment must have been sufficiently stable throughout the time of varnish accretion for the varnish not to have undergone erosion (cf. Dorn and Oberlander, 1982). (2) Semiarid to arid cycles that affected the $\delta^{13}C$ composition in varnish were not missed in sample preparation. This is likely because the sequence of $\delta^{13}C$ values found on two separate fans is similar. (3) Semiarid and arid periods were of duration to allow enough varnish development to be recorded by $\delta^{13}C$ sampling. (4) We assume that

TABLE 1. δ^{13}C VALUES OF ORGANIC MATTER IN VARNISH LAYERS OF HANAUPAH CANYON ALLUVIAL FAN, DEATH VALLEY

Varnish depth below surface* (µm)	δ^{13}C† (per mil)			
	Qal-4	Qal-3	Qal-2	Qal-1
0–10	−15.1	−15.4	−15.1	−15.4
10–20		−21.1	−22.8	−23.3
20–30			−14.1	−19.2
30–40			−18.3	−23.4
40–50			−23.6	−16.1
50–60				−23.2

* Approximate.

† Less negative values indicate more arid conditions.

TABLE 2. δ^{13}C VALUES OF ORGANIC MATTER IN VARNISH LAYERS OF JOHNSON CANYON ALLUVIAL FAN, DEATH VALLEY

Varnish depth below surface* (µm)	δ^{13}C† (per mil)			
	Qal-4	Qal-3	Qal-2	Qal-1
0–10	−14.8	−15.4	−16.0	−14.6
10–20		−17.5	−21.8	−22.1
20–30		−22.2	−15.5	−18.3
30–40			−18.5	−23.4
40–50			−22.9	−15.7
50–60				−21.1
60–70				−22.2

* Approximate.

† Less negative values indicate more arid conditions.

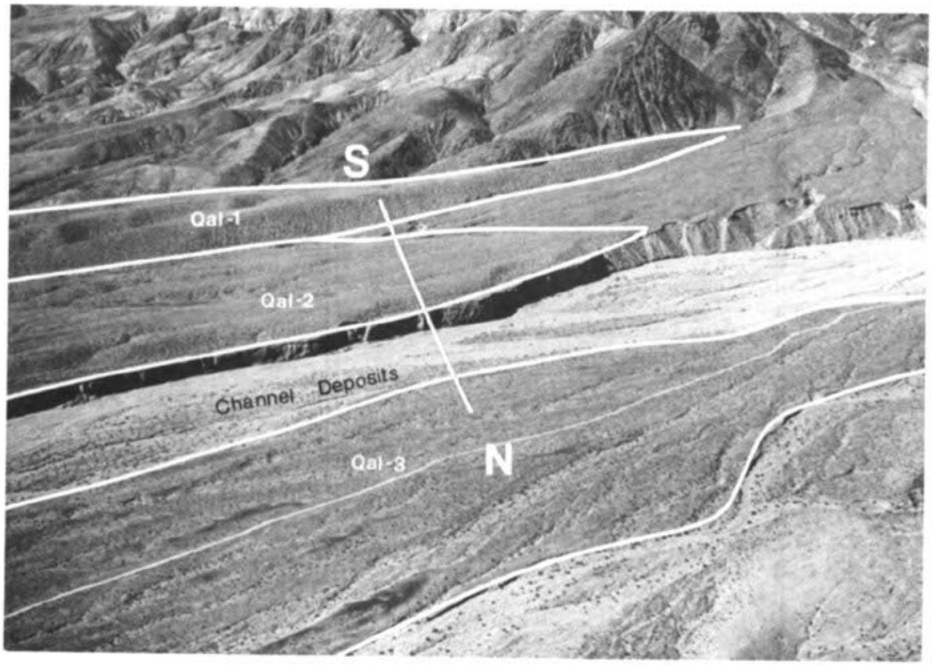

Figure 3. Aerial photograph of head of Hanaupah Canyon fan.

the sampled boulders and large cobbles represent the depositional surface and that subsequent weathering and pavement development did not change their subaerial orientation. This is most questionable for the Qal-1 surface, and we must assume that intact pavements survive despite ongoing pedogenic activity, such as reported by Wells et al. (1984). (5) Varnish accretion starts soon after deposition ceases. Dorn and Whitley (1984) found that this lag is minimal, only about 100 yr in the Mojave Desert. In the more arid climate of Death Valley, the lag is probably only slightly longer because drier and warmer climates can slow varnish development (Dorn and Oberlander, 1982).

CONCLUSIONS

Our reconstruction of the history of Hanaupah Canyon and Johnson Canyon alluvial fans starts with the Qal-1 surface. The $\delta^{13}C$ values of organic matter in the basal layer of varnish indicate that soon after the deposition of Qal-1 at the fanhead the environment was significantly more humid than at present. Similarly, the lowest layers in Qal-2 and Qal-3 varnishes, sampled near the heads of the alluvial fans, have more humid $\delta^{13}C$ values. Cation-ratio dating (Dorn, 1983) of varnishes on these surfaces indicates that deposition on Qal-1, Qal-2, and Qal-3 gradually shifts downfan with time (Dorn, in prep.). Thus, as geomorphic activity ceased near the fanhead, the more humid $\delta^{13}C$ signal that is recorded at the base of the varnishes is likely associated with continued aggradation downfan.

Arid periods, however, punctuate the deposition of these surface facies. Each successive semiarid aggradational period that was lengthly and of enough magnitude to affect the $\delta^{13}C$ values in varnish has been followed by an arid period of permanent fanhead entrenchment. When a subsequent environmental change then produced a more humid $\delta^{13}C$ signal, another aggradational phase started at a lower elevation. The gradual eastward tilting of Death Valley (cf. Davis and Maxson, 1935) likely provided the energy for permanent incision of the fans, but this entrenchment seems to have been triggered by climatic changes that were of sufficient length and magnitude to change the photosynthetic pathways of plants adjacent to the varnishes on these fan surfaces.

These data are not in conflict with the hypothesis that an additional pulse of aggradation occurs during the transition from a relatively humid to a more arid climate (cf. Bull, 1979). This issue, however, cannot be evaluated with $\delta^{13}C$ analysis of varnish. Bull (1986) pointed out further complications in that the effects of climatic changes may vary with range height, basin size, lithology, slope, and tectonic patterns.

The geomorphic interpretation we favor is that the Pleistocene alluvial-fan surfaces in Death Valley were deposited during lengthy humid periods, probably under a landscape of more extensive vegetation cover (e.g., Wells and Woodcock, 1985) that was subject to more intense weathering and soil development than at present. Under such a transport-limited geomorphic regime, the particles generated on the hillslopes and transported to streams were probably smaller than at present. These hillslope-hydrologic conditions would have probably reduced the intensity and competence of the greatest stream flows. As many others have postulated (e.g., Lustig, 1965; Melton, 1965; Bull, 1979; Mayer et al., 1984), when the late Quaternary climate changed to an arid regime in the Holocene, progressively more regolith cover was stripped from the hillslopes, exposing more bedrock and leading to more erosive stream flows with greater stream competence.

In contrast to the more gentle aggradational regime during the major semiarid to humid phases, more arid conditions promoted stream incision at fanheads and punctuated depositional episodes concentrated at fan toes. By the time another lengthy semiarid phase of fan aggradation took place, these climatically induced entrenchments were made permanent by the tectonic eastward tilting of the Panamint fans. At least three such aggradation-entrenchment cycles are recorded in the surface segments and varnishes of the Johnson and Hanaupah canyon fans that exit the Panamint Range into Death Valley.

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