To John
From
Bennie

QUATERNARY TECTONICS OF SOUTHERN DEATH VALLEY

FIELD GUIDE,

PACIFIC CELL, FRIENDS OF THE PLEISTOCENE

OCTOBER 31 — NOVEMBER 2, 1986

John Casbey

QUATERNARY TECTONICS OF SOUTHERN DEATH VALLEY, CALIFORNIA FIELD TRIP GUIDE

Editor: Bennie W. Troxel

Leaders: Roland H. Brady, III

Paul R. Butler

Bennie W. Troxel

Prepared for the 1986 annual meeting and field trip of the

Friends of the Pleistocene, Pacific Cell

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QUATERNARY TECTONICS OF SOUTHERN DEATH VALLEY, CALIFORNIA

FRIENDS OF THE PLEISTOCENE, PACIFIC CELL
1986 ANNUAL MEETING AND FIELD TRIP

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FRONTISPIECE. Compilation of ERTS imagery courtesy California Division of Mines and Geology. Central and southern Death Valley form the prominent valley that occupies the center of the photograph. Panamint and Owlshead Mountains on left; Fort Irwin area and Avawatz Mountains occupy lower third of photo. Black Mountains, Greenwater Range, Resting Spring Range in uppermost right and Nopah Range from center to right center of photo. Funeral Mountains occupy upper left part of photo.

COVER PHOTO. Low-altitude oblique photograph of the southern part of the Noble Hills. Avawatz Mountains in background. Southwest-trending branches of the southern Death Valley fault zone extend through the Noble Hills. They bend to a more easterly trend along north margin of the Avawatz Mountains. Spence aerial photograph, courtesy of Levi F. Noble.

DEDICATION: This volume is in memory of Levi F. Noble, pioneer in Death Valley tectonics, and Richard H. Jahns who had, among his many interests, a strong love for the Avawatz Mountains.

High-altitude aerial photograph taken from a point over the southern Nopah Range. View to southwest. Avawatz Mountains, in center, are bordered by large dark-colored fans composed mostly of coarse fragments of diorite. Mojave River flows northward around east (left) margin of Avawatz fan. River was ponded where channel flows between the two dark masses (Salt Spring Hills). Channel continues westward along Avawatz fan and joins Amargosa River, which then flows through Saddle Peak Hills, around south tip of Saratoga Hills and northwestward along southern Death Valley fault zone. The Amargosa River channel is deeply incised in Quaternary and Pliocene (?) gravel and lake sediments in center and lower right of photo. Prominent fan of the river extends below the channel (right center of photo). Intersection of Garlock and Death Valley fault zone forms east-pointing V on north flank of Avawatz Mountains. Photo from U.S. Geological Survey.

PROLOG

The idea for this volume arose from the expressed interest of many of the participants of the Friends of the Pleistocene 1985 field trip. The volume was hastily compiled by me with the enthusiastic assistance of the authors herein and Betty Troxel. Any flaws in the volume are the responsibility of the editor- - me.

Death Valley has much to offer to those who are concerned about on-going or barely quiescent tectonics. Although seismically inactive, Death Valley contains abundant physical evidence that much has happened in the near-recent past, and is continuing. This volume is a small sample of what has happened in Death Valley during Quaternary time, and what is happening now.

The 8 articles in this volume present original data and most of the articles will probably be expanded with additional data provided by on-going or future research. Lacking are sufficient correlation of Death Valley fans and fan surfaces, the interrelations of tectonism and volcanism, and definitive information about the history of Lake Manly. A handy field method to compare fans and fan surfaces from one area to another would do much to provide quantitative information about the Quaternary history of Death Valley.

The authors solicit your critique of the articles in this volume. The editor begs your forgiveness for flaws in the volume.

Acknowledgements.

Many of the aerial photographs were obtained from the U.S. Geological Survey. Others were obtained from or through the efforts of individuals, usually credited as the source. Betty Troxel provided the sketches of desert flowers illustrated here and there in the volume. The sketches are borrowed from her sketchbook of Death Valley flowers, soon to be published. The U.S. Postal Service failed to deliver a manuscript sent to me by Paul Butler and this resulted in panic and a serious delay in completing the volume. Nevertheless, Grape Press Printing of Napa, California managed to print the volume in time for our trip.

The volume.

Instead of a traditional field guide, this volume contains six articles with suggested traverses in them. Two other articles contain new data relevant to the theme of the 1986 field trip.

Brady's article contains data he acquired while completing a PhD dissertation. From the dissertation, he has abstracted information pertinent to Quaternary tectonism. Butler has likewise synthesized information from his PhD dissertation and presents it herein. Troxel has put field information acquired by him during the 1960's into various articles herein, some with co-authors with whom he has worked more recently. Sylvester and others have for several years, been acquiring geodetic information. The area of concern is farther north in Death Valley than the target area for this trip, but the data acquired by them is relevant to understanding Quaternary tectonics, hence is included in this volume.

The trip.

Introduction. The articles are arranged in the order that the various areas will be visited during the 1986 field trip. It will take a full day to visit the areas discussed in the first three articles. If you have a choice, it is recommended that you follow the trips outlined by Brady and Butler before visiting the area described by Troxel.

A second full day can easily be spent in the Confidence Hills, and at the tephra locality farther north. If you move swiftly you can visit the small canyon on the west flank of the Mormon Point turtleback.

A third partial day is recommended to visit the tephra locality then proceed northward along the east side of Death Valley to the vicinity of Furnace Creek Ranch. This can be accomplished by about 2p.m. if you don't dally at too many points.

The following is a recommended tour.

First Day. Proceed southward from Shoshone by way of State Highway 127 to the turnoff westward marked by an historical marker (about 25 miles from Shoshone). The first several miles are through and across Quaternary lake sediments that formed during a ponding of the Amargosa River from at least 2 million years ago until about .5 million years ago. The sediments, known as the Tecopa lake beds, were discussed in the 1985 Friends of the Pleistocene guidebook. Southward beyond the lake beds, the paved road encroaches upon fans emanating from the Black Mountains to the west. The road then passes over the Ibex Pass. Beyond the pass the road traverses downstream on a fan surface that extends southward to the Amargosa River. The fan debris is rarely more than a few feet thick (unpublished maps of L. A. Wright and B. W. Troxel) particularly downstream beyond the relay station that is situated on the west (right) side of the road a few miles south of Ibex Pass. The fan is a pediment in which the bedrock surface is close to and parallel to the fan surface.

About where the road to the Dumont Dunes extends left from the paved road, the paved road continues southward upon material transported by the Amargosa River. The material has the form of a fan with a convex upward surface that apexes at the point where the Amargosa River crosses the road. This point is marked by a single tamarisk tree, designated as the Amargosa National Forest by Roland Brady, Paul Butler, and others.

Barely beyond the fan or delta of the Amargosa River is the gravel road on your right that leads westward into southern Death Valley from the Harry Wade historical monument.

Follow the gravel road. Within a few miles it passes the south tip of the Saddle Peak Hills. On your right, the west-flowing Amargosa River has cut through the hills rather than flow around the south tip of the hills. This phenomenon was discussed by Butler in 1982 in a guidebook for the Cordilleran Section of the Geological Society of America. Continue westward. The gravel road is more or less parallel to the Amargosa River channel. Choose which of the first three articles you wish from this volume and proceed accordingly. For the official trip, return to Shoshone at the end of your excursions.

Second Day. Proceed north from Shoshone on State Highways 127 and 178. Turn left about one mile north of the town and follow highway 178 westward. At this point you are nearly at the upstream limit of the Tecopa lake beds. To the north the sediments are interbedded with gravel of the Amargosa River. To the west the lake beds are interbedded with fan gravel from the Greenwater Range.

Within about a mile after you make a wide turn to the left and pass over an obvious fan surface, you pass over a shallow drainage divide and turn gradually to the right and cross Greenwater Valley. Well-paved and varnished fan surfaces at the drainage divide and beyond are probably upstream equivalents of the Greenwater surface discussed in the 1985 guidebook of the Friends of the Pleistocene. This surface is less than 250,000 years old. A similar surface is preserved in many places upstream on both sides of Greenwater Valley.

Continue across the valley. At Salsberry Pass the road follows drainage directly into Death Valley. Much of the alluvium-covered surface for the next several miles is a veneer of gravel that is, at most, a few feet thick and rests upon a moderately smooth surface cut onto bedrock.

Continue downstream. The road passes from one drainage to another at Jubilee Pass then continues into the floor of Death Valley. The first intersection in the floor of the valley is the point at which you turn left for an excursion of the Confidence Hills. The article by Troxel and Butler will lead you from the road intersection. A supporting article contains a discussion of ash beds in the Confidence Hills.

North of the intersection is the site to see tephra that was emitted as a base surge deposit from a cinder cone on the West Side road. This phenomenon is discussed in another article by Troxel and Butler. On your way to the tephra deposit, be sure to note the well-preserved shorelines cut into basalt in Shoreline Butte. If you have the time you may wish to make a brief side trip on the West Side road to Cinder Hill to see the offset source area of the tephra. This ends the planned excursions of the second day of the field. Return to Shoshone.

Third Day. Repeat your trip from Shoshone to the West Side road turnoff slightly northeast of Shoreline Butte. One detailed stop is planned this day. From there you are encouraged to continue north in Death Valley to Furnace Creek.

You must take great care to find the main point of interest on this day. Watch your mileage at the West Side road turnoff and watch for the mileage markers on the road. The article by Troxel describes in detail how to reach the small canyon of interest.

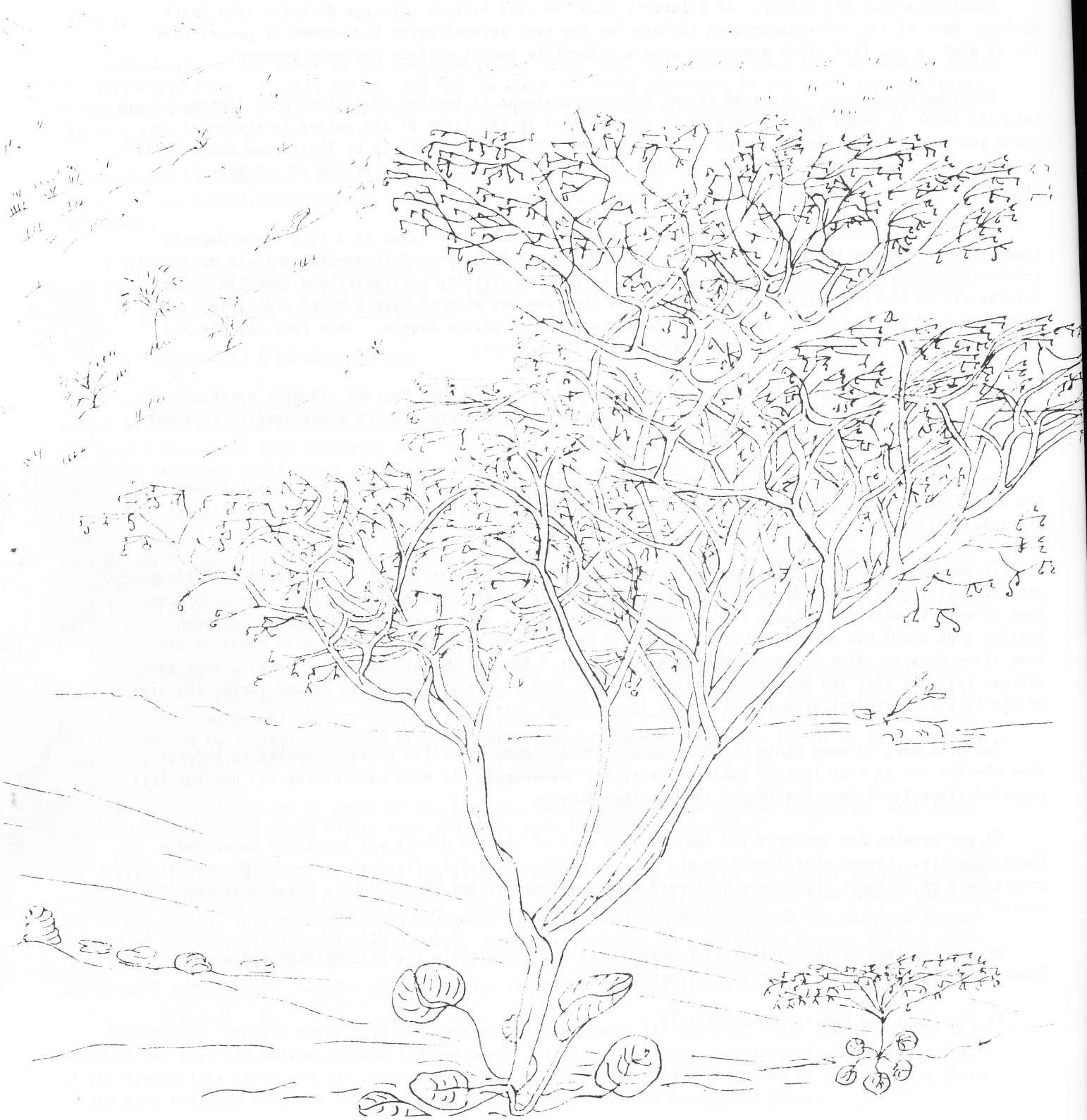
If you continue north from this area you will see many features of interest related to Pleistocene activity. These include an abundance of fault scarps near the Black Mountains. The scarps cut fans of several ages and closely follow the mountain front. Most scarps reflect normal movement (valley side down) but some bound small grabens. Desert varnish attains various hues based on age. Some steep fans or talus cones contain as many as 4 or 5 hues of varnish (or fresh rock). Fans have various textures that are dependent upon the type of rock in the source area. By and large, the size of the fans is dependent upon the extent of the drainage area.

You will see, in many parts of the mountain front, remnants of fan gravel cemented to bedrock when the fan was at that level. Fault activity has downdropped the main mass of the fan but has left cemented segments of fans hanging on the mountain front.

If you examine fan surfaces you can see that much of the fan debris was deposited as episodic flood deposits. Levees that formed on the lateral margins of debris flows are common. Occasional snouts made up of large clasts are preserved here and there at the tip of debris flows that came to rest.

As you continue northward towards Furnace Creek examine closely the fan surfaces and mountain front. You will be rewarded for your efforts.

We hope that you had a successful trip.



ERIOGONUM RIXFORD or CHINESE PAGODA. 6 to 16 in. tall with two or more levels. Tiny pearl-pink flower clusters hang down. 2500-5000 ft elevation in the open areas. TECOPA SKELETON WEED (right) is seldom over 4 in. tall but up to 3 ft wide. -8000 ft elevation. Abundant along the highways. Both plants dry to a rich lacy brown and growth is upward and divides into threes at flower stems.

STRATIGRAPHY AND TECTONICS OF THE NORTHERN AVAWATZ MOUNTAINS AT THE INTERSECTION OF THE GARLOCK AND DEATH VALLEY FAULT ZONES, SAN BERNARDINO COUNTY, CALIFORNIA-- A FIELD GUIDE

Roland H. Brady III
Department of Geology
California State University, Fresno

ABSTRACT

The Quaternary stratigraphy and structure of the Avawatz Mountains is the product of the dynamic interaction between the Garlock and southern Death Valley fault zones. The left-lateral Garlock fault zone lies along the northern margin of the range, and the right-lateral southern Death Valley fault zone lies along its eastern margin. The two faults intersect at nearly right angles in the northeast corner of the range.

Sedimentological and structural evidence indicates that during the latest Tertiary time, the Avawatz Mountains had not yet fully uplifted. At the site lay a complex of shallow, non-marine basins that collected sediment mainly from the east and south. During late Pliocene and Pleistocene time, the bedrock of the Avawatz Mountains rose over 2000 m through the overlying sedimentary cover, complexly deforming it and dramatically changing the local sedimentation pattern. This uplift appears to have been caused by a change in the kinematic regime at the intersection of the southern Death Valley and Garlock zones: whereas during Tertiary time nearly pure strike-slip had occurred along the eastern Garlock fault, during Quaternary time, the movement became left-lateral oblique, up to the south.

The southern Death Valley fault zone appears to be a major, regional structure that extends at least 20 km south of the Avawatz Mountains. Sedimentological evidence suggests that there has been a minimum of 20 km of slip along the fault zone since Plio-Pleistocene time.

INTRODUCTION

The Avawatz Mountains lie at the southern end of Death Valley, rising nearly 3000 m from the sea-level elevation of the valley floor. The range is arcuate in shape, concave southwest and has a steep escarpment on its east side (Fig. 1). A string of low-lying hills extend northwest from the northeastern side of the range. Herein, these hills are referred to as the Noble Hills, in honor of Levi Noble who was one of the geological pioneers in the Death Valley area.

The route taken in this excursion is covered by the Avawatz Pass 15 minute topographic quadrangle. The area is also included on the Trona 2 degree geologic quadrangle.

LOCAL GEOLOGY

The bedrock core of the eastern Avawatz Mountains is a heterogeneous complex of Mesozoic intermediate intrusive rocks--mainly monzodiorite with lesser granite (Fig. 2). Within the complex are roof pendants of Precambrian and Paleozoic metasedimentary rock. The bedrock in the southern and western parts of the range is mainly Mesozoic metavolcanic rocks and minor granite.

The southern Death Valley fault zone strikes northwest, and lies along the northeastern margin of the Avawatz Mountains. The Garlock fault zone lies along the northern part of the range. The two fault zones intersect at nearly right angles in the northeastern Avawatz Mountains (Noble and Wright, 1954).

STRUCTURAL FEATURES

Garlock Fault Zone. Extending northeastward from the San Andreas fault to southern Death Valley, the Garlock fault zone is the second longest on-shore fault in California. Between 50 km and 65 km of left-lateral offset across it is well established (for a review see Carter, 1980).

In the Avawatz Mountains, the Garlock fault zone is six kilometers wide; it extends from the southern edge of the Owlshead Mountains to Leach Lake (Fig. 2). In the region of the Avawatz Mountains, the Garlock fault zone contains numerous, anastomosing, east-striking branches that cut through and juxtapose bedrock with Tertiary and Quaternary deposits. The most prominent branch is the Mule Spring fault, an arcuate fault. On the north side of the range, the Mule Spring fault is an east-striking, near-vertical, left-lateral oblique fault,

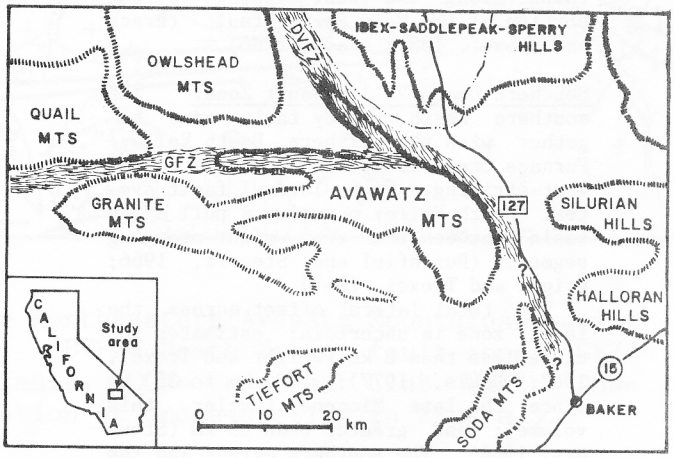


Figure 1. Location map of the Avawatz Mountains at the intersection of the Garlock and Death Valley fault zones.

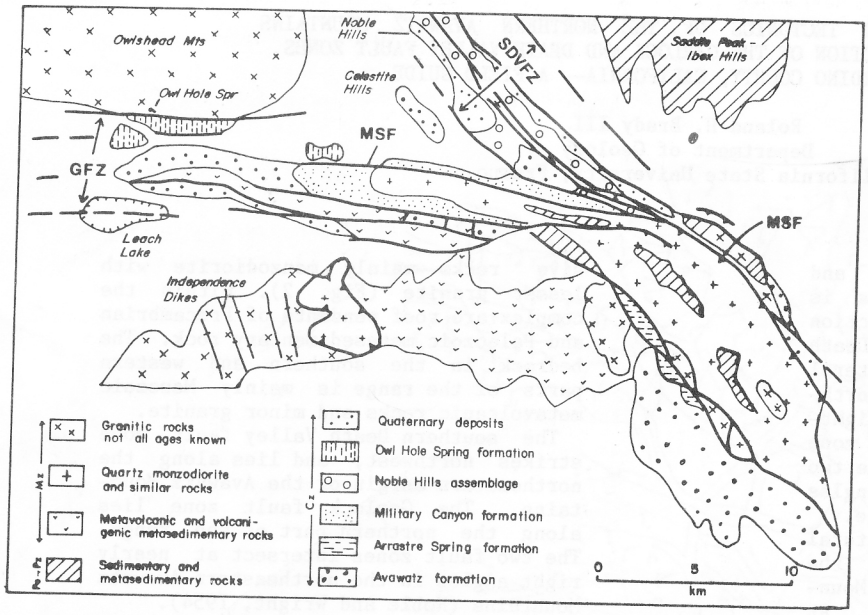


Figure 2. Generalized geologic map of the Avawatz Mountains showing the relationship between the Garlock fault zone (GFZ), the Mule Spring fault (MSF) and the southern Death Valley fault zone (SDVFZ).

but on the east side of the range, it flattens and becomes a west-dipping reverse fault that emplaces crystalline rocks eastward over bedrock and over sedimentary strata of Tertiary and Quaternary age.

The location and geometry of the eastern termination of the Garlock fault zone is controversial. Hewett (1954), and Jahns and Wright (1960) speculated that the Garlock fault zone dies out in the Avawatz Mountains. In contrast, Davis and Burchfiel (1973) and Pleiscia and Henyey (1982) suggested that the Garlock fault zone extends across the Death Valley fault zone approximately 25 km east of the the Avawatz Mountains, and that it has been offset less than 5 km by the Death Valley fault zone. Structural and geophysical studies in the Avawatz Mountains and in the region of the proposed "Garlock extension" support the earlier contention, and indicate that the Garlock fault zone terminates in the eastern Avawatz Mountains along the west-dipping reverse portion of the Mule Spring fault (Brady and Troxel, 1981; Brady, 1986).

Southern Death Valley Fault Zone. The southern Death Valley fault zone together with the northern Death Valley/ Furnace Creek fault zone forms a northwest-striking, right-lateral fault system. Death Valley occupies a pull apart basin between the two, right-stepping segments (Burchfiel and Stewart, 1966; Wright and Troxel, 1967).

The total lateral offset across the fault zone is uncertain: estimates include less than 8 km (Wright and Troxel, 1967; Davis, 1977); 20 km to 35 km since the late Miocene (Butler, this volume); and greater than 85 km (Stewart, 1966). The southern extent and the amount of right-lateral offset on the southern Death Valley fault zone are also debated. Stewart (1967), Wright and Troxel (1967), and Dibblee, (1980) suggested that the fault zone may extend more than 100 km south of the Avawatz Mountains. In contrast, Davis (1977) suggested that the Death Valley fault terminates in the northern Avawatz Mountains. Structural and sedimentological evidence in the Avawatz Mountains though, suggests that there is a minimum of 20 km of offset across the southern Death Valley fault zone, and that it extends at least 20 km south of the Avawatz Mountains.

In the Avawatz Mountains region, the southern Death Valley fault zone is well exposed along the Noble Hills. There, it contains six main branches that tectonically intersheave Cenozoic sedimentary strata with crystalline basement rocks. Overall, the amount of deformation within the fault zone increases from northwest to southeast; the greatest offset and the youngest offset are on the eastern branches. At the south end of the Noble Hills several branches of the Death Valley fault zone strike obliquely into the east side of the Avawatz Mountains, where they appear to be over-faulted by crystalline rocks moved eastward along the reverse segment of the Mule Spring fault.

CENOZOIC DEPOSITS

Five tectono-stratigraphic assemblages of Neogene continental strata flank the bedrock on three sides of the range (Troxel and Butler, 1979; Brady, 1984). In some of these strata, clasts of migmatitic gneiss are a major component; as well, there are essentially no clasts of monzodiorite or metavolcanic rock. Because there is no apparent source for gneiss in the Avawatz Mountains, and because the deposits contain a paucity of Avawatz rock types, the detritus in these strata was probably eroded from gneissic bedrock terrane that lay east of the Avawatz Mountains. The sediment was deposited by alluvial fan, braided river and lacustrine pro-

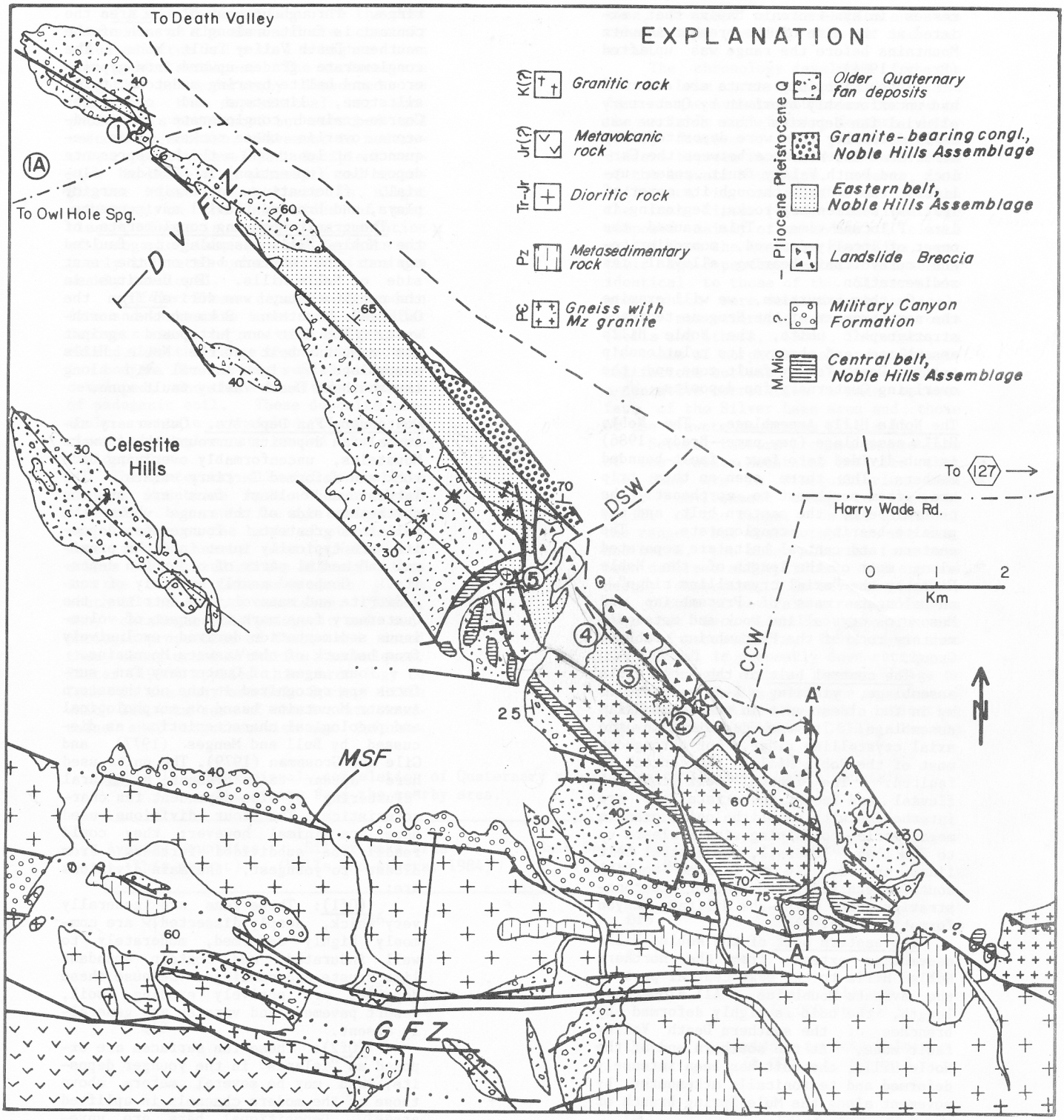


Figure 3. Generalized geologic map of the northeastern Avawatz Mountains showing the locations of stops on this excursion. DVFZ= Death Valley fault zone, GFZ= Garlock fault zone, MSF= Mule Spring fault, CCW= Canadian Club Wash, DSW= Denning Spring Wash. A-A' indicates location of cross-section in Figure 5.

cesses in syn-tectonic basins that existed at the site of the present Avawatz Mountains before the range was uplifted (Brady, 1984).

These Tertiary strata are deformed and unconformably overlain by Quaternary alluvial fan deposits whose detritus was derived locally from were deposited when structural interference between the Garlock and Death Valley fault zones uplifted the bedrock through its cover of Tertiary sedimentary rocks, beginning in late Pliocene time. This caused the onset of locally-derived, monzodiorite- and metavolcanic-bearing alluvial fan sedimentation.

On this excursion, we will examine the northernmost of the Neogene tectonostratigraphic units, the Noble Hills assemblage, and observe its relationship to the Death Valley fault zone and the overlying Quaternary fan deposits.

The Noble Hills Assemblage. The Noble Hills assemblage (new name--Brady, 1986) is sub-divided into four, fault-bounded members. The three seen on this trip are, from southwest to northeast: the central belt, the eastern belt, and the granite-bearing conglomerate. The eastern and central belts are separated along most of the length of the Noble Hills by the "axial crystalline ridge"--an elongate mass of Precambrian and Mesozoic crystalline rock and metasedimentary rock of the Precambrian Pahrump Group.

The central belt of the Noble Hills assemblage, yielding a K-Ar age of 11.3 my is the oldest unit in the Noble Hills assemblage. It was deposited on the axial crystalline ridge, but throughout most of the Noble Hills, the contact is faulted. The central belt contains fluvial and lacustrine strata that are interbedded with monolithologic granite megabreccia containing single clasts up to 70m long. Overall, the central belt fines upward. It is faulted on its southwestern side with another tectonostratigraphic unit--the Military Canyon formation (Fig. 3).

The eastern belt of the Noble Hills assemblage extends from the northern Noble Hills to the east-central part of the Avawatz Mountains. All along its length, the unit is highly deformed by branches of the southern Death Valley fault zone. At the southern end of the Noble Hills, the unit has been intensely deformed and tectonically attenuated by movement along the Mule Spring branch of the Garlock fault zone.

The eastern belt is considerably younger than the central belt. Based on stratigraphic evidence and tephra analyses, it is probably correlative with Plio-Pleistocene strata in the Confidence Hills, located 22 km north of the Noble Hills.

The basal cobble conglomerate of the eastern belt was deposited on a landslide mass containing crystalline rock and Precambrian metasedimentary rock derived from the axial crystalline ridge. Throughout most of the area the contact is faulted along a branch of the southern Death Valley fault zone. The conglomerate grades upward into gypsiferous and halite-bearing mudstone, tuff, siltstone, limestone and celestite. Coarse-grained conglomerate and sandstone overlie these rocks. This sequence, at least 500 m thick, represents deposition (upsection) in braided fluvial, fluctuating lacustrine margin, playa, and braided fluvial environments.

The granite-bearing conglomerate of the Noble Hills assemblage is faulted against the eastern belt on the east side of Noble Hills. The detritus in the conglomerate, was derived from the Owlshead Mountains 8 km to the northwest. The unit was juxtaposed against the eastern belt of the Noble Hills assemblage by right-lateral slip along the southern Death Valley fault zone.

Quaternary Fan Deposits. Quaternary alluvial fan deposits surround the Avawatz Mountains, unconformably overlying bedrock and deformed Tertiary strata. The largest and oldest fans are on the northeast side of the range where the relief is greatest. Younger fan deposits are typically inset into the proximal and medial parts of older fan deposits. Composed nearly entirely of monzodiorite and metavolcanic detritus, the Quaternary fans mark the onset of voluminous sedimentation derived exclusively from bedrock of the Avawatz Mountains.

Four ages of Quaternary fan surfaces are recognized in the northeastern Avawatz Mountains based on morphological and pedological characteristics as discussed by Bull and Menges (1977) and Gile and Grossman (1979). The units used here appear to represent a natural "clustering" of time-dependent fan characteristics. The four divisions used here are minimal however; they could readily be subdivided further. From oldest to youngest, the main divisions are:

(Qf1): These fans are generally very thick, deeply dissected, are commonly highly deformed, moderately to well indurated, and contain abundant lime crusts and coatings. Because these deposits are actively eroding, soil, desert pavement and varnish are generally absent.

(Qf2): These fan surfaces are exposed as "islands" in the younger deposits, and may be several meters above those of the modern channels in uplifted areas. Depositional bars are unrecognizable; the surface relief is due solely to single clasts. Many clasts have fractured or crumbled in place. The desert pavement is strongly interlocking. The surface is very darkly varnished, and the undersides of most clasts are brick red color. Beneath the clasts is a vesicular soil having cambic horizons up to tens of centimeters thick. Pedogenic lime is widespread as coatings and as an incipient- to moderately-developed K horizon.

(Qf3): These surfaces are the most extensive in the area and are commonly situated from 1/2 m to 1 m higher than the modern surfaces. The surfaces are slightly to moderately dissected so therefore, the depositional bar morphology is pronounced but smoothed and reduced by erosion. Pavement is moderately to poorly developed. Incipient varnish is notable on quartzite and monzodiorite clasts, and there is slight reddening on the undersides of most clasts. There is a slight accumulation of pedogenic lime, but the deposits are poorly indurated and cambic horizons are weakly developed.

(Qf4): These deposits of modern fans and washes are inset into all older deposits along the active drainages, and extend into the range beyond the actual fan bodies. The surface relief is highly developed, and there is little evidence of pedogenic soil. These deposits commonly contain varnished clasts and clasts of conglomerate eroded from older fan deposits.

The Quaternary alluvial fans of the Avawatz Mountains have not been dated directly, but tentative age assignments can be made on the basis of other work done in the nearby area. Wells and others (1984) studied the alluvial fans in the Silver Lake area about 10 km south of the Avawatz Mountains. There, they catalogued the pedogenic and morphologic properties of fans, and dated them using uranium/thorium techniques. Ritter (1985) applied this chronology to fans in the southern Salt Spring Hills which lie 4 km east of the Avawatz Mountains and, together with new information, proposed a correlation and age relationship between fans in the two areas.

The chronology developed for the Silver Lake area is applicable to the fans of the Avawatz Mountains because of the variable soil-forming factors Jenny (1941) discussed, only parent material differs between the dated fans and those of the Avawatz Mountains. However, this difference is considered minor because the fans Ritter (1985) described are composed mainly of monzodiorite clasts eroded from the Avawatz Mountains, yet their age-dependent features are nearly identical to those of the Silver Lake area which were derived from metavolcanic, monzodioritic and granitic rocks (Wells and others, 1984). Therefore, on the basis of morphological and pedological factors outlined in these two works, a tentative correlation is made between fans of the Silver Lake area and those of the Avawatz Mountains (Table 1).

Several factors present in the fans of the Avawatz Mountains indicate that the fans are in disequilibrium with their environment owing to tectonic uplift of the range. On all sides of the range, but most notably on the east and north, the older alluvial fans have been deformed and uplifted, and are now deeply dissected. In several places, the floors of several stream channels that cut into older fan deposits are free of loose debris, indicating that the channel is presently down-cutting.

Although either climatic change or subsidence in the basin are capable of producing similar features indicating disequilibrium (Schumm, 1973), in the

Table 1. Provisional correlation of Quaternary alluvial units in the Avawatz Mountains with others from the nearby area.

Avawatz Mountains (This report)	Silver Lake Area (Wells and others, 1984)	Salt Spring Hills Area (Ritter, 1985)	Inferred Age (1)
Qf4	Qf6	Qf5	latest Holocene
		Qf4b	
	Qf5	Qf4a	late Holocene (3,000 yr B.P.)
Qf3			
	Qf4b	Qf3	middle to late Holocene (3,000 - 8,000 yr B.P.)
?	Qe2		
	Qf4a	Qf2	early Holocene (10,500 - 8,000 yr B.P.)
Qf2			
	Qe1	Qe1	
?	Qf3	Qf1	late Pleistocene (36,600 - 15,500 yr B.P.)
Qf1			Pleistocene

(1) Ages reported in Wells and others (1984).

Avawatz Mountains, the cause is most certainly tectonic uplift of the range. Climatic change would affect fans on all sides of the range fairly equally, but here, the fans on the east and north sides of the range, the parts most greatly uplifted, are the most deeply entrenched.

If the disequilibrium had been caused by subsidence of the basins on the north and east sides of the range, the alluvial fans would probably have prograded into the basins from all of the ranges that rim basin. That is not the case here. Fans on the Ibex and Saddlepeak Hills north of the basin are poorly developed. In fact, the fans on the north and east margin of the the Avawatz Mountains have been most actively prograding; they have prograded northward, burying the Saddlepeak and Ibex Hills in debris eroded from the Avawatz Mountains. This progradation has deflected the course of the Amargosa River northward, causing it to flow through a watergap cut into quartzite of the southern Saddlepeak Hills.

The progradation of the Avawatz fans on the northwest edge of the range is also marked sedimentologically where deeply incised stream channels have cut through upfaulted sections of metavolcanic- and diorite-derived fan strata. Exposed beneath is a persistent coarsening- and thickening-upward sequence that begins with fine-grained, lake or lake-margin facies and grades upward into upward-coarsening fan deposits.

In several areas, the alluvial fans show that deformation occurred during and after deposition. Just south of here, Qf1 deposits contain buttress unconformities that step out, away from the range. On the east-central side of the range bedrock monzodiorite is faulted over older Quaternary fan deposits (Qf1) that dip 60 degrees east. At the southern end of the range, bedrock is faulted over younger Qf2 deposits. These features emphasize the young uplift of the range and the sedimentological instability.

Activity along the southern Death Valley fault zone has also affected the fan environment. Intermittent displacement along the southern Death Valley fault zone in the southern Noble Hills has produced a complex succession of fan deposits that were laid down in response to stream piracies. The channels involved cross branches of the fault zone; uplift between the branches triggered the piracies (Butler and Brady, 1982).

The alluvial fans in the northwest part of the range record the activity of the Garlock fault zone. Between the Owlshead and Avawatz Mountains, Qf3 and Qf2 fans are cut by scarps and shutter ridges. The scarps are larger and the dips more steep in the older fans than they are in the younger fans. This too, indicates that tectonism and sedimentation were synchronous.

FIELD EXAMINATIONS

Some of the most interesting, if not perplexing, structural and stratigraphic aspects of the Avawatz Mountains are spectacularly exposed in the Noble Hills where the southern Death Valley fault zone, the main Cenozoic stratigraphic units, and the eastern limit of the Garlock fault zone are all exposed. This excursion will concentrate on stratigraphic and tectonic features of the Plio-Pleistocene eastern belt and the granite-bearing conglomerate of the Noble Hills assemblage, and their relationships with the overlying Quaternary alluvial fan deposits.

ACCESS

Access to the area is via state Highway 127 north from Interstate 15 between Las Vegas and Barstow at the town of Baker (Fig. 1). Take Highway 127 past the east side of the Avawatz Mountains. Turn west on the dirt road that is the southern entrance to Death Valley, 28 mi north of Baker. The turn off is marked by a stone historical marker commemorating the escape of the Harry Wade party from Death Valley. The "Harry Wade" road leads west, then north to the first stop (Fig. 3). Although four-wheel drive is not required on the Harry Wade road, it is recommended for other roads on this excursion.

From the Harry Wade road, turn west (left) onto a dirt road toward Owl Hole Spring. The turnoff is immediately north of a sign on the Harry Wade road that warns that "Driving off roads is prohibited". Take the left fork for 0.3 mi through a depression in the northern end of the Noble Hills. Stop here and walk north to the nearest hill (Figs. 3, 4).

STOP 1, NORTHERN NOBLE HILLS

This stop affords an overview of the Garlock fault zone and exposures of upper-level deformation along the southern Death Valley fault zone.

The prominent ridge on the southwestern skyline is the bedrock mass of the Avawatz Mountains. Monzodiorite composes the eastern half and metavolcanic rock, the western half. In the left foreground are the Celestite Hills, a doubly-plunging anticline whose structure is similar to the upper-level structure of the Noble Hills. The Celestite Hills have a core of lacustrine clastic and carbonate rocks that are correlative with the eastern belt of the Noble Hills assemblage. In both areas, these rocks are overlain by Plio-Pleistocene (Qf1) and younger fanglomerate.

The Garlock fault zone extends from the southern flank of the Owlshead Mountains on the northwestern skyline, to Leach Lake on the south side of the southern skyline ridge. The irregular topography of the alluvial fan surfaces on the north flank of the Avawatz Mountains was formed by differential move-

Figure 4. Vertical air photo of the northeastern Avawatz Mountains at the intersection of the Garlock fault zone (GFZ) and the southern Death Valley fault zone (DVFZ). MSF= Mule Spring branch of the Garlock fault zone. Note graben formed between the Mule Spring fault and the western branch of the Death Valley fault. Numerals indicate stops on this excursion. Area shown is approximately the same as in Figure 3. North is to the top of the page.

ments along sub-parallel branches of the Garlock fault zone which juxtaposed Quaternary fan surfaces of different ages and uplifted the underlying lacustrine rocks.

The isolated wedge-shaped mound on the western skyline between the Avawatz and the Owlshead Mountains, near Owl Hole Spring, is the southern limb of a syncline having a south-dipping axial surface. The oldest strata exposed in the fold are lacustrine evaporite and carbonate rocks of the Owl Hole Spring formation (new name, Brady, 1986). These rocks are similar lithologically to rocks of the eastern belt of the Noble Hills assemblage that are exposed just south of us. Furthermore, the Owl Hole Spring formation contains abundant tephra beds whose shards are very similar morphologically and chemically to shards in the Confidence Hills. Strata there contain tephra ranging in age from approximately 2.2 my in the lower beds (Troxel and others, this volume) to 0.62 $\pm$ 0.52 m.y. in the upper beds (Butler, 1984; this volume).

Overlying the lacustrine strata at Owl Hole Spring are 200 m of alluvial fan deposits. The lower part of the section contains discrete, alternating beds each having detritus derived solely from the Avawatz or the Owlshead Mountains. Detritus in the upper part of the section though, is a mixture of sediment derived from both sources. Since the top of the fanglomerate section is 200 m above the level of the present depositional surface on either side, this "wedge" of strata must have been uplifted a minimum of 200 m since the fanglomerate was deposited. The orientation of the axis of the fold that uplifted the strata suggests that the fold formed by left-lateral drag along a branch of the Garlock fault zone, and consequent compression between the Avawatz and Owlshead Mountains.

Looking southward, the Mule Spring fault extends across the northern margin of the skyline bedrock ridge separating it from the Quaternary fans to the north. On the eastern escarpment of the range, the fault flattens southward and emplaces bedrock eastward over Neogene and Quaternary strata and branches of the southern Death Valley fault zone, thereby forming the eastern termination of the Garlock fault zone.

The Noble Hills along which we are standing, formed when Quaternary alluvial fan strata and the underlying Cenozoic and older rocks were deformed by movement along branches of the southern Death Valley fault zone. On the northern end of the Noble Hills, deformation appears to be fairly mild; however, this is because only the uppermost layers are exposed. Southeastward where progressively deeper levels are exposed, the true complexity of deformation is evident.

The overall geometry of the Noble Hills is anticlinal, although locally the structure is highly complex. Here on the northern end tightly folded lacustrine claystone and evaporites of the eastern belt of the Noble Hills assemblage form the core of the anticline. These strata are significantly less deformed than the overlying Quaternary fanglomerate which is broadly folded.

Within the overlying Quaternary fanglomerate, there are three distinctive conglomerate units whose structural relationships record intermittent movements along branches of the Death Valley fault zone. The clasts within these conglomerates were derived partly from the Avawatz Mountains to the south, and partly from the Owlshead Mountains to the northwest.

From Stop 1, continue approximately 1/4 mile west on the road to Owl Hole Spring. Stop where the road crosses a segment of old, smooth alluvial fan.

STOP 1A, OWL HOLE SPRING ROAD. This site is the most accessible example of a Qf2 alluvial fan surface. The deep desert varnish, well-developed desert pavement, minimal micro-topographic relief, well-developed cambic soil horizon, and well-developed lime crusts are characteristic of these deposits. The Qf2 fans are deeply eroded throughout the range, and are preserved only as isolated remnants such as this.

Along the northern flank of the range, Qf2 fans are cut by scarps up to several meters high, and sub-parallel shutter ridges. Similar features are abundant from the south flank of the Owlshead Mountains to the south side of Leach Lake (Fig. 3). The fault scarps and shutter ridges strike nearly due west, parallel to the major traces of the Garlock fault zone. The sense of vertical offset is consistently up to the south. In some places, the scarps have been degraded to a smooth topography, but in several places, sharp scarps are well preserved, exposing the soft, pale-colored soil beneath the pavement.

Return to Harry Wade road and head south toward the Avawatz Mountains. Immediately after the road bends west, turn south (right) onto the dirt road up Canadian Club Canyon, heading into the range. If you reach the turnoff to Saratoga Spring, you have gone 0.7 mi past the turnoff. The road heads up a broad wash, and intersects another at the mouth of the wash adjacent to a large, isolated gypsum boulder. Turn northwest (right) onto this road, and continue into the next canyon. You are passing over a branch of the Death Valley fault zone which places Qf3 fan deposits against Tertiary landslide breccia.

STOP 2, PIPELINE WASH

This stop provides an examination of the faults which bound and deform the strata of the Noble Hills assemblage and deform the pediment surface eroded onto it.

The large mound on the southwestern skyline is composed of Qf1 Quaternary

fanglomerate. This deposit represents one of the oldest Quaternary fan deposits in the range, and is probably Plio-Pleistocene in age. The clasts are nearly entirely "dioritic" detritus derived from the eastern Avawatz Mountains. By projecting the top of this deposit upward into the range, it is evident that this deposit is but a remnant of an enormous fan complex that must have completely buried the ancestral Noble Hills. The entire deposit now lies in a graben that has dropped down into strata of the eastern belt along arcuate normal faults (Figs. 3, 4). These faults developed a the wedge-shaped, tensile stress domain that formed through the kinematic interaction between the left-lateral Mule Spring branch of the Garlock fault zone which lies "behind" the graben, and the westernmost branch of the right-lateral Death Valley fault zone which lies "in front" of it.

The walls at the mouth of Pipeline Wash expose Tertiary landslide breccia that was derived from the front of the Avawatz Mountains. The eastern belt of the Noble Hills assemblage was deposited on this breccia, but throughout most of the length of the Noble Hills, the contact is faulted (Fig. 5). The upper part of the eastern assemblage is faulted against the axial crystalline ridge which forms the prominent linear ridge on the near western skyline. The older strata of the Noble Hills assemblage, the 11.3 my-old central belt, lie on the southwest side of the axial crystalline ridge.

The eastern belt contains clasts of distinctive Precambrian metasedimentary rock derived from roof pendants in the axial crystalline ridge which have now been nearly completely eroded away. Granitic rock, which compose the bulk of the axial crystalline ridge, is present only in minor quantity as clasts in conglomerates of the upper eastern assemblage.

Further along on the northwestern wall of Pipeline Wash, complex folds in lacustrine strata of the eastern belt are exposed. These, and similar-appearing folds farther upstream in the same formation, are consistently overturned to the northeast. This geometry indicates that they were formed in a local transpressional domain along the Death Valley fault zone.

On either side of Pipeline Wash a well-developed pediment surface has been eroded into the eastern belt, and armored by Qf2 fanglomerate. Here and farther north, the pediment surface is deformed by a series of northwest-striking shutter ridges that have formed along a branch of the Death Valley fault zone that cuts through the eastern assemblage. The sense of vertical offset is south, west side up. The presence of "dioritic" detritus in the fan deposits constrains the amount of cumulative horizontal offset to be less than 0.5 km.

The structural and stratigraphic relationships seen here point to a recurrence of activity along different branches of the Death Valley fault zone through the region. The axial crystalline ridge was uplifted during deposition of the eastern belt, exposing the metasedimentary roof pendants. Following deposition of the eastern belt, the axial crystalline ridge was uplifted again, cutting across facies lines and complexly folding the eastern belt. The eastern belt was later uplifted and eroded, forming a pediment surface which was cut by still younger faulting.

From Pipeline Wash, turn northwest (right) onto the first road and proceed 1/4 mi into Salt Basin.

STOP 3, SALT BASIN

This is the best place to examine the complexly-deformed strata of the eastern belt of the Noble Hills assemblage which are faulted down between the axial crystalline ridge (to the southwest) and the Tertiary landslide complex (to the northeast).

The basal conglomerate of the eastern belt has been nearly completely faulted off against the landslide mass. Halite and halite-rich claystone overlying the conglomerate have been dissolved, forming the channel that the road follows. Massive gypsum overlies the halite. The grain size coarsens upward into a clastic sequence that was derived primarily from pendants of of the Precambrian Kingston Peak Formation in the axial crystalline ridge and not from the granitic rocks against which these beds are faulted. This indicates that the eastern belt was deposited essentially in its present location and later, the granitic rock of the axial crystalline ridge was faulted up through it.

The strata in Salt Basin are complexly folded by oblique drag between branches of the southern Death Valley fault zone and by uplift of the basin margins. Folding is most complex and tight in the evaporite-rich members. In order to best see the eastern belt section and the deformation within it, walk up the narrow canyon at the southern end of the basin, on the far left when facing the cabin. Round trip takes about 15 minutes.

Continue along the road through Salt Basin and drive up onto the pediment surface on the opposite side.

STOP 4, PEDIMENT SURFACE

On either side of the road are exposed remnants of the pediment surface that once covered much of the central Noble Hills including Salt Basin.

As seen on air photos or maps, stream channels emanating from the northeastern Avawatz Mountains make sharp clockwise bends, and drain through the Noble Hills. Each of the four main channels that cut through the Noble Hills also had to cut through the axial crystalline ridge. Therefore, the amount

of right-lateral slip on branches of the Death Valley fault zone in the Noble Hills that occurred since the drainage pattern was established, is constrained to be no greater than the width of the channels that cut through the ridge.

Abrupt, linear fault scarps can be seen in several places cutting the pediment surface. One of the best exposed is the one just east of the road near the contact of the eastern assemblage and the landslide complex. On the basis of the extent of soil development, there appears to be more than one age of soil on the pediment surface. Did these soils form before of after the scarps formed?

Continue across the broad wash and into the next major drainage.

STOP 5, DENNING SPRING WASH

Denning Spring Wash cuts across four major branches of the southern Death Valley fault zone, as well as Quaternary fanglomerate, the eastern and central belts of the Noble Hills assemblage, and the axial crystalline ridge.

The overall structure in the capping Quaternary fanglomerate here is anticlinal, but the internal structure is more complex. Major drag folds in the pale-colored lacustrine beds of the eastern belt have wavelengths of 100 m to 150 m, and contain numerous parasitic folds. Gypsiferous material has migrated into the axial zones of many of the folds.

The bright red breccia mass crossing the wash is the Tertiary landslide complex derived entirely from bedrock of the Avawatz Mountains. This breccia underlies the eastern belt and crops out along the eastern margin of the Noble Hills.

Up the wash approximately 200 m, is the northernmost exposure of the fault contact between the eastern belt of the Noble Hills assemblage and the axial crystalline ridge. Note how the vertical displacement of the axial crystalline ridge increases southward. At the south end of the Noble Hills, the entire Noble Hills assemblage and the axial crystalline ridge are truncated by the Mule Spring fault and parallel, related faults.

The gray wedge of well-bedded conglomerate exposed on the northeast flank of the Noble Hills at the mouth of Denning Spring Wash is a distal alluvial fan deposit referred to here as the "granite-bearing conglomerate". These beds extend northward from here nearly the entire length of the Noble Hills. The clasts in the conglomerate are mainly pink, coarse-grained granite with minor vesicular basalt and scattered smokey quartz crystals up to four centimeters long. This material was undoubtedly derived from the Owlshead Mountains to the northwest, where identical detritus lies in the modern washes.

The granite-bearing conglomerate has been emplaced into its present position by a minimum of 8 km of right-lateral movement along an eastern branch of the southern Death Valley fault zone. The age of this movement was Quaternary because the fault cuts obliquely across beds in the eastern assemblage that contain tuff which correlates morphologically and chemically with the Quaternary tephra in the Confidence Hills discussed above.

As seen from the earlier stops, Quaternary lateral offset along western branches of the Death Valley fault zone in the Noble Hills is no more than 0.5 km, but the eastern branch of the Death Valley fault zone has transported the granite-bearing conglomerate at least 8 km. This trend suggests that any large movements that might have occurred on the southern Death Valley fault zone did so on branches east of the Noble Hills. Furthermore, the amount of offset on just this single branch of the southern Death Valley fault zone during Quaternary time is equal to the conservative estimates proposed by earlier workers for the total offset across the entire fault zone. The evidence seen here in the Noble Hills supports the contention that there has been large offset on the southern Death Valley fault zone (Brady, 1984). Furthermore it is consistent with evidence in the Owlshead Mountains that there has been 20 km to 35 km of Plio-Pleistocene offset on the southern Death Valley fault zone (Butler, this volume).

If indeed, there has been at least 20 km of Plio-Pleistocene offset along the southern Death Valley fault zone, it is highly unlikely that the fault zone terminates in the northern Avawatz Mountains as has been previously suggested. Most likely, the southern Death Valley

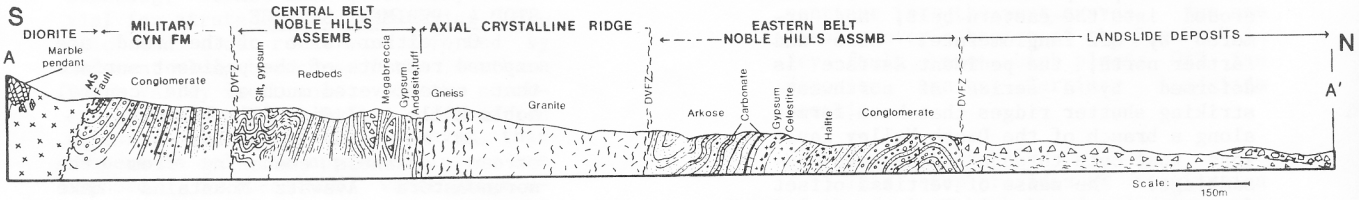


Figure 5. North-south cross-section through the southern Noble Hills showing the relationships between the major Neogene tectono-stratigraphic units, branches of the Death Valley fault zone (DVFZ), the Mule Spring fault (MS), and the bedrock "diorite" of the Avawatz Mountains. Location of the cross-section is shown on Figure 3.

fault zone continues south beyond the Avawatz Mountains, and is buried by Recent sediments beneath Silver Lake Valley.

Thus ends this portion of the trip. Drive down Denning Spring Wash to Harry Wade road and turn east (right) back to highway 127. (P.S. Happy Halloween).

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MARIPOSA LILY. 3 petals yellow to vermillion. 3 to 12 in. tall. Gray-blue-green foliage. Common in heavy soil from 3500 to 6500 ft elevation. White to lilac STRAGGLING MARIPOSA LILY (right) has a weak stem and leans on other plants. 3300-6000 ft elevation. Both lilies have hairy dark brown spots on inner petal bases. March-June. White Pincushion (left) blossoms are a cluster of tiny white tube flowers.

PLEISTOCENE AND HOLOCENE DEFORMATION ON A SEGMENT OF THE SOUTHERN DEATH VALLEY FAULT ZONE, CALIFORNIA

Bennie W. Troxel
University of California,
Davis, California

Introduction.

Strands of the southern Death Valley fault zone record Quaternary fault movement. The area perhaps is undergoing deformation at present. A remarkably well-exposed fold is preserved near the gravel road that extends westward then northward from the Harry Wade monument on State Highway 127. The monument is about midway between Shoshone and Baker, California.

The site is 12 miles by gravel road northwest of the Harry Wade monument. From the monument it is 10.4 miles to a Y junction. The left branch is the Owl Hole Springs road. The branch that continues more northerly eventually joins with the paved road that lies in the floor of Death Valley. The site discussed in this paper is situated a few hundred yards northeast of the gravel road. You should park 1.6 miles north of the Y and use Figure 1 for finding the folded sediments.

Geology.

The folded pale units on Figure 1 are fine-grained lake sediments. They are interbedded with gravel beds that are darker than the fine-grained beds. Traces of beds are marked on Figure 1 to help delineate the folded nature of the beds. The principal fold is an anticline. Between the northwest part of the anticline and the through-going fault is a small syncline. Graded beds identify the tops of beds. Both folds plunge gently northwestward and diverge slightly westward from the fault. The folded beds are overlain by very young gravel, which has been gently folded and is in the process of being eroded from the folded lake sediments. The gravel units are denoted on Figure 1. The relative ages are designated by numbers, number 1 being the youngest unit. Some of the gravel units can be correlated with those of Brady (see article, this volume) but are discussed only on an informal basis herein.

Age and correlation of units.

The gravel beds in the deformed lake sediments contain a high proportion of metamorphosed volcanic rock fragments. In general, they are dark to medium green in color and commonly have a mottled texture. Nearly all of the volcanic clasts are composed of very fine-grained material. The most likely source area for these clasts is from bedrock source areas situated south of the Garlock fault zone in the western Avawatz Mountains (see Jennings and others, 1962). The clasts could not have been transported from any other source area based upon the present distribution of bedrock in the surrounding region.

Coarse younger gravel overlies deformed Tertiary and younger sediments in the Noble Hills (Troxel, unpublished data). The gravel lies in older fan segments that abut the southwest side of the Noble Hills and border stream channels that cut through the Noble Hills. The gravel becomes finer grained downstream of the Noble Hills. Upstream from the gravel is a bedrock source area made up mostly of Mesozoic metavolcanic rocks that crop out south of the Garlock fault zone. Because the deformed lake sediments contain fragments of Mesozoic metavolcanic rocks, they are interpreted as being distal portions of gravel beds that extended beyond fans onto lake beds being deposited at that time in the floor of the valley.

That the lake beds are Pleistocene in age is based upon the fact that they are clearly unconformable upon deformed lake sediments in the Noble Hills, some of which appear to be early Pleistocene in age (see Brady article, this volume; Troxel, unpublished data).

History of deposition and deformation.

The Pleistocene events recorded on Figure 1 consist of deposition of the lake sediments and interbedded gravel beds at the northeast end of a fan that emanated from the western Avawatz Mountains. The beds were probably deposited upon more-strongly deformed lake sediments of Pliocene (?) age that are exposed slightly farther northwestward along the Death Valley fault zone (Troxel, unpublished data, and Figure 2).

After deformation, the sediments were buried at least by gravel unit 2 of Figure 1 as indicated by the presence of remnants of unit 2 resting unconformably upon the folded lake sediments. One tongue of gravel unit 2 clearly extends northward from the main mass. Another elongate mass is only barely disconnected from the main outcrop. Both lie across traces of folded beds.

After deposition of gravel unit 2 it was folded on the southwest side of the main trace of the Death Valley fault zone in Figure 1. The folding was slight and resulted in a gentle southwest dip of the distal portions of unit 2 that still overlie the deformed lake sediments. Between the gravel road (Figure 2) and the deformed lake sediments, unit 2 remains undisturbed.

It cannot be clearly demonstrated, but is likely that during deformation of gravel unit 2, right lateral motion on the fault resulted in stream deflection to the right

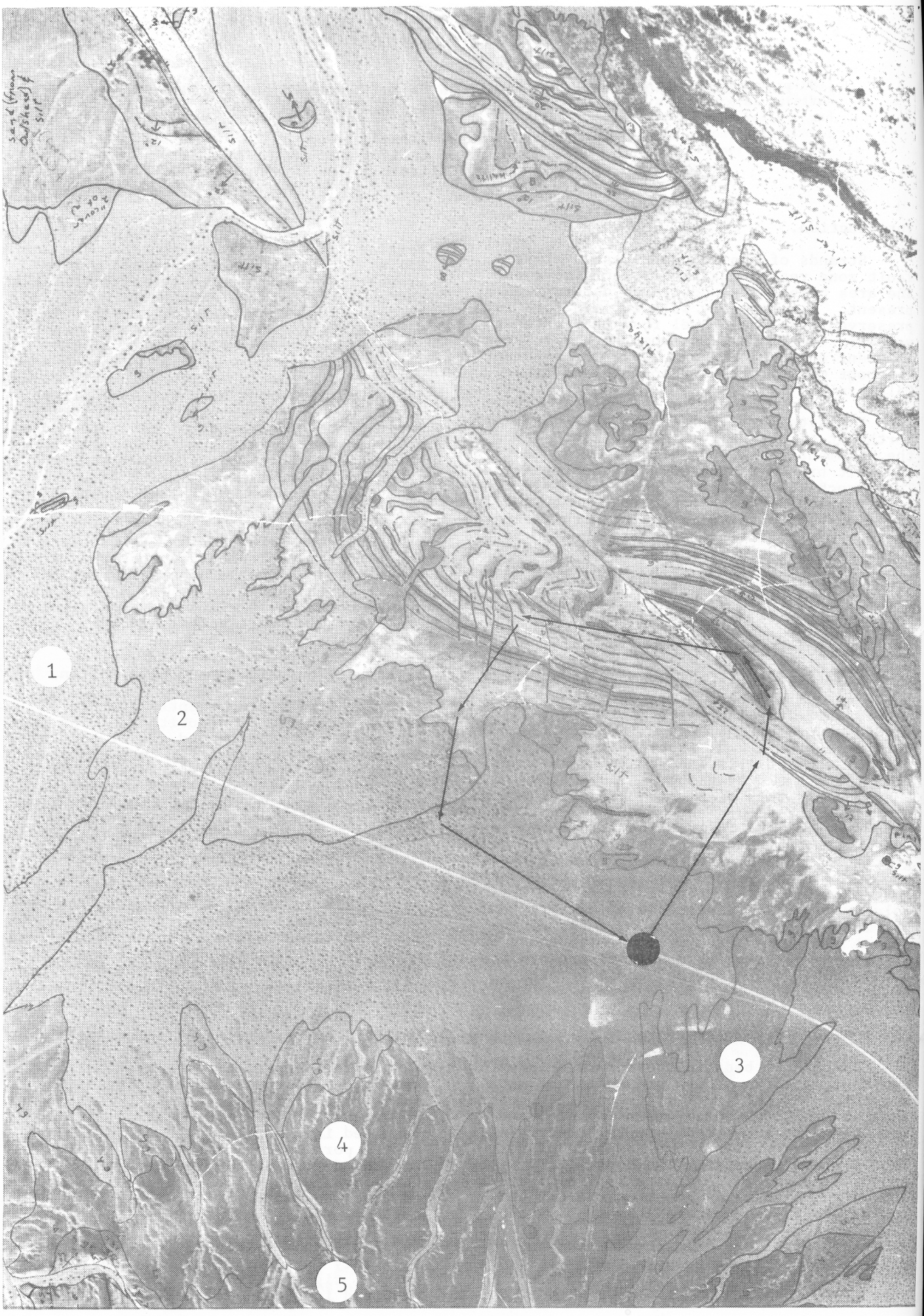
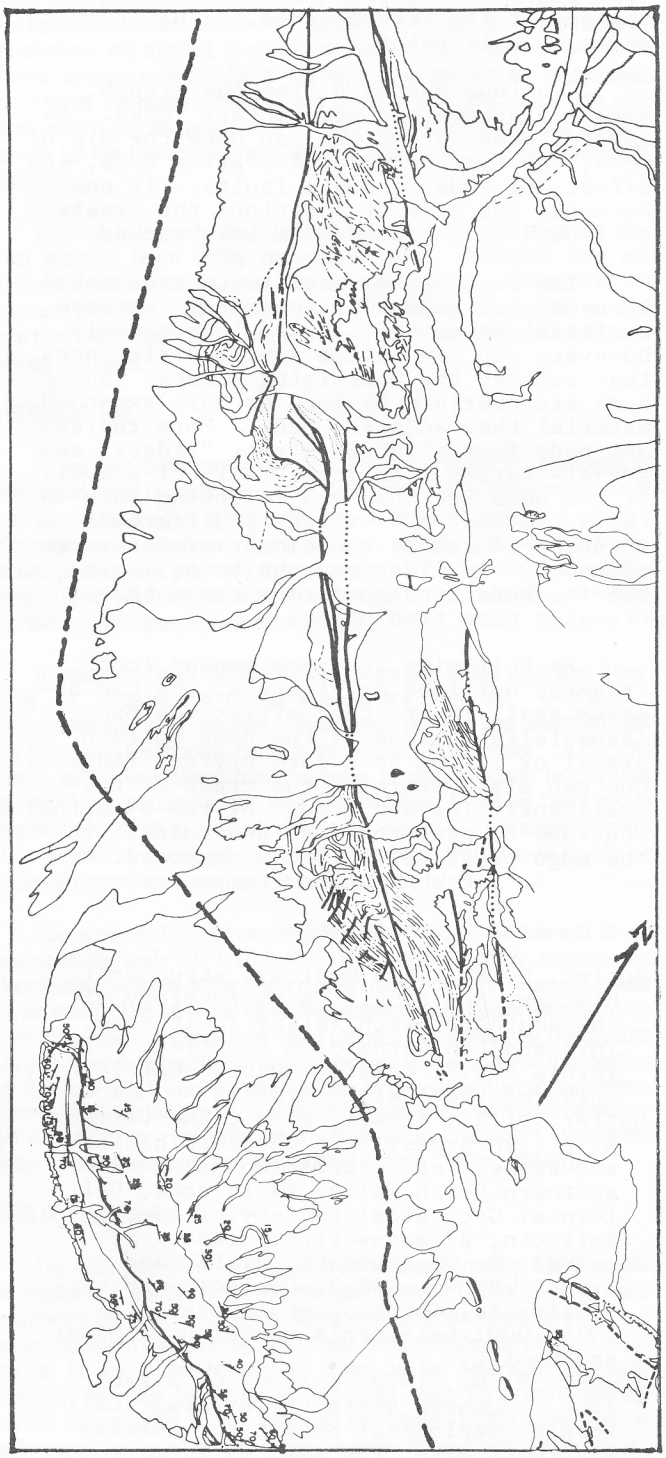

1
2
3
4
5

Figure 1. Copy of field map (enlarged photograph) of folded Pleistocene lake sediments and interbedded gravel layers. Compare with Figure 2 for orientation and scale. Numbers indicate relative ages of fan units from 1 (youngest) to 5 (oldest). Pale sediments of Amargosa River (upper right) and playa units are even younger. (Geology by B. W. Troxel, 1966; unpublished). Arrows indicate a suggested traverse. Irregular white lines are flaws (breaks) in original field map.



(southeast). See, for example, the stream deflection in gravel unit 1 of Figure 1. Barely southwest of Figure 1, playa sediments are currently being ponded upon very young gravel.

Between 3/4 and 1 mile north of the junction of the Owl Hole Spring road, the main gravel road crosses a strongly upwarped fan surface that is only slightly eroded. The fan surface is moderately old as it has a deeply varnished surface and a well-developed pavement. Slight dissection indicates the youthful nature of the uplift. Between the Owl Hole Spring turnoff and the parking area designated on Figure 1, are abundant topographic features that are indicative of very young upwarping, downwarping, and fault slip.

Other features.

The fault trace that extends through the folded lake sediments discussed to this point extends about 1 mile farther north, where it is bent abruptly westward and steps left (southwest) and continues northwestward. This is an excellent example of a left-stepping en echelon right-lateral strike-slip fault zone. The confined area between the two fault branches is a zone of transpression. The more tightly-folded strata about half a mile even farther north may be older sediments and hence subjected to more episodes of deformation. Another factor involved in the amount of deformation is that the strata contain a high proportion of gypsum. In the Noble Hills (Troxel, unpublished data) and farther southeast, gypsum-bearing strata interbedded with fine-grained strata are much more highly deformed than coarse-grained strata or fine-grained strata that contain no gypsum (Troxel, unpublished data).

Sequence of Cenozoic tectonic events.

Troxel (1970) pointed out that offset along the strands of the southern Death Valley fault zone migrated from southwesternmost branches to northeasternmost branches through time. In addition, the southeastern part of at least one of the traces was offset before the northwesternmost part of the same trace, suggesting a northwestern migration of stress. Furthermore, the southwestern traces of the southern Death Valley fault zone are deformed along with the sediments as one fault plane was abandoned and movement picked up along younger fault planes farther northeast.

Figure 2. Tracing from field map (enlarged photograph) of segment of southern Death Valley fault zone. Northern tip of Noble Hills in lower left (see also Figure 3 of Brady, this volume). Amargosa River flows through channel in upper center of figure (see also Butler, this volume). Heavy dashed line is graded road that extends from Wade Monument to intersection of paved road near Shoreline Butte. North arrow is .5 mile long. (Geologic mapping by B. W. Troxel, 1966; unpublished). See Figure 1 for identification of units.

Butler (1984) and Butler and others (1986, in press) recognized an even older offset along long-abandoned strands of the southern Death Valley fault zone. These strands located farther northwest, along the east margin of the Owlshead Mountains, record a possible maximum right-lateral offset of about 22 miles in Miocene time. Troxel (unpublished data) recognized a maximum of about 20 miles of younger right lateral offset along a strand of the southern Death Valley fault zone that is exposed within the northeastern part of the Noble Hills at Denning Spring Wash (see Brady, this volume).

The latest episodes of movement along strands of the southern Death Valley fault zone are recorded in strands exposed in Figure 2. The latest movement farther northwest is discussed by Butler (this volume).

The northwestern tip of the Noble Hills (lower left part of Figure 1) contains field evidence of either a fault that has had recurrent movement along the northwestern part of the fault or is a fault plane that is growing or extending in a northwestern direction. Field evidence tends to support either interpretation. The main fault in the Noble Hills (Figure 2) is deformed as indicated by its slightly irregular trace. It's northwestern trace is overlapped by gravel that is folded into a gentle anticline, the crest of which has a trend about the same as the strike of the fault and plunges gently northwest. The fine-grained lake sediments beneath the overlapping gravel dips steeply away from the deformed (?) fault zone near the point where the fault trace disappears beneath the gravel. Farther southeast, however, the gravel and underlying fine-grained sediments are nearly conformable. One fault strand on the northeast flank of the Noble Hills is overlain by younger gravel that is cut farther northwest by the same fault.

Significance,

The area of folded rocks for field investigation during this field trip contains a record of very young deformation along one strand of the southern Death Valley fault zone. Discussion above indicates that movement along the fault zone is episodic and, more importantly, stress has migrated from southwestern strands to northeastern strands and northwest along individual strands.

The offset fold can be used to demonstrate a limited amount of right lateral offset of very late Pleistocene movement along one strand of the southern Death Valley fault zone. Slightly later arching and erosion of a much younger distal fan unit, records even later tectonic activity. Uplift and down-warping of surfaces and ponding of sediments slightly farther southeast of Figure 2 suggests that tectonic activity may be continuing.

Further qualitative information needs to be gathered from this region. The data may resolve several of the many problems that are unanswered relating to strike-slip movements.

Suggested field visitation.

After parking at the suggested point (Figure 1 and text) proceed by foot northeastward to the southeastern tip of the darker ridge on the northeastern (far) side of a strand of the southern Death Valley fault zone (Figure 1). Continue along the ridge to a trench that has been cut at right angles across the ridge. The trench affords details of the dip and makeup of beds that underlie the ridge. From the trench walk westward across the strand of the southern Death Valley fault zone. (The trace of the fault is barely west of the end of the trench and difficult to perceive at this point).

Continue westward from the trench across fine-grained sedimentary rocks. By careful observation one can note the dip of beds, the trace of gravel-bearing beds, and offsets of beds by small faults. If one occupies the correct positions the crests or trough of the folds can be observed.

The fine-grained sediments are masked by a crustal veneer of "popcorn" textured surficial material. If you look closely, however, you can detect subtle differences that reflect the underlying strata. Some beds are overlain by less or more expanded material than adjacent beds. More resistant beds form slightly higher "ridges" and gravel-bearing beds form trails of gravel. If the beds are observed following rain in the area, they have slightly different shades produced by the amount of water retained or expelled from the beds. Salt-bearing beds tend to form a crust that crackles when trod upon.

By following the recommended foot traverse outlined on Figure 1, one can observe small faults that offset the beds (especially obvious if the beds contain gravel or if the beds form obvious ridges). One can also determine the crest of the small anticline and trough of the syncline. Continue towards the cars and note where the edge of gravel unit 2 is exposed.

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Fluvial Response to Ongoing Tectonism, Lower Amargosa River, Southern Death Valley, California

Paul Ray Butler
The Evergreen State College
Olympia, WA 98505

ABSTRACT

Terrace formation along the lower reaches of many rivers is attributed to climatically induced base-level changes. However, along the lower Amargosa River in southern Death Valley, tectonism appears to be the controlling factor. The river flows within a small graben for several kilometers, and adjacent to and downstream of this graben three sets of fluvial terraces have developed. Surveyed cross sections and longitudinal profiles of the modern channel and terraces plus analyses of the size distribution and composition of the terrace gravels point to a tectonic origin for the terraces and also indicate that the style of deformation is continuing.

The area is lower in elevation than the maximum high stand of a lake that occupied Death Valley periodically during Pleistocene time and therefore was subject to base-level changes. However, formation of the terraces probably occurred after most of the lake dried up. The terraces are the river's response to continued local uplift along the southern Death Valley fault zone.

INTRODUCTION

It has long been recognized that fluvial terraces are remnants of abandoned river floodplains and that their formation is a response to some change or changes that affect water and/or sediment production within a drainage basin. However, there has been considerable debate over the actual process that produces these features. Controversies often involve determining whether tectonism or changes in climate have been the primary controls on terrace formation.

In southern Death Valley, flanking a portion of the Amargosa River (Fig. 1), three sets of fluvial terraces are preserved. This area is topographically lower than the highest stands of a lake that occupied Death Valley during Pleistocene time (Blackwelder, 1933; Hooke, 1972). As Death Valley is a closed basin, changes in climate would be manifest primarily as changes in lake level. In this area, the river flows within the southern Death Valley fault zone (Figs. 2 and 3). Thus an opportunity is provided to investigate whether climate-controlled base levels or tectonic factors were dominant in producing the terraces.

The area of Fig. 4 was mapped on an aerial photograph at an approximate scale of 1:18,000. Then detailed cross sections and longitudinal profiles of the modern river channel and terraces were made using a Leitz B-4 level and tape. The measurements lead to the conclusion that climatically induced base-level changes represented by fluctuations in lake level do not suffice to explain terrace formation along this portion of the Amargosa River. In addition, the form and position of the modern channel indicate that the style of tectonism that produced the terraces may be still going on. The information contained in this report is modified from information published previously (Butler, 1984a; 1984b).

GEOLOGIC SETTING

The Amargosa River drains an area of approximately 8800 square kilometers in southern Nevada and southeastern California. It flows southward for most of its length, turns west for a few kilometers where it enters southern Death Valley, then heads north to Badwater (Fig. 1). This region is one of the hottest and driest in the American Southwest. Summer day-time temperatures commonly reach 50°C while average annual precipitation is only about 40 mm (Hunt, 1975). The river is ephemeral for most of its lower course in southern Death Valley. However, within the study area (Fig. 4) the river maintains a spring-fed base-flow of approximately 0.1-0.2 m^3/s. This constant flow is confirmed by the presence of pupfish (*Cyprinodon*) and aquatic plants along portions of the channel.

Southern Death Valley is a narrow structural trough created in part by movement along the southern Death Valley fault zone. The southern Death Valley fault zone, along with the Northern Death Valley-Furnace Creek fault zone, appear to be related to extension within the southern Basin and Range province (Stewart, 1983). Burchfiel and Stewart (1966) and Wright and others (1974) have suggested that movement along these faults produced a "pull-apart basin" in central Death Valley.

Late-Cenozoic deposits in the southern Death Valley region have been offset approximately 35 km by right lateral strike slip on the southern Death Valley fault zone since Miocene time. Virtually all of the slip took place prior to approximately one million years ago along western traces of the fault zone (Fig. 2). During the last one million years, however, the eastern traces of the fault zone (Fig. 2) have been active and characterized by oblique slip, with a lateral component of only a few hundred meters. Movement along these eastern traces has formed normal faults and tight to isoclinal folds that have uplifted fan gravel and lacustrine sediments as much as 200 m above the modern alluvial fan surface. Details of the late-Cenozoic history of the southern Death Valley fault zone can be found in Butler (1984a) and Butler and others (manuscript submitted for publication).

For the purpose of discussion, it is convenient to subdivide the eastern subzone of the southern Death Valley fault zone into a northern region adjacent to the Confidence Hills, and a southern region adjacent to a large, uplifted alluvial fan (Fig. 2). Both regions of the eastern subzone are characterized by a sequence of lacustrine sediments overlain by alluvial fan gravels. In places the contact is gradational and thus conformable. At both locations, the gravel and fan units are folded and faulted but the lacustrine deposits are locally more deformed than the overlying fan gravels. This indicates that deformation within the basin started before the encroachment and deformation of the alluvial fans. As discussed in Butler (1984a) and Butler and others (manuscript submitted for publication), both the northern and southern regions are assumed to have been part of the same lake basin, based primarily on their stratigraphic relationships and on their magnetic polarity stratigraphy. In addition, it appears that the end of lacustrine deposition and the beginning of alluvial-fan deposition began approximately one million years ago at both locations.

The channel pattern of the Amargosa River within southern Death Valley is controlled by the river's position with respect to the eastern subzone of the southern Death Valley fault zone. Where the river follows a trace of the fault east of the Confidence Hills and west of the uplifted fan, there is a single incised channel (Fig. 2). The tectonic controls on stream position at these two sites contrast with areas upstream and downstream where the river does not follow a fault. Upstream and downstream of the incised channels the river is braided and the floodplain is as much as 4 km wide. The channel's position in these wider parts of the valley is controlled by the relative amount of material brought to the river by the adjacent alluvial fans. Larger fans on one side of the valley tend to push the river toward the side of the valley with smaller fans.

Near the point where the Amargosa River begins to turn northward into southern Death Valley, the river flows within a graben that truncates the distal end of the uplifted alluvial fan (Figs. 3 and 4). The river

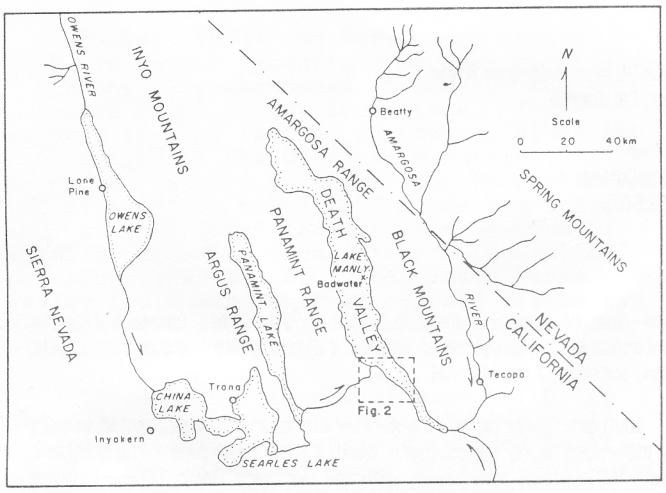

Figure 1: Index map of the Death Valley region. Pleistocene lake levels and drainage connections are shown at pluvial maxima (modified from Blackwelder, 1954).

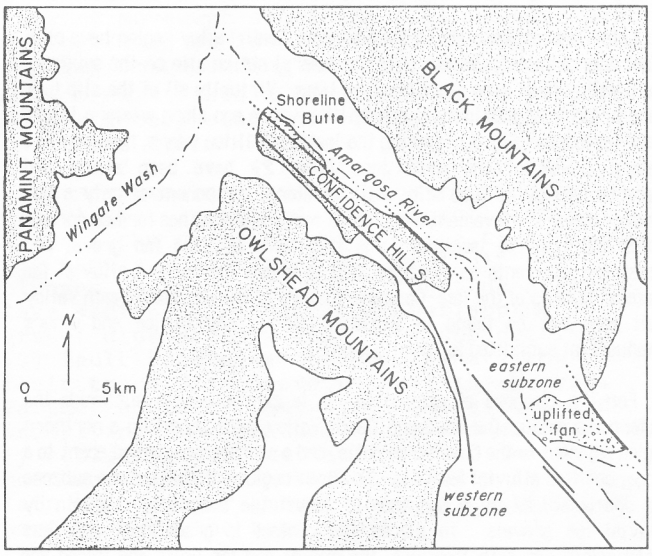

Figure 2: Location map for southern Death Valley showing the eastern subzone and the western subzone of the southern Death Valley fault zone with respect to the Amargosa River.

enters the graben at point A (Figs. 3 and 4), follows it for almost 2 km, then exits the graben at point B. At point A, where the fault that forms the eastern boundary of the graben crosses the channel, there is a waterfall more than 1 m high. The lithified channel gravel on the upthrown block dips 20° upstream. If this gravel was deposited with an initial dip near 0°, the present dip indicates that the gravel has been deformed and that the waterfall is an expression of the fault.

TERRACES

Fluvial terraces of three ages are preserved adjacent to and downstream of the graben (Fig. 4). Longitudinal profiles of the terraces were surveyed and plotted along with the longitudinal profile of the modern channel and its floodplain (Fig. 5). The levels of the two youngest terrace gravels merge to a common elevation approximately 2 km downstream from cross section 5A (near D in Figs. 3, 4, and 5), and the lower terrace (Qt2) merges with the modern channel approximately 3 km downstream from point D.

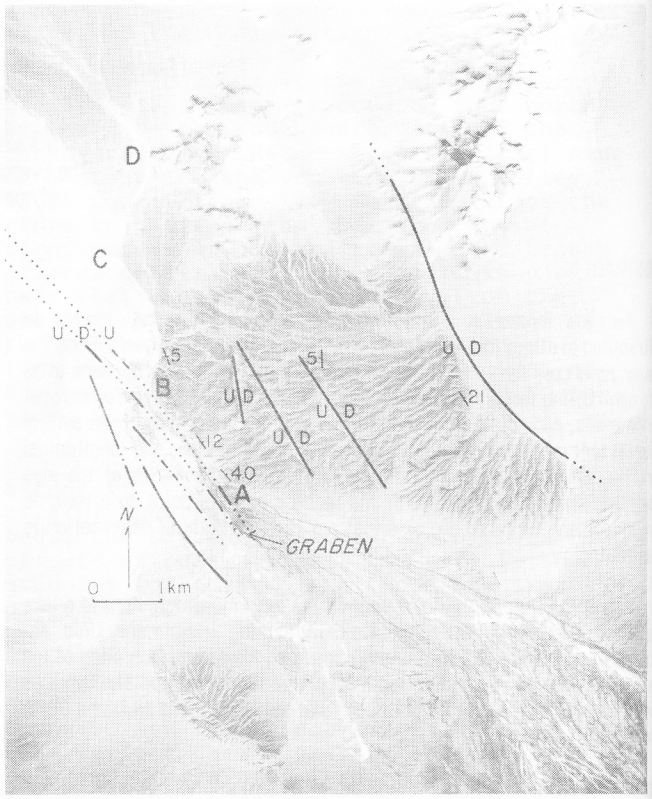

Figure 3: Aerial photograph showing the part of the Amargosa River adjacent to the uplifted alluvial fan where the terraces were studied. Points A, B, C, and D identify places discussed in the text. U and D designate relative up and down movement along faults. Faults are dashed where approximate, dotted where concealed. Representative strikes and dips of bedding are indicated for the gravel of the uplifted alluvial fan. Photograph from National Oceanic and Atmospheric Administration.

Remnants of the oldest terrace (Qt0) are restricted to an area east of the graben in the vicinity of cross section 1A and west of the modern channel near the west end of cross section 5A (Fig. 4). Correlation between the two areas of outcrop is based on grain size and terrace-surface elevation above the better preserved Qt1 gravel. The upstream deposits are 1 to 1.5 m thick and overlie the uplifted alluvial fan with a sharp, high-angle unconformity. Armored mudballs with an average diameter of 4 to 5 cm are common at the base of the deposits. At the downstream site, the Qt0 deposit consists of gravel that appears identical to the adjacent Qt1 gravel. However, its upper surface is 4.2 m higher than the upper surface of the Qt1 gravel directly to the east on either side of the stream (cross section 5A, Fig. 6). This is virtually the same as the difference between the top of the Qt0 and the top of the Qt1 surfaces at the upstream site.

The gravels in the terrace deposits contain a wide variety of rock types that reflect the diversity of rock types upstream in the basin. The surface has been winnowed of the finer material leaving behind what could be considered a desert pavement. Using a one-meter-square grid with 10 cm intervals, pebble counts were made to measure the size and type of the surface clasts. Size data were analyzed using a method described by Leopold (1970). Although this method ignores the sand-size fraction, it allows for comparison between terrace deposits. Two parameters of the size distribution were used to compare the samples; D_{50}, the median grain size and D_{84}, 84% of the deposits are finer than this value. In the Qt0 gravel east of the graben in the vicinity of cross section 1A, D_{50} = 44 mm and D_{84} = 81 mm. In the Qt0 gravel at the west end of cross section

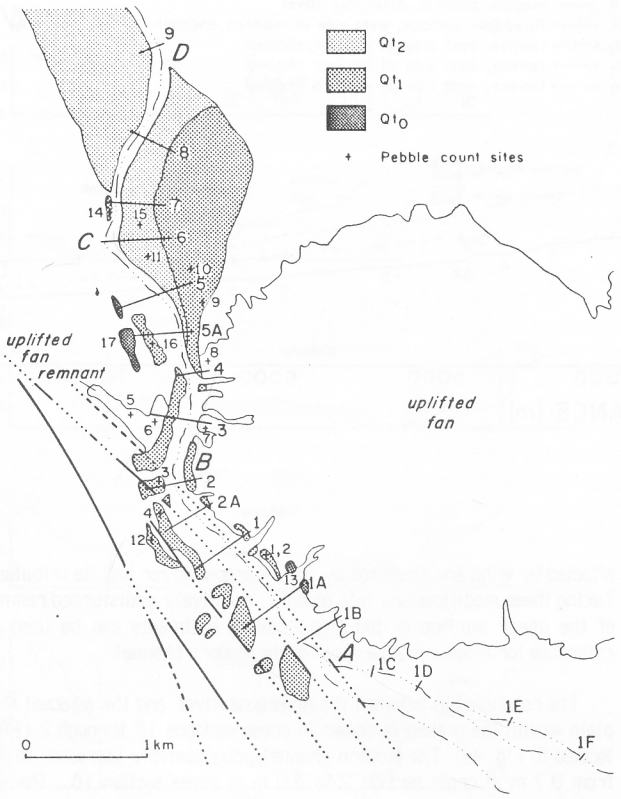

Figure 4: Outline map of the area containing fluvial terraces showing location of surveyed cross sections (1F through 9, plotted in Fig. 6), distribution of terrace gravels, and pebble-count sites (data plotted in Table 1). Points A, B, C, and D are the same as those in figure 3.

5A, D_{50} = 44 mm and D_{84} = 79 mm. These data are summarized in Table 1. In figure 7, D_{50} is plotted against D_{84} in order to characterize the terrace deposits and the deposits of the uplifted alluvial fan. Although the size data and diversity of rock types compiled in table 1 and figure 7 are not sufficient in and of themselves to distinguish between the alluvial fan and the three ages of terrace deposits, the data are consistent with the subdivision made using mapping and surveying techniques.

The Qt1 terrace is the most extensive of the three terrace remnants (Fig. 4). Certain of its characteristics vary within the study area, so for this discussion the terrace deposits will be compared at three localities. The deposits west of the graben unconformably overlie the deformed lake sediments and reach a maximum thickness of 3 m. The entire unit is generally well cemented with calcium carbonate. The gravel in the terrace deposit is matrix-supported and the matrix is fine to coarse sand. Occasional sandy interbeds, containing both parallel lamination and tabular cross beds, become more abundant near the top of the deposits. Much of the sand is composed of angular quartz and feldspar. It appears to be locally derived from weathered granite from the Owlshead Mountains, as the sand in the terrace deposits is very similar to the sand in the washes now draining the Owlshead Mountains. The Qt1 gravel west of the graben is sub-rounded to rounded; D_{50} = 32 mm and D_{84} = 47 mm.

The Qt1 gravel deposits east of the graben, between cross sections 1A and 1 (Fig. 4), are not very extensive due to erosion. The gravel rests unconformably on lacustrine sediments and has a maximum thickness of 0.5 m. The clasts are sub-angular to rounded and somewhat coarser than the Qt1 gravel west of the graben, with D_{50} = 36 mm and D_{84} = 54 mm. The sub-angular clasts and slight coarsening reflect proximity to the uplifted alluvial fan, the sediments of which are significantly less rounded and coarser than any of the terrace gravels (Table 1 and Fig. 7). The fan also influences the clast content; whereas the Qt1 gravel west of the graben contains virtually no gneiss (Table 1), the Qt1 deposits east of the graben contain 28% gneiss. Pebble counts at a series of sites along the axis of the uplifted fan to the east show that gneiss makes up more than 40% of the clasts at the head of the fan and decreases toward the distal end. In this arid environment, gneiss and granite tend to break down to their constituent mineral grains extremely rapidly. The presence of gneiss and granite clasts in relatively large amounts generally indicates a local source. At all sites where pebble counts were made, on terrace gravels and the uplifted alluvial fan, 31 to 64% of the clasts were of some type of quartz-rich sedimentary rock (mostly orthoquartzite), derived primarily from late Precambrian and Paleozoic sedimentary strata (Table 1). The highest percentage of orthoquartzite cobbles occurs on the west side of the graben. This high degree of compositional maturity indicates an upstream rather than local, source for the Qt1 gravel west of the graben.

The basal contact of the Qt1 gravel downstream of the graben (Fig. 4) is not exposed. Just upstream of cross section 5A, along the east side of the modern channel, the bank is 8 m high and exposes Qt1 gravel down to stream level. The thickness of the deposit is therefore at least 8 m. The composition of the clasts indicates that they were derived from the uplifted fan, the Owlshead Mountains, and sources upstream in the basin. The clasts are subangular to rounded and generally well cemented with calcium carbonate. The size distribution is virtually identical to that of the Qt1 gravel west of the graben (Table 1). This, along with detailed surveying (Figs. 5 and 6), is the basis for correlation for Qt1 deposits east and west of the modern channel.

The youngest terrace (Qt2) is preserved primarily downstream of the graben (Fig. 4). One other remnant of a surface lower than Qt1 occurs along the east side of the graben just upstream of cross section 1 (Fig. 4). Some of the channels that drain the uplifted fan contain remnants of a low terrace that may be equivalent to the Qt2 surface adjacent to the Amargosa River. The most extensive Qt2 surface appears to be cut into the Qt1 gravel and is covered with slightly coarser, less rounded and more poorly sorted cobbles than the Qt1 surface adjacent to it (Table 1).

HISTORY OF DEFORMATION

Terraces

The Qt1 surface along the west side of the graben has been domed and faulted. At cross section 1A, the Qt1 surface is 8 m above the level of the modern channel (Fig. 6). The fault that forms the western boundary of the graben cuts this surface at the west end of cross section 2 (Fig. 6). West of this fault, the terrace surface is 20.4 m above the modern channel while east of the fault the surface is 8 m above the modern channel (Figs. 5 and 6). Downstream of the graben, away from the effect of the faulting, the height of the Qt1 surface above the modern channel becomes progressively lower until just upstream of point D (Fig. 5), the Qt1 surface is less than 3 m above the modern channel.

Only a few remnants of the terraces are preserved along the eastern side of the graben (Fig. 4), so it is not possible to determine precisely the degree of deformation along that side of the graben. However, it appears that the movement on the fault that formed the eastern boundary of the graben ceased prior to the formation of the Qt0 surface. At cross section 1A, the Qt0 surface is 11.2 m above the modern channel (Fig. 5; located in Fig. 4). At cross section 1, the Qt1 surface on the east side of the graben is 7.0 m above the river (Fig. 6). The elevation difference between the Qt0 and Qt1 surfaces on the east side of the graben is therefore approximately 4.2 m. On the west side of the channel, downstream of the graben at cross section 5A, the difference in elevation of the Qt0 and Qt1 surfaces is 4.0 m.

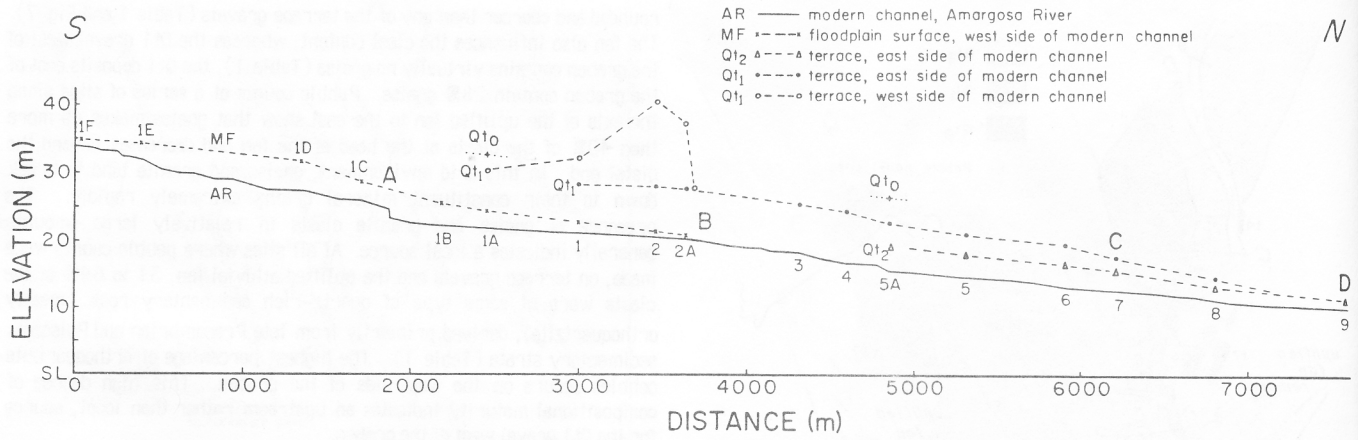

Figure 5: Longitudinal profile of the modern channel, its floodplain and associated terraces. Location of points A, B, C, and D and cross sections 1F - 9 are shown in figure 4.

At cross section 2 the elevation of the Qt1 surface above the modern channel on the down-thrown side of the fault that forms the western boundary of the graben is 7.9 m and the elevation of the Qt1 surface above the modern channel east of the fault that forms the eastern boundary of the graben is 7.7 m (Fig. 6). Therefore very little, if any movement could have taken place along the fault that forms the eastern boundary of the graben after the formation of the QtO surface. Quite clearly, movement on the fault that forms the western boundary of the graben is younger that movement on the fault that forms the eastern boundary.

Modern floodplain

During the deformation of the Qt1 gravel, upwarping of the terrace was followed by faulting. Detailed surveying along the modern channel of the Amargosa River reveals that a new phase of deformation may be underway upstream of the graben.

The present course of the Amargosa River upstream of cross section 2 (Fig. 4) is cut into fine-grained sediments that were probably deposited during a small-scale ponding event related to movement on a branch of the southern Death Valley fault zone. Although these deposits flank the modern channel within the graben, the bulk of the deposits extend for approximately 10 km upstream of the graben (shown in part in Fig. 3). These clay and silt layers are younger than the graben as they are not offset by the faults. It is assumed that the fine-grained deposits were flat-lying when deposited, although their surface has subsequently been affected by wind and dissected by the Amargosa River and its tributaries. Taking these modifications into account, relatively undisturbed remnants of the upper surface of the fine-grained sediments can be used as a reference for measuring the depth of the modern channel.

TABLE 1: Pebble-count data for river-terrace and uplifted fan surfaces[1].

Site Number[2]	Surface	Number Counted	D_{50}, mm	D_{84}, mm	Composition, %						
					Gneiss	Carbonate	Quartzite	Basalt	Diabase	Granite	Andesite
1	Qt1	98	38	53	22	20	50	-	5	2	-
2	Qt1	105	33	58	32	26	31	-	10	1	-
3	Qt1	109	24	31	-	13	60	2	2	5	19
4	Qt1	107	36	56	2	3	64	4	-	12	15
5	Qf2	104	51	110	24	8	50	11	6	2	-
6	Qf2	85	65	107	38	8	49	1	1	2	-
7	Qf2	105	51	94	26	25	36	4	10	1	-
8	Qf2	102	61	110	15	15	56	1	15	-	-
9	Qt1	101	34	47	5	5	54	4	8	2	22
10	Qt1	105	27	40	3	7	54	7	2	2	26
11	Qt2	108	40	65	12	4	37	2	21	4	20
12	Qt1	125	33	47	-	6	57	7	4	10	15
13	QtO	127	44	81	32	13	36	3	6	8	2
14	Qt1	108	29	39	6	5	46	9	5	9	19
15	Qt2	119	46	66	12	18	41	4	8	3	14
16	Qt1	119	34	50	2	15	50	5	3	5	20
17	QtO	119	44	79	5	7	49	6	8	4	22

[1] terrace surfaces designated QtO, Qt1, and Qt2; uplifted fan surface designated Qf2 (Fig. 4).

[2] sites located in figure 4.

The relationship between the Amargosa River and the adjacent floodplain within the graben is shown in cross sections 1B through 2 (Fig. 6, located in Fig. 4). The modern channel progressively increases in depth from 0.7 m at cross section 2 to 3.0 m at cross section 1B. The depth reaches a maximum of 4.6 m approximately 1.1 km upstream of cross-section 1B at cross section 1E, then decreases to 1.0 m 1.3 km farther upstream at cross section 1F (Figs. 5 and 6).

A similar relationship between a fault trace and fine-grained sediments occurs downstream, along the east side of the Confidence Hills (Fig. 2). There, the modern channel enters a branch of the southern Death Valley fault zone and immediately upstream there is a relatively flat area of fine silt and clay that flanks the channel for approximately 10 km. However, unlike the relationships described for the uplifted alluvial fan, there is virtually no difference in channel depth within and away from the fault trace. Upstream of the Confidence Hills, before the river re-enters the southern Death Valley fault zone, the depth of the modern channel is generally 0.8 to 1.2 m. Within the fault zone adjacent to the Confidence Hills, the depth of the modern channel is essentially the same, ranging from 0.8 to 1.4 m deep.

This comparison of channel depth along the uplifted fan and Confidence Hills suggests that tectonism is no longer a factor in controlling incision of the river adjacent to the Confidence Hills. However, uplift is responsible for the incision upstream of the graben. Without young or ongoing deformation the Amargosa River upstream of the uplifted alluvial fan would be about the same depth as it is adjacent to the Confidence Hills. A reconnaissance survey was done along the lower course of the Amargosa River and the maximum depth of the channel is nowhere more than 1.9 m and generally the depth averages 1 m except upstream of the graben adjacent to the uplifted alluvial fan where the channel depth reaches a maximum of 4.6 m.

The longitudinal profiles of the modern channel also suggest a new phase of tectonism. Within the graben, the slope of the modern channel is .0026 between points A and B (Fig. 5). Upstream of the graben (point A in Fig. 5), the slope of the channel is .0050, almost twice as steep. For contrast, in the area adjacent to the Confidence Hills (Fig. 2), the slope of the channel there along the fault is .0022, whereas the slope through the fine-grained sediments upstream of the fault is .0015. If there were no young or ongoing deformation upstream of the graben adjacent to the

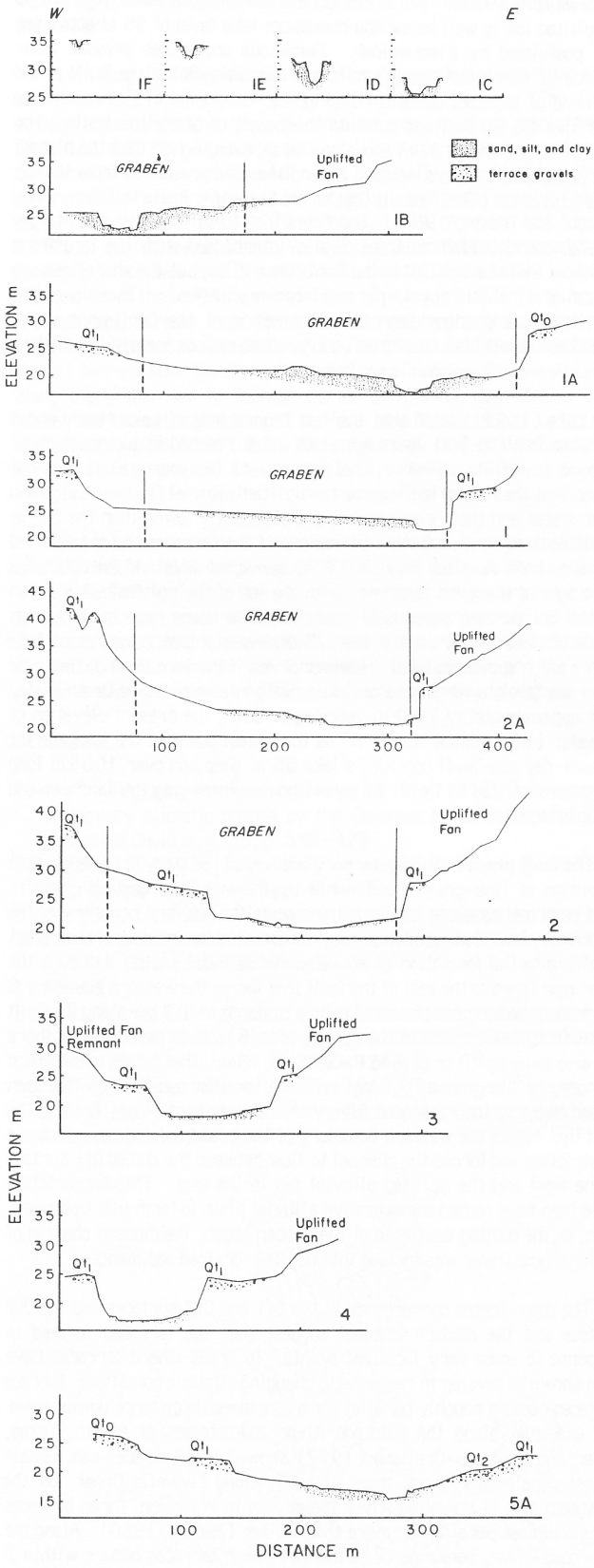

Figure 6: Surveyed cross sections 1F through 9 showing the relationship between the terraces and modern channel. See figure 4 for location of sections.

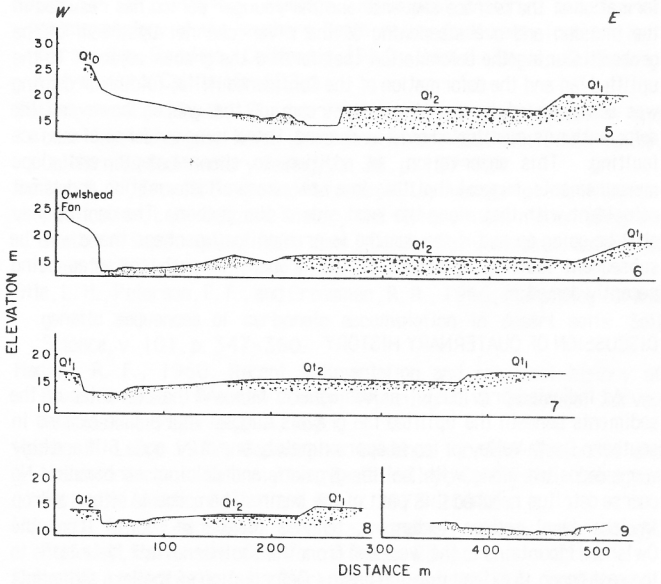

Figure 6 - continued

uplifted fan, then the gradient of the river through the fine-grained sediments upstream of the graben should be approximately equal to the gradient of the stream within the graben. In the Confidence Hills, where there is no evidence of any ongoing deformation, the gradient of the river within the fault zone is only slightly steeper than the gradient through the fine-grained sediments upstream of the fault zone. However, adjacent to the uplifted alluvial fan, the gradient through the fine-grained sediments upstream of the graben is almost twice the gradient within the graben and over 3 times as steep as the gradient in the fine-grained sediments just upstream of the Confidence Hills. These gradient relationships suggest that adjacent to the Confidence Hills there was one period of deformation

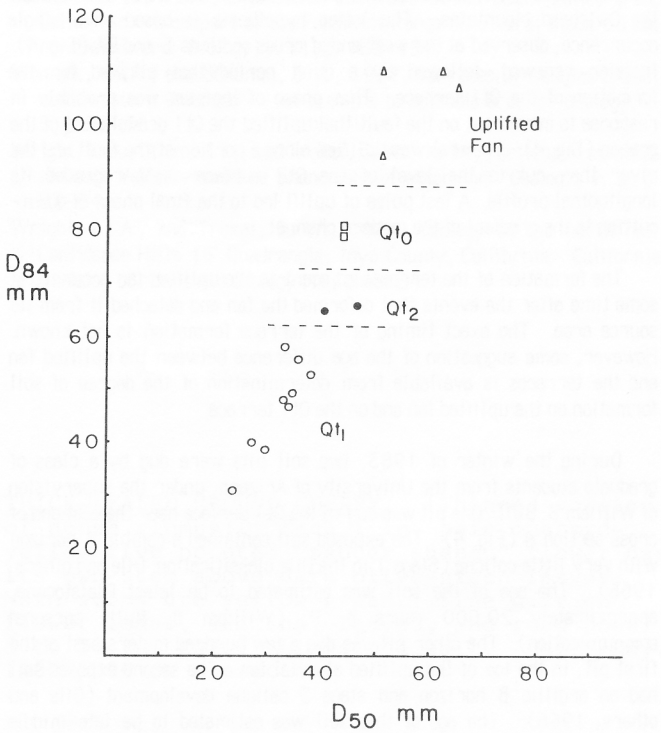

Figure 7: Plot of D_{50} versus D_{84} for all the pebble counts. Pebble count sites located in figure 4.

that is now inactive, whereas adjacent to the uplifted alluvial fan there were two periods of deformation. The older period resulted in the formation of the terrace sequence and the younger period has resulted in the incision and oversteepening of the river channel upstream of the graben. During the deformation that formed the graben adjacent to the uplifted fan and the deformation of the Confidence Hills, folding or doming was accompanied by faulting. Upstream of the graben however, the deformation is manifested only as doming; there is no evidence of surface faulting. This observation, in addition to channel depth and slope measurements, suggest that this is a new phase of deformation and is not coincident with that along the west side of the graben. The doming may still be going on and if the doming is premonitory perhaps there will be subsequent faulting upstream of the graben, through the area being recently domed.

DISCUSSION OF QUATERNARY HISTORY

As indicated previously, paleomagnetic data and the character of the sediments beneath the uplifted fan gravels suggest that a lake existed in southern Death Valley prior to approximately one m. y. ago. Silt and clay were deposited along with halite, gypsum, and calcium carbonate. No coarse detritus reached this part of the basin. Then, due to either a drop in lake level and/or tectonism, tongues of coarse debris from the Owlshead Mountains to the west and from the southern Black Mountains to the east began to extend into the basin. Deformation of the lake sediments was taking place in parts of the basin at the same time as the coarse debris was being deposited. The alluvial fan east of the present graben was uplifted, folded, and faulted as were the lake sediments west of the graben. It was at this time that the fault that forms the eastern boundary of the graben was active. When deformation of the fan ended, the ancestral Amargosa River cut through a topographic low near the toe of the fan, leaving a remnant of the fan gravel west of the river (Fig. 4). The uplift of the distal end of the fan would have decreased the gradient of the river upstream of the deformation and steepened the gradient downstream. It seems likely that the river then cut down through the area of uplift in an attempt to regrade its longitudinal profile.

During this period of incision the oldest terrace (Qt0) was formed. It was probably not originally very extensive, and all but a few remnants were subsequently eroded away along the graben or buried by debris from the Owlshead Mountains. The latter hypothesis is based on a single occurrence, observed at the west end of cross sections 5 and 5A (Fig. 4). Incision renewed, followed by a quiet period that allowed for the formation of the Qt1 terrace. This phase of incision was probably in response to movement on the fault that uplifted the Qt1 gravel west of the graben (Fig. 4). The area was uplifted along a portion of the fault and the river then cut to the level of the Qt2 surface as it regraded its longitudinal profile. A last pulse of uplift led to the final phase of down-cutting to the gradient of the modern channel.

The formation of the terraces adjacent to the uplifted fan occurred at some time after the events that deformed the fan and detached it from its source area. The exact timing of the terrace formation is not known. However, some suggestion of the age difference between the uplifted fan and the terraces is available from determination of the degree of soil formation on the uplifted fan and on the Qt1 terrace.

During the winter of 1983, two soil pits were dug by a class of graduate students from the University of Arizona, under the supervision of William B. Bull. One pit was dug in the Qt1 surface near the east end of cross section 4 (Fig. 4). The exposed soil contained a cambic B horizon with very little caliche (Stage 1 in the Gile classification: Gile and others, 1966). The age of the soil was estimated to be latest Pleistocene, approximately 20,000 years B. P. (William B. Bull, personal communication). The other pit was dug a few hundred meters east of the first pit, in the toe of the uplifted alluvial fan. The second exposed soil had an argillic B horizon and stage 3 caliche development (Gile and others, 1966). The age of this soil was estimated to be late-middle Pleistocene, approximately 75,000 to 100,000 years B. P. (William B. Bull, personal communication).

The Amargosa River was one of three main sources of water for Lake Manly, which occupied Death Valley periodically during Pleistocene time (Blackwelder, 1933). The elevation of the Amargosa River adjacent to the uplifted fan is well below the maximum lake level of 95 m above sea level postulated by Blackwelder. Numerous shorelines provide clear evidence for numerous changes in lake levels along Shoreline Butte at the north end of the Confidence Hills (Fig. 2). Hooke (1972) reported no fewer that 26 strandlines cut into the basalt of Shoreline Butte. The highest is more than 127 m above sea level, even higher than the highest level postulated by Blackwelder. Strandlines are preserved from the top to the base of the butte. Basalt that forms Shoreline Butte is 1.5 m. y. old (Wright and Troxel, 1984). The flows that form the butte are steeply dipping, and debris from the flows is interbedded with the lacustrine sediments that are uplifted in the Confidence Hills, but the shorelines are horizontal (B. W. Troxel, personal communication). Therefore, the shorelines are younger than the deformation of the Confidence Hills, which has been determined to be younger than approximately one million years. How much younger is not known.

Hooke (1972) stated that the last high stands of Lake Manly ended approximately 10,500 years ago when water reached an elevation of 87 m above sea level. However, that age may be too young, as is does not appear that the fluvial terraces or the uplifted alluvial fan have ever been under water and their elevations are significantly lower than the 87-m shoreline on Shoreline Butte. Elevations of the terraces and the uplifted fan range from near sea level to 120 m above sea level. If the estimates of the ages of the soils associated with the toe of the uplifted alluvial fan and the Qt1 terrace deposits are correct, then there have been no high stands of Lake Manly in the last 75,000 years that have raised lake waters much above sea level. However, even if the lake level did not rise above sea level, a large lake or lakes could have existed in Death Valley after approximatel3y 75,000 years ago. Using the present elevation of Badwater (86 m below sea level) as the lowest point in the lake and the present-day sea-level contour, a lake 86 m deep and over 100 km long could have existed in Death Valley without submerging the terraces and the uplifted alluvial fan.

The final phase in the Quaternary history of the study area began with deposition of fine-grained sediments upstream of the graben. Small-scale deformation along the fault that forms the western boundary of the graben may have caused a temporary constriction or ponding of the river, resulting in the formation of an extensive alluvial plain. Although the river now flows to the east of the fault that forms the western boundary of the graben, doming has occurred over a distance of 1.2 km along the fault that forms the west side of the graben (Fig. 5). It is possible that there was also some uplift or drag to the east of the fault that forms the western boundary of the graben, but any evidence for that deformation has been eroded away by the Amargosa River. A small amount of uplift along the fault that forms the western boundary of the graben would have caused a constriction and forced the channel to flow between the domed Qt1 surface to the west and the uplifted alluvial fan to the east. This constriction could then have caused the extensive alluvial plain to form just upstream. Then, as the doming upstream of the graben began, the modern channel of the Amargosa River was incised into the fine-grained sediments.

The downstream convergence of the Qt1 and Qt2 surfaces and the Qt2 surface and the modern channel suggest that the terraces formed in response to some very localized events. In areas where terraces have been shown to develop in response to changing climatic conditions, terrace surfaces remain roughly parallel for a considerable distance downstream. For example, along the Colorado River downstream of Austin, Texas, Baker and Penteado-Orellana (1977) showed that terraces can remain almost parallel for more than 70 km. Along Fivemile Creek, on the northeast side of the Wind River Mountains in Wyoming, three terraces remain almost parallel for more than 80 km (Hadley, 1960). Along the Amargosa River, convergence of the two lower terraces occurs within 2 km and convergence of the Qt2 surface and modern channel occurs within 5 km (Fig. 5). A similar convergence of terraces was reported along the Ventura River in southern California (Putnam, 1942; Keller and others, 1982) where the river cut across the Ventura anticline as the anticline

was being uplifted. There, terraces converge within 5 km downstream of the fold axis.

It is recognized that terrace formation during Quaternary time can be attributed to climate, base-level, and tectonic changes. The fluvial system adjusts, commonly in a complex way, to these perturbations (Schumm, 1977). A growing body of literature suggests that terraces can form in a matter of days to years, especially in arid and semi-arid environments where there is an abundant sediment supply (see for example Born and Ritter, 1970; Schick, 1974; Womack and Schumm, 1977). In southern Death Valley, as deformation proceeded, the Amargosa River was able to maintain its channel, episodically incising it into the toe of the uplifting alluvial fan. During initial terrace-forming incision, downstream from the deformation along the graben, the river began to spread out and created a wider floodplain. That floodplain became the Qt1 terrace after the next phase of stream incision. Subsequent uplift along the graben led to another period of incision downstream of the graben and the cutting of the Qt2 surface. One final pulse of uplift along the graben would have led to the ponding of fine-grained sediments upstream of the graben. Then as the area of doming shifted upstream, a new phase of incision resulted in the cutting of the modern channel.

The age of the formation of the terraces is much younger than the age of a lake that would be large enough to fill Death Valley to the elevation of the uplifted alluvial fan. Therefore, base-level changes are not adequate to explain the formation of the terraces. The convergence of the terraces and the modern floodplain over such a short distance argues for localized tectonic controls over terrace formation. The terraces are the river's response to deformation along the southern Death Valley fault zone.

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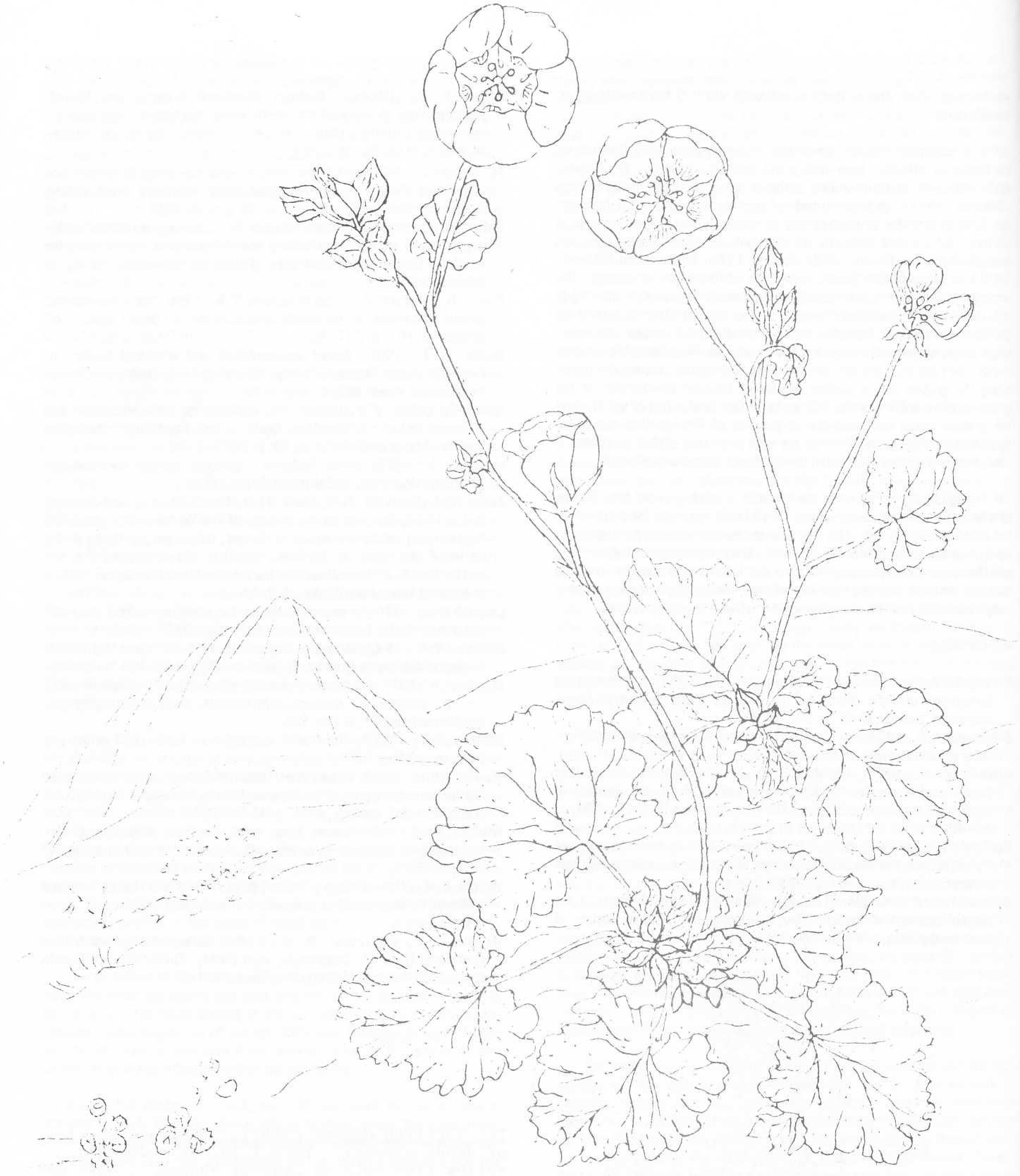
THICK-LEAFED GROUND CHERRY. (Thinned version of dense clumps). Each 1 in. pale mustard-yellow five pointed "saucer shaped" flower has its own stem above dark olive-green leaves. Main stems are yellow-green. Fine hair on flower lobes, stamens, leaves, and seed pods. 8 to 16 in. tall. Limestone soil. March-May. 1400-5000 ft elevation.



DESERT FIVE-SPOT, GLOBE MALLOW, or CHINESE LANTERN. Almost transparent 1 in. magenta to rose 5 petal globe flowers with reddish-brown spots inside. Pink-stemmed yellow stamens and black seeds radiate from the flower center. Hairy rusty red flower and leaf stems. Red leaf veins and edges. March-May. 100-4200 ft elevation. Dry sandy areas

MULTIPLE QUATERNARY DEFORMATION, CENTRAL PART OF THE CONFIDENCE HILLS, DEATH VALLEY, CALIFORNIA: AN EXAMPLE OF FOLDING ALONG A STRIKE-SLIP FAULT ZONE

Bennie W. Troxel
University of California
Davis, California

and

Paul R. Butler
The Evergreen State University
Olympia, Washington

Introduction.

The Confidence Hills contain Quaternary rocks that have been folded during at least two episodes of movement along strands of the southern Death Valley fault zone. Even later movement has offset or folded moderately young gravel that flanks the hills. The oldest sediments in the Confidence Hills are about 2.2 m.y. old based upon correlation of volcanic ash beds in the lower part of beds exposed in an anticline (see Troxel and others, this volume).

The northern part of the Confidence Hills was mapped by Wright and Troxel (1984). Butler (1984) mapped the southern part of the Confidence Hills. Troxel (unpublished data) mapped all of the Confidence Hills.

Access to the Confidence Hills is provided by a gravel road that extends southeast from its junction with the paved road in the floor of Death Valley. The paved road extends southward from State Highway 190 at Furnace Creek or westward beyond State Highway 178 that extends from Shoshone to the boundary of Death Valley National Monument.

Fom the paved road travel about 2.5 miles southeast along the gravel road. The nearest identifiable area to park is the point where a west-draining stream channel crosses the road. The stream channel lies between two fans that extend westward from the Black Mountains. From this point hike westward down drainage to the Amargosa River channel then upstream in a channel that crosses the Confidence Hills. The recommended traverse is indicated by a line of arrows on Figure 1. When the arrows end follow the stream channel to the far upstream side of the pale fine-grained sediments. The sediments are flanked by darker and younger gravel that lie on the southwest side of a strand of the southern Death Valley fault zone. The complete traverse involves about 4 miles of hiking. The general geologic features are outlined on Figure 2.

Geology.

The Confidence Hills sediments consist of lake beds composed of silt to sandstone with interbedded gravel, gypsiferous beds, halite, celestite, and volcanic ash. The gravel beds contain clasts that were derived from the Owlshead Mountains to the west. The beds are best exposed in the walls of a through-going stream channel, where they dip steeply in the core of an anticline.

The lake sediments are overlain by coarse gravel also derived from the Owlshead Mountains. The contact below the gravel is an angular unconformity but, in places, is nearly conformable with the underlying lake sediments.

The age of the lake sediments is between about 2 million years (Troxel and others, this volume) and 1.5 million years (Wright and Troxel, 1984) or younger. Butler (1984) collected a sample of ash collected from just below the fan gravel that lies above the unconformity. The age is inconclusive but is probably older than 0.62 and younger than 1.14 m.y. The Shoreline Butte basalt has yielded an age of 1.5 m.y. (R. L. Drake in Wright and Troxel, 1984). The upper part of the Confidence Hills lake sediments contain debris derived from the basalt flows, thus they must be younger than 1.5 m.y. Further work on the age of the strata in the Confidence Hills is anticipated.

The main mass of sediments that comprise the Confidence Hills lies between two strands of the southern Death Valley fault zone. The trace of the western strand is clearly exposed as a slightly warped line (Figure 1). It separates tightly folded lake sediments on the east from coarse gravel that appears to be only slightly deformed. The eastern fault is not exposed but its location can be determined by inference. For instance, the Amargosa River channel is remarkably straight throughout its course across Figure 1. Two fans are gently warped near their termination at the river channel and linear features in and adjacent to the channel appear to be fault scarps (Figures 1 and 3).

The folds are reflected in the topography. The anticlines underlie the higher topography and the syncline underlies low topography. Where the hills are widest, in the lower part of Figure 1, there are two anticlines. The narrower part of the hills (Figure 1) is underlain by a single anticline.

The two strands of the southern Death Valley fault zones that bound the Confidence Hills appear to be left stepping. The folds, thus, are in a transpression zone. The axes of the anticlines are remarkably parallel to the fault traces. The intervening syncline trends more northerly than the anticlines (Figure 2).

N
1 KM
1 mile

Figure 1. Photo map of central Confidence Hills. Geologic units not formally designated. All units on photo are Quaternary in age. Pale sediments are lacustrine sand and salt with interbedded gypsum, halite, celestite, and ash beds. Darker beds are coarse sediments comprised of fan gravel derived from Owlshead Mountains to the west (left). Gravel deposits derived from the Black Mountains (right) are preserved in small patches on east (right) side of hills at Amargosa River channel. Course of Amargosa River channel is controlled by traces of southern Death Valley fault zone. Older fan unit is deformed along western side of probable trace of fault zone. Length of north arrow denotes one mile. White lines and patches are field-worn flaws in photos.

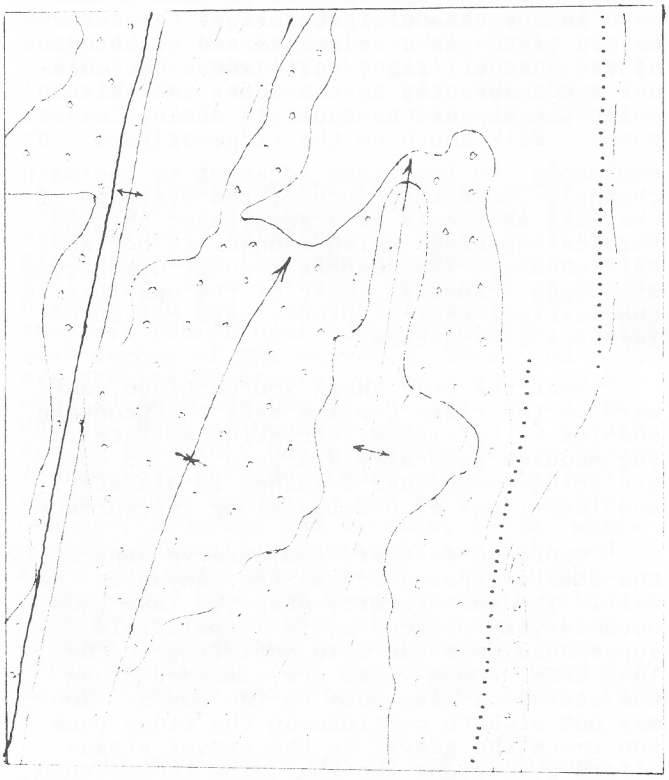


Figure 2. Sketch of principal features in part of Figure 1. Lake sediments (dashed lines) are highly deformed. Older gravel (open circles) is less highly deformed. Fold axes approximate. Older and younger gravel units each include more than one unit. Western strand (solid heavy line) and probable eastern en echelon strands (closely-spaced dots) of southern Death Valley fault zone flank hills.

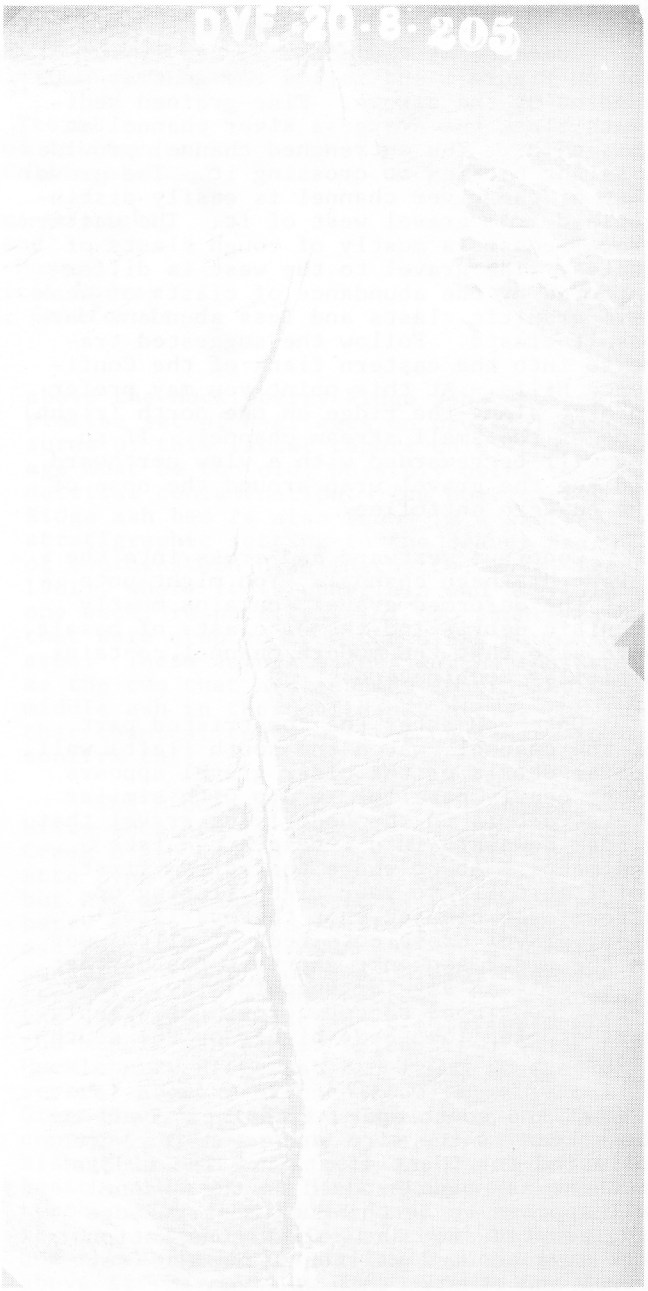


Figure 3. Low-sun-angle photograph of segment of southern Death Valley fault zone along the Amargosa River channel. See Figure 1 for location. Entrenched channel appears to occupy fault zone. Linear features along river channel are well defined by the low sun angle. Scale 1:12,000. Photo courtesy D. B. Slemmons.

Suggested traverse.

Commence at the point marked by the black dot on Figure 1 and follow the general path denoted by the arrows. Fine-grained sediments flank the Amargosa River channel at this point. The entrenched channel provides a slight problem to crossing it. The gravel east of the river channel is easily distinguished from gravel west of it. The eastern gravel consists mostly of tough clasts of gneiss. The gravel to the west is differentiated by the abundance of clasts of weak pale granitic clasts and less abundant dark basalt clasts. Follow the suggested traverse into the eastern flank of the Confidence Hills. At this point you may prefer to hike along the ridge on the north (right) side of the small stream channel. If so, you will be rewarded with a view northward and see the gravel wrap around the nose of the eastern anticline.

Continue westward and cross into the larger drainage channel. You might note that the deformed gravel contains mostly granitic debris and lesser clasts of basalt. Note also that the modern channel contains a similar combination.

Once you enter the constricted part of the channel, watch the south (left) wall. Coarse debris of the older gravel appears to be nearly parallel in dip with similar coarse debris in the underlying gravel that grades downward into fine-grained lake sediments. About where the stream first turns abruptly to your right (facing upstream) you can see that the overlying older gravel cross cuts beds of silt lower in the older sequence and that the contact is clearly an angular unconformity. The gravel continues to cut across the steeply-east-dipping lake beds higher on the south ridge.

At the south apex of the next bend in the stream is the site where samples were collected for identification. The middle of three ash beds exposed in the channel wall appears to be the Huckleberry Ridge ash, erupted from the Yellowstone National Park area about 2 million years ago (see Troxel and others, this volume).

As you continue up the stream channel you can note details of the beds in the steep channel walls. Gypsum occurs in beds and as white stringers that fill fractures. Halite beds or halite-enriched silt are resistant to erosion, generally pink in color and are undercut by stream erosion. Celestite occurs as pale tan nodules rarely more than 2" in diameter. Lake sediments in the gentler slopes are masked by a crustal material that commonly has a texture similar to popcorn.

The point where the stream branches along the west side of the lake sediments (Figure 1) marks the position of the western branch of the southern Death Valley fault zone. The fault underlies the stream channel to your right (north) but is exposed farther north where it emerges from the channel.

You may wish to climb the ridge of gravel in the right (north) bank of gravel beyond the fault. The surface developed atop the gravel is well developed but moderately dissected. The clasts of granite and basalt are typical representatives of bedrock directly upstream in the Owlshead Mountains. The part of the Owlshead Mountains drained by this channel and the next two channels north of it is the source area for fan debris offset 20 miles to the southeast, where the debris is preserved along the east side of the Noble Hills (see Troxel, this volume).

The easiest return trip is by reversing your course. For the more energetic it is recommended that you climb to the crest of the ridge that forms the north wall of the canyon you walked through. This traverse requires some short steep climbs and descents. The best access is to walk northward in the channel that follows the west margin of the lake sediments and climb out of the channel (right wall) where the channel bends abruptly to the left. At this point the dip of the fault is clearly exposed. Walk south on the ridge of lake sediments to the ridge adjacent to the main channel. Note that much of the drainage of the lake sediments is accomplished through vertical openings which connect to horizontal tunnels. The tunnels connect downstream with open channels. Most of the openings to the vertical shafts (pipes) have collapse features around them.

Near the area where you continue eastward on the ridge top are beds that contain nodules of celestite (strontium sulfate). The nodules generally are pale tan in color, are seldom more than 2 inches in diameter, and form lines of nodules along the surface.

Continue eastward and observe especially the strata exposed across the canyon to the wall. The unconformity atop the lake beds becomes very obvious as is a small fold superposed upon the main anticline in the lake beds. Good views are afforded along the strike of lake beds to the north. You may not wish to continue on the ridge once you reach the gravel as the gravel slopes afford precarious footing. The recommended traverse is to return to the main channel before you reach the gravel then proceed to your vehicle by walking around the north side of the anticline beyond the mouth of the canyon. End of trip.

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AGES, CORRELATIONS, AND SOURCES OF THREE ASH BEDS IN DEFORMED PLEISTOCENE BEDS, CONFIDENCE HILLS, DEATH VALLEY CALIFORNIA

B. W. Troxel
University of California,
Davis, California

A. M. Sarna-Wojcicki,
and
C. E. Meyer,
U.S. Geological Survey
Menlo Park, California

Three ash beds are present in highly deformed Pleistocene fine-grained lake beds of the Confidence Hills, in Death Valley. Samples of these ash beds were collected by Troxel from the south wall of an east-draining channel that drains the Owlshead Mountains. Separated glass shards were analyzed by electron microprobe (EMA) at the U.S.G.S., in Menlo Park, Calif., in order to identify the ash beds and to provide age control to the Pleistocene beds exposed at this locality.

The lowest of the three ash beds (CHA-86BT-1), as inferred by Troxel from stratigraphic relations at this locality and his assumption that the structure here is an anticline, is chemically very similar to the highest ash bed (CHA-86BT-3; table 1), and they are indistinguishable within the analytical errors of EMA analysis. These two beds are chemically similar to an ash bed (W3A) exposed near the top of the section in the Waucoba Beds of Owens Valley, and to an ash bed in the Manix basin, in the Mojave Desert (Sarna-Wojcicki and others, 1984), as well as to tephra layers in the Tuff of Taylor Canyon (Krauskopf and Bateman, 1977), where coarse proximal exposures of air fall and ash flow tephra are present. This tephra was erupted from the Glass Mountain volcanic complex, a predecessor of the Long Valley caldera in east-central California, from which the Bishop Tuff was erupted about 0.74 Ma ago (Bailey and others, 1976; Izett, 1982).

The middle ash bed in the Confidence Hills, as inferred from structure and straigraphy (CHA-86BT-2), is most similar to the Huckleberry Ridge ash bed (formerly known as the Pearlette type B ash bed), erupted from the Yellowstone National Park area of northwestern Wyoming and eastern Idaho (Izett and Wilcox, 1982). The age of this ash bed is about 2 Ma, based on K-Ar analysis of proximal ash-flow sheets of the same eruption that produced the air-fall ash blanket (Christiansen and Blank, 1972; J. D. Obradovich, written commun., 1986). The Huckleberry Ridge ash bed is also found in Pleistocene alluvium in the Manix basin, where it underlies with little stratigraphic separation an ash bed that correlates with ash bed W3A from the Waucoba Beds, based on neutron activation analysis of the volcanic glass (Sarna-Wojcicki and others, 1984). W3A has been dated at 2.3 Ma by K-Ar analysis of feldspars (Hay, 1966), but considering the stratigraphic position of this ash bed above the Huckleberry Ridge ash bed, and the precise set of K-Ar ages on proximal exposures of this latter tephra unit, the former age must be too old, possibly owing to detrital contamination. The Huckleberry Ridge ash bed is also found in a similar stratigraphic setting in the Beaver basin of southwestern Utah (Machette, 1984; Izett, 1981), where it is underlain and overlain by one each, respectively, of two tephra layers that were erupted from the Glass Mountain area. These tephra layers may be the same as the two that are assumed to bracket the middle ash in the Confidence Hills, but further chemical tests will be necessary to confirm this.

The middle ash bed at the Confidence Hills locality is also similar to the Lava Creek B ash bed (0.62 Ma: formerly the Pearlette type O ash bed; Izett and Wilcox, 1982), but not as similar as it is to the Huckleberry Ridge ash bed (table 1). The latter ash bed, as well as CHA-86BT-2, generally contains higher iron and calcium than the Lava Creek B ash bed (table 1). Furthermore, the stratigraphic sequence associated with the middle ash bed is characteristic of the Huckleberry Ridge ash bed found at the several above mentioned localities in the Great Basin. The Lava Creek B ash bed, by contrast, is frequently associated with the Bishop ash bed below and, in the Great Basin, no major ash beds above it, or in the northwestern Great Basin and northern California, with the Dibekulewe (about 0.6 Ma), and the Rockland (about 0.4 Ma) ash beds above it (Sarna-Wojcicki, 1985). The Bishop ash bed is chemically similar to the older tephra layers erupted from the Glass Mountain complex on the northeastern rim of the Long Valley caldera, but the Bishop can be distinguished from these layers by its higher iron and calcium, and lower manganese concentrations. Thus, although further, more precise analysis by other analytical methods could provide a more definitive chemical identification, the middle ash bed in the Confidence Hills of Death Valley is fairly reliably identified as the Huckleberry Ridge ash bed. Further chemical analyses by X-ray fluorescence or neutron activation analysis are necessary to determine the identities and correlatives of the other two ash beds, and to determine whether they are indeed different or whether they are the same ash bed.

Table 1. Electron-microprobe analysis of volcanic glass shards of three ash beds from the Confidence Hills, Death Valley, Calif., and chemically similar ash beds. CHA-86BT-1, 2, and 3, ash beds in Confidence Hills, with 1 assumed to be oldest, and 3 youngest. W3A, ash bed at top of tephra sequence in Waucoba (lake) Beds (Sarna-Wojcicki and others, 1984). 68W98, Huckleberry Ridge ash bed (formerly the Pearlette type B ash bed), ca. 2.0 Ma, Borcher's faunal locality, Meade Co., Kansas (Izett and Wilcox, 1982). 67W104, Lava Creek B ash bed (formerly Pearlette type O ash bed), ca. 0.62 Ma, Grand Co., Utah, (Izett and Wilcox, 1982). C. E. Meyer, USGS, Menlo Park, analyst. Oxides are recalculated to 100% on a volatile-free basis. Totals shown are original values before recalculation.

Oxide	Lowest ash bed CHA-86BT-1	Waucoba Beds W3A	Middle ash bed CHA-86BT-2	Huckle-berry Ridge 68W98	Highest ash bed CHA-86BT-3	Lava Creek B 67W104
SiO_2	77.76	77.54	77.09	76.67	77.75	76.85
Al_2O_3	12.43	12.35	11.95	12.28	12.39	12.21
Fe_2O_3	0.58	0.65	1.71	.1.71	0.64	1.57
MgO	0.02	0.03	0.01	0.02	0.02	0.02
MnO	0.09	0.09	0.05	0.05	0.09	0.03
CaO	0.33	0.33	0.59	0.58	0.29	0.54
TiO_2	0.06	0.05	0.11	0.12	0.06	0.10
Na_2O	3.55	3.61	3.33	3.35	3.53	3.57
K_2O	5.17	5.35	5.17	5.22	5.23	4.98
Total	94.60	93.25	92.74	93.98	94.03	94.02

The samples were collected from steeply-east dipping beds exposed in the nearly vertical south wall of a stream channel that originates in the Owlshead Mountains, cuts through the Confidence Hills, and joins the Amargosa River farther east. The ash beds are a few meters apart and average about half a meter in thickness. CHA-86BT-1 is the westernmost bed and lowest stratigraphically (based on graded beds in the enclosing lake sediments). The location where they were sampled is long. 116°38'W, latt. 35°51'21"N.

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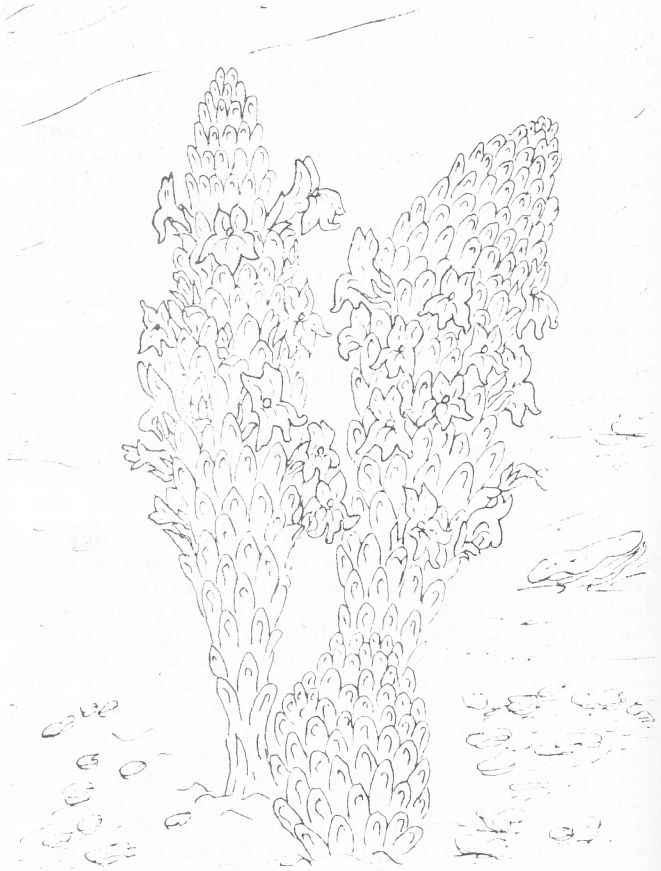

BROOMRAPE are 2 to 12 in. tall root parasites with no chlorophyll. Purplish or yellow flowers. These lavender "monkey" flowers had a yellow-tinged lower lip, a double brown stigma and 2 pair of short hidden stamens. Scale leaves were rusty-tan. January-September. 800-10,000 ft elevation. Sandy areas or drainage washes.

TIME RELATIONS BETWEEN QUATERNARY FAULTING, VOLCANISM, AND FAN DEVELOPMENT, SOUTHERN DEATH VALLEY, CALIFORNIA

Bennie W. Troxel
University of California
Davis, California

and
Paul R. Butler
The Evergreen State University
Olympia, Washington

Introduction.

A cinder cone that lies athwart the northwesternmost trace of the southern Death Valley fault zone is composed of basaltic or andesitic rocks (herein referred to as basalt) that is 0.69 m.y. old accoding to a K-Ar age determination made by R. L. Drake (personal communication in Wright and Troxel, 1984). Tephra emitted from the cone (Cinder Hill on Figure 1) is preserved in at least 21 localities (Figure 1). The tephra deposits are remnants of a base-surge event (Bruce Crowe, personal communication) that expelled material at least as far as 6 miles from Cinder Hill.

The tephra and cone deposits emitted from Cinder Hill are important to Quaternary history in that they record a young volcanic event and subsequent or concurrent movement along the southern Death Valley fault zone. The tephra was deposited upon various bedrock units but most importantly upon the oldest Quaternary fan unit recognized by Wright and Troxel (1984). The fan had been eroded before the tephra was deposited. The fan was subsequently uplifted, tilted, and eroded following deposition of the tephra, which is overlain by younger fan deposits. In addition, the tephra deposits were eroded, and cut by shorelines of Lake Manly. The oldest fan unit abuts basaltic rock that is tentatively correlated with the basalt of nearby Shoreline Butte. The basalt of Shoreline Butte is 1.5 m.y. old according to R. L. Drake (in Wright and Troxel, 1984), thus the oldest fan unit of Wright and Troxel (1984) is younger than 1.5 m.y. and older than 0.69 m.y. At least one strand of Lake Manly is younger than 0.69 m.y.

Geologic mapping in this area was done by Wright and Troxel (1984), who distinguished three gravel or fan units. They are: Qg1 (their map) consisting of fan and stream gravel deposits, deeply dissected and slightly deformed: Qg2 fan and stream gravel deposit, moderately dissected and undeformed; and Qg3, fan and stream gravel deposits, undeformed and relatively undissected. Unit Qg3 could be further divided into modern stream channel deposits and slightly older stream and fan deposits, but were not by Wright and Troxel (1984).

One of the tephra masses has been cut along a shoreline of Lake Manly and is overlain by beach gravel. All tephra deposits presently are below 400 feet in elevation with one exception, which is barely above the 400-foot contour (Figure 1).

The tephra was deposited upon exposed bedrock and Qg1 of Wright and Troxel (1984) after the gravel had been tilted and cut by stream channels. The tephra is mainly preserved in abandoned stream channel, where covered by younger gravel, or where preserved along banks of stream channels that are protected from erosion.

Cinder Hill (Figure 1) is about 80 feet high and 1,300 feet wide. The cone is composed of blocks, cinders, and coarse ash--all basaltic in composition. The cone is offset about 700 feet in a right-lateral sense. It is surrounded and partly buried by gravel at the eastern toe of a fan that extends from Wingate Wash. The fan gravel shows no surficial evidence of being faulted.

Discussion.

The oldest fan deposit of Wright and Troxel (1984) is younger than the basalt of Shoreline Butte. It was eroded, tilted, and probably uplifted before the tephra of Cinder Hill was deposited upon it. It was then further eroded, partly buried by younger gravel, which also overlies some of the tephra masses. One of the tephra masses at about 200 feet elevation is cut by a shoreline of Lake Manly and partly buried by beach gravel. Shorelines exist at higher levels on the old gravel but none is obvious below 200-feet elevation in this small area (Figure 2).

The old gravel is tilted gently eastward. It is moderately deeply dissected and its flanks are partly buried by younger gravel deposits. Still younger gravel deposits are preserved along the flanks of modern channels, which are occupied by the youngest gravel deposits. In this area, all but the modern gravel in stream channels are cut by normal faults related to the Death Valley fault zone (see map of Wright and Troxel, 1984).

The tephra deposits consist of well-layered coarse to medium tephra. Layers are planar and parallel to the surface upon which the tephra was deposited. The strike and dip of the layers in the tephra are a record of the orientation and slope of stream channels or other surfaces in existence when the tephra came to rest.

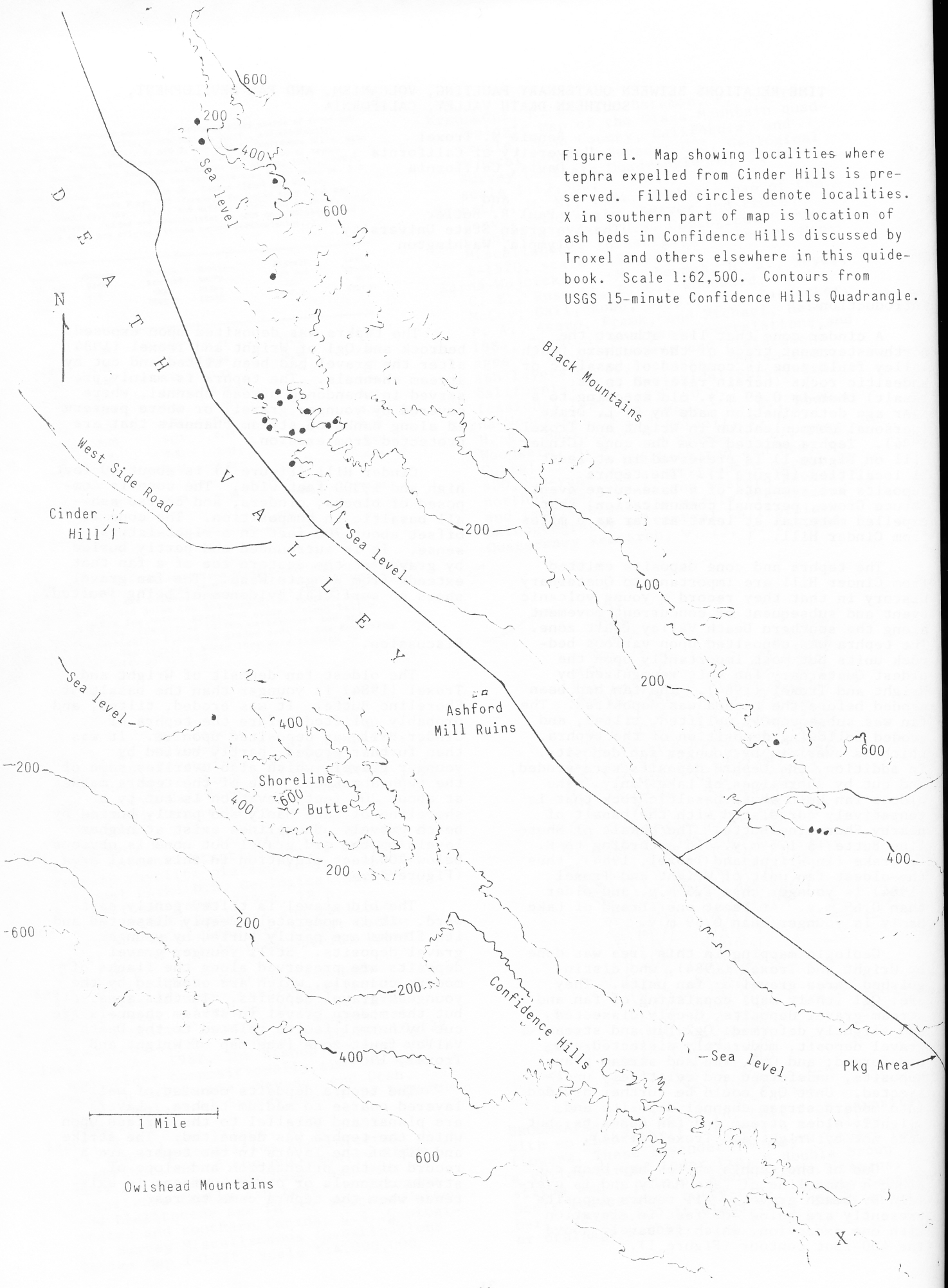

Figure 1. Map showing localities where tephra expelled from Cinder Hills is preserved. Filled circles denote localities. X in southern part of map is location of ash beds in Confidence Hills discussed by Troxel and others elsewhere in this guidebook. Scale 1:62,500. Contours from USGS 15-minute Confidence Hills Quadrangle.

Most outcrops of tephra are less than a few hundred feet in maximum areal extent and rarely more than three or four feet thick. Many are overlain by reworked tephra and many contain remarkably well-preserved worm trails filled with castings (P. E. Cloud, oral communication). Most trails are horizontal or parallel to layering. Some trails connect to nearly-vertical components. These occurences could be confused with buried roots and stems of plants. The tubes are circular in cross section and erratic in orientation. The tubes range in diameter from about half an inch to a quarter of an inch. The worm trails invariably are preserved on the walls of a channel--never in a trough.

The tephra ranges in color from dark gray to mustard yellow, but mostly is medium gray. Most of the fragments are scoriaceous in texture. Beds are well layered and layers are persistent throughout the individual outcrop. Fragments range in size from a maximum of about ¼ inch to a minimum of the size of medium sand grains.

Several episodes of faulting have occurred in Death Valley since the various fans have been formed. The oldest fans are downdropped along the mountain front on the east side of Death Valley and are tilted. The next younger fans are downdropped relative to the oldest fans and also are tilted, but less so than the oldest fans. The still younger fans are also downdropped but have not apparently been tilted. The modern stream channel deposits are not cut by normal faults in this area. Similar fault-fan relations abound along the east margin of south-central Death Valley. Most of the faults have west-facing scarps that are only slightly eroded. Only in active stream channels are the scarps destroyed or deeply eroded. The scarps range in height from about ten feet to a few inches.

The volcanic cinder cone formed along the northern segment of a branch of the Death Valley fault zone. The fault zone extends about 30 miles southeast of the cinder cone but has no surface expression northwest of the cone. The cone is bisected by the fault and is offset about 700 feet by right-lateral slip. Because the fault trace is not exposed in the gravel of the fan that extends eastward from Wingate Wash, movement was probably no later than the formation of the next to youngest fan.

Sequence of events.

The Quaternary history in the local area commenced with the formation of the oldest fan following uplift of the Black Mountains along normal faults that were active in late Tertiary time. Subsequent fans also were developed during a span of time in which more faulting occurred. Lake Manly existed some time after deposition of the oldest fan and perhaps before the volcanic cinder cone and ash were formed. Right lateral slip occurred following eruption of the volcanic rock. Fan deposits buried segments of the volcanic ash and probably formed around the base of the cone at Cinder Hill. Normal faults offset all but the youngest deposits.

Significance

It is clear that fan development in Death Valley has been accompanied by several episodes of normal faulting and at least two episodes of lateral faulting (one before the formation of the cinder cone and one afterwards). Volcanism preceded the final dessication of Lake Manly. Further normal faulting occurred after volcanism and the dessication of Lake Manly. It is not clearly established that volcanism and faulting have ended in Death Valley.

Site for field trip visitation.

An outcrop of the Cinder Hill tephra preserved near the paved road in Death Valley is ideal for observation (Figures 1 and 2). It lies about 1.5 miles northeast of Cinder Hill. It can be reached by traveling about 1½ miles north from the point where the West Side road joins the paved road. The deposit lies on the north side of a stream channel about ½ mile from the paved road (Figure 2). The stream channel can be identified as the one that lies immediately north of the northernmost outcrop of black basalt that crops out east of the pave road.

In this area, four identifiable gravel units can be identified. From youngest to oldest they are: Modern stream channel deposits; Fans marked by surfaces that are 3 to 6 feet above the level of the stream channels (locally dissected and faintly varnished)- this unit is cut by a fault (Figure 2); The next older unit is fan gravel, that here lies over the tephra at the westernmost extent of the north bank of the stream channel (it is extensively eroded and has desert paved and varnished surfaces elsewhere); The oldest unit lies beneath the tephra at this locality. It is deeply dissected and tilted. Shorelines of Lake Manly are preserved on it at elevations of 200 feet and higher in this area.

A tephra deposit is preserved on the north wall of the older segment of the modern stream channel. The tephra rests unconformably upon the oldest gravel deposit. It is overlapped to the west by the next younger gravel deposit. It's down-dip projection to the south is overlapped by the next-younger gravel unit, which, in turn, is cut by the modern stream. Slightly upstream, the tephra is exposed on the west-facing portion of the old stream channel.

The south-dipping segment of the tephra preserved on the north wall of the stream channel is typical of many of the other 20 remnants preserved in this area (Fig. 1). It lacks evidence of worm borings and overlying reworked tephra. Details of the layers of tephra are well preserved as is the contact of the tephra and underlying old gravel. The angular unconformity of

Figure 2. Vertical aerial photograph of large fan extending west from the Black Mountains. Lower edge of photo is barely north of point where West Side Road joins main paved road. Dark outcrops barely east of road are basaltic rocks preserved along east side of normal faults. Traces of young faults that cut very young gravel are denoted by white linear traces on photo. Main mass of uplifted fan east of basalt is composed of gently-eastward-tilted old fanglomerate (Qg1 of Wright and Troxel, 1984). Tephra deposit discussed in text is denoted by arrow. Road trends approximately N40°W.

the tephra and underlying and overlying gravel units is particularly well preserved.

While examining the tephra please be careful to avoid walking upon it. The tephra is poorly cemented at best and heavy traffic upon it will soon destroy the outcrops.

Acknowledgements

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LESSER MOHAVEA means "short flowered". Actual size above. Sticky clusters of dark olive leaves around ½ in. yellow five-lobed tube flowers with "monkey faces". 2 to 8 in. tall plants grow in southern drainage washes. March-April. 250-3500 ft elevation. Grows along with Gravel Ghost and Phacelia.

High altitude oblique photograph of northern part of southern Death Valley. Photo taken from point above southernmost Greenwater Range north of Shoshone. Greenwater Valley, Black Mountains, Death Valley, Owlshead-Panamint Mountains occupy lower two-thirds of photo. Sierra Nevada in upper right part of photo. The Garlock fault underlies the diagonal valley at upper left and extends towards small cloud mass at top center of photo.

Death Valley fault zone flanks both sides of Confidence Hills (center of photo) and terminates in Cinder Hill (small dark spot in valley floor to right of Shoreline Butte in Confidence Hills). Mormon Point lies at point on left margin of embayment of Death Valley into Black Mountains. U.S. Geological Survey photograph.

SIGNIFICANCE OF QUATERNARY FAULT PATTERN, WEST SIDE OF THE MORMON POINT TURTLEBACK, SOUTHERN DEATH VALLEY, CALIFORNIA; A MODEL OF LISTRIC NORMAL FAULTS

Bennie W. Troxel
University of California,
Davis, California

Introduction.

Quaternary listric and planar normal faults that join downwards with a gently west-dipping planar fault are exposed in the walls of a small drainage channel on the west flank of the Mormon Point turtleback. The canyon is one mile south of Mormon Point. It's mouth is marked by a west-facing fault scarp a few feet west of the mountain front. Gravel in the north wall at the mouth of the canyon contains interbedded pale-colored silt that may help you to identify the appropriate canyon .

The canyon is one mile south by road from Mormon Point or 8.2 miles north of the junction of the West Side road with the paved road. It lies .3 mi north of mileage marker sign 36 and .5 mi south of mileage marker sign 37. A sign denoting curves in the road farther north on the paved road is posted a few tens of yards north of the canyon mouth. Parking facilities are limited along the road.

Geologic background.

The Basin and Range Province, in which Death Valley is situated, has long been known to be the loci of abundant normal faults. In the past few decades it has been demonstrated that extension has resulted from movement along normal faults. Work in Death Valley has resulted in recognition of major nearly horizontal faults that extend through moderately large areas (see, for instance, Hunt and Mabey, 1966; Wright and Troxel, 1984; and others).

Associated with the main faults are swarms of more-steeply dipping faults that merge downward and join the main faults. The steeper faults are commonly curved in plan view or in cross section but can be planar. The turtlebacks of Death Valley (Otton, 1974; Drewes, 1966) are also related to extension in the region (Wright and others, 1974).

Only by detailed mapping can the relations of the more steeply-dipping faults and the nearly horizontal faults be demonstrated. The subject canyon of this report provides easy access to a small example of the relations of the faults.

The main fault exposed in the canyon walls (Figure 1) is a segment of the Mormon Point turtleback (Otton, 1974). During Miocene time major movement of Tertiary sedimentary and volcanic rocks were transported northwestward on the turtleback faults (see Wright and others, 1974, for instance).

Subsequent to the Tertiary movement the turtlebacks have been exhumed by erosion of the broken and faulted overriding material. The exhumed Mormon Point turtleback fault has since been partly covered by Quaternary fan gravel. Further faulting has occurred, resulting in relative down dropping of the central Death Valley and uplift of the Black Mountains.

Along the Mormon Point turtleback, Quaternary normal faulting has resulted in renewed movement along part of the turtleback fault. Extension of the Quaternary gravel has been accommodated, in part, along the steeper normal faults above the turtleback fault. Even later Quaternary (perhaps Holocene) faulting has resulted in further down dropping (valley side down). Many small scarps are preserved in present-day fans derived from the Black Mountains (Figure 2).

Discussion of canyon wall.

Figure 1, a diagrammatic sketch of the north wall of the subject canyon, demonstrates the fault pattern so commonly developed during Miocene and younger extension in the Death Valley region. The bedrock beneath the turtleback fault is here composed of Precambrian marble (Otton, 1974). Elsewhere in the Mormon Point turtleback the marble is underlain by foliated Precambrian gneiss and both are intruded by Mesozoic (?) diorite (Otton, 1974). In the easternmost segment of the canyon wall (Figure 1) the degree and style of deformation of the marble can be observed. The marble is distended by numerous small faults and fractures which result in lens-shaped masses oriented as illustrated diagrammatically in Figure 1. Exposures of the marble are best in the canyon walls beneath the dry falls (where the sketch terminates). One can see a certain amount of lessening of deformation of the marble downward from the turtleback fault. The presence of at least one slightly-steeper fault in the marble demonstrates that extension has occurred beneath the turtleback fault as well as above it. Faults abound above and below the main planes of extension elsewhere in the Death Valley region (see, for instance, Wright and Troxel, 1984).

Brecciation of the overriding rocks is common along the plane of the turtleback faults but here the fault breccia of previous movement has been removed by erosion. The Quaternary gravel has probably been transported only a short distance and is relatively thin, hence is little brecciated.

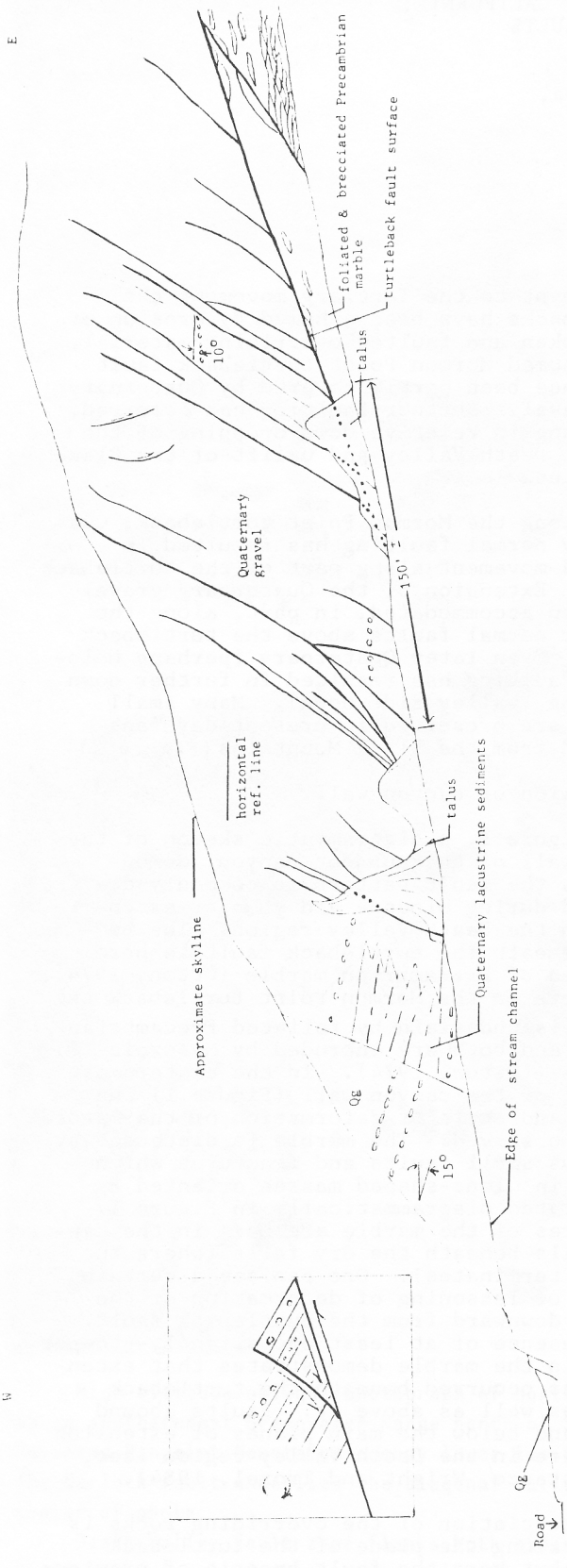

Figure 1. Diagrammatic sketch of north wall of a drainage channel on the west side of the Mormon Point turtleback. Aligned circles denote approximate bedding planes in gravel. West-dipping faults have normal movement (down to the west) as does the turtleback fault with which they merge. A few east-dipping faults have down-to-the-east movement. Fault pattern suggests that some faults are listric (flatten downward), others are planar, and still others are concave eastward even though they dip to the west. Most of the steeply-dipping faults flatten abruptly westward within a few inches of the point where they intersect the turtleback fault. Not to scale.

The fault planes in the Quaternary gravel are remarkably parallel in the canyon walls. They appear, for the most part, to be planar rather than listric (shovel shaped). However, some clearly flatten downward within a few feet above the turtleback fault. Most of them flatten abruptly within a few inches above the turtleback fault.

Throughout the Death Valley region, rotation commonly is associated with extension along the normal faults. In the left

Figure 2. Vertical aerial photograph of part of west flank of Mormon Point turtleback. Sun is low on west horizon. Mormon Point is barely beyond upper (north) limits of photo. White lines in fans are west-facing fault scarps. Arrow denotes canyon discussed in text. Photo courtesy D. B. Slemmons. Scale 1:12,000.

(western) half of this exposure, beds dip gently eastward (Figure 1), which is to be expected with west-dipping listric faults (see inset, Figure 1). Bedding in gravel in the center of Figure 1 is approximately horizontal and to the right dips gently westward. If one assumes that the gravel had an initial dip westward in a fan, then the gravel has been tilted downward in a clockwise sense as viewed in a northward view. The lacustrine beds in the sketch must have had no initial dip hence record about 15° of rotation during transport.

Small arcuate east-dipping faults high in the wall of the canyon are rare but predictable results of infilling voids created during westward transport. These features are analogous to small blocks that fall in the breakaway zone at the head of a landslide mass.

One other feature is demonstrated here that is common elsewhere with extension in the Death Valley region. That is that younger rocks are transported over older rocks. This phenomenon is common in all of the turtlebacks and in the Amargosa chaos immediately to the south (see Wright and Troxel, 1984).

Lacking in this scale model of extension on normal faults is any evidence of folding during extension. Although rare, folding accompanies extension in some areas, especially if the main lower fault curves upward and results in local compression.

Lastly, younger faults at the front of the range here cut very young gravel that has emanated from the small canyon. Two young fault scarps are shown on Figure 1 between the road and the mountain front.

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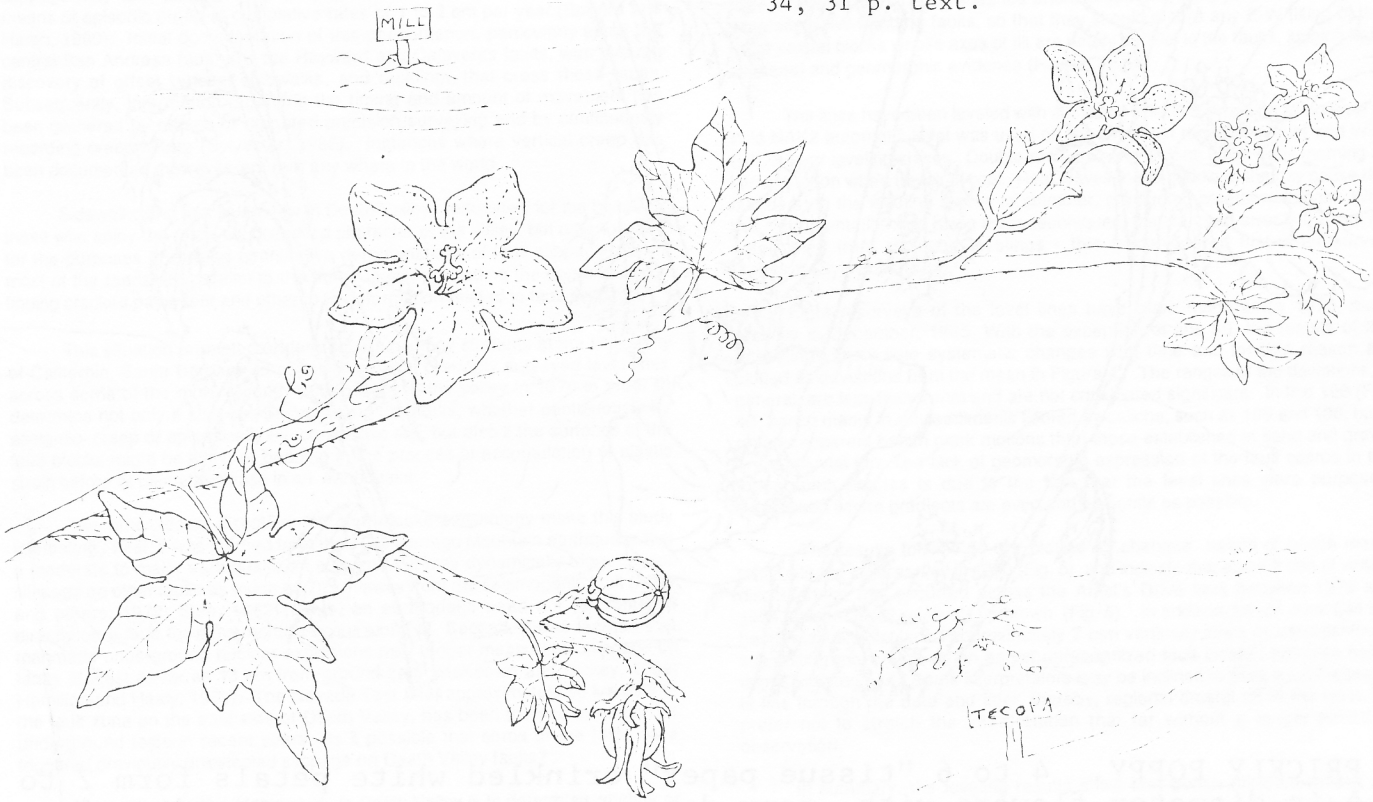

COYOTE MELON. Some of the 2 to 4 in. long cream to yellow flowers develop into 3 in. diameter dark green striped gourds, which dry to a pale cream color. 1 to 3½ in. pale olive green leaves with white veins grow on a burred 4 to 6 ft vine. Sand and gravel on valley floors and washes below 4000 ft elevation. June-August.

PRICKLY POPPY. 4 to 6 "tissue paper" crinkled white petals form 2 to 4 in diameter flowers with many deep yellow stamens surrounding 3 to 6 green stigmas in the center. Yellow spines on the leaves. Pale blue green branching stems and bud calyxes. 2 to 3 ft tall. April-July. 1400-3500 ft elevation. Stem milk and foliage are poisonous.

GEODETIC MONITORING OF FAULT MOVEMENTS IN DEATH VALLEY 1970 - 1985

by

Arthur G. Sylvester and Scott W. Bie

Department of Geological Sciences
University of California
Santa Barbara, California 93106

Death Valley has long been known as one of the best areas in California to see geomorphic evidence of recent faulting related to regional tilting of major crustal blocks. The asymmetrical deposition of salt flat sediments along the eastern side of the central part of the valley, the relatively small alluvial fans at the mouths of canyons issuing from the Black Mountains, and the enormous apron of coalescing fans of the Panamint Mountains on the west side of the valley indicate the presence of a major fault boundary between the easterly tilted Panamint Mountains and Black Mountains blocks (Hunt and Mabey, 1966). Fault scarps, crushed rock, and fault gouge along the steep western front of the Black Mountains confirm the presence of a major fault zone there as well as the recency of activity along it (Hunt and Mabey, 1966). Indeed, some of the scarps are so sharp and look so fresh that one might conclude that they were produced within the last few years and have only been modified subsequently by floods from occasional cloudbursts (Fig. 1).

Death Valley is located within the western part of the basin and range province, one of the most earthquake-prone areas in the United States. However, there is no record of a damaging earthquake occurring in Death Valley within historic time (Hunt and Mabey, 1966, p. A100). Nevertheless, the geologic and geomorphic evidence of geologically recent faulting invariably raises questions about the likelihood of a major earthquake occurring in the valley in the near future.

Recent studies elsewhere in California, however, have shown that fault slippage may take place without earthquakes. Horizontal slippage occurs by means of episodic creep at cumulative rates of 1 to 2 cm per year (Burford and Harsh, 1980). Initial documentation of this phenomenon, particularly along the central San Andreas fault, and the Hayward and Calaveras faults, was through discovery of offset fences, sidewalks, and buildings that cross these faults. Subsequently, information regarding the timing and amount of movement has been gathered by means of repeated precision surveying and by continuously recording creepmeters (Sylvester, 1986). Instances where vertical creep has been documented, however, are rare any where in the world.

Sidewalks and fences are few in Death Valley, fortunately for the benefit of those who enjoy the relatively unspoiled character of the valley, but unfortunately for the purposes of making quantitative determinations of fault slippage. Even most of the roads are parallel to the major faults, precluding the opportunity for finding cracked pavement and other road deformation related to fault slippage.

This situation prompted undergraduate geology students at the University of California, Santa Barbara, to establish several precisely surveyed level lines across some of the more recently active faults in the valley in 1970 in order to determine not only if slippage occurs along the faults, whether continuously by aseismic creep or episodically by co-seismic slip, but also if the surfaces of the fault blocks might be tilting or bending in the process of accumulation of elastic strain before its ultimate release in an earthquake.

Two other recent discoveries in earthquake seismology make this study interesting. First, it was learned from the 1968 Borrego Mountain earthquake that a moderate to major earthquake on a given fault may dynamically trigger minor slippage on other faults as much as 70 km away from the seismogenic fault (Allen and others, 1972; Sieh, 1982). Thus, an earthquake need not be centered directly on a fault for movement to occur along it. Second, it was learned that manmade underground nuclear explosions may trigger measurable slippage on faults at least as far as 13 km from ground zero (McKeown and Dickey, 1969; Hamilton and Healy, 1969). The Nevada Test Site, approximately 50 km east of the fault zone on the east side of Death Valley, has been the site of numerous underground tests in recent years. Is it possible that some of the tests have triggered previously undetected slippage on Death Valley faults?

Thus, the objective of this study in Death Valley is to determine whether or not slippage is taking place on some of the more obvious recently active faults, and if so, to measure the vertical component of that movement and to understand its causes. The students realized at the outset that this was not a one or two year project, that fault slippage is a geologic phenomenon and, as such, operates on a geologic time scale. For example, average geologic rates of tilting in Death Valley (280 microradians/1000 years, Hooke, 1972) are small and difficult to detect confidently over the relatively short period (15 years) of our survey. Thus, if tilt were continuous at the average geologic rate, then in 15 years, the cumulative tilt would be equal to 4.2 microradians, a value which can be detected under very carefully controlled surveying (Sylvester, 1984).

In fall 1970, precision level lines were established across several of the most recently active faults in the central part of the valley (Fig. 2). These include: 1) the Artist's Drive fault in two locations north and south of Furnace Creek on the east side of the valley, and 2) the Hanaupah scarp on the west side of the valley near Shorty's Well. A level line and triangulation array were established across the Furnace Creek fault zone at Triangle Spring, north of Stovepipe Wells, in an attempt to determine both vertical and horizontal slippage on a major fault which, from geologic evidence, appears to be a major strike-slip fault. An additional line across the Furnace Creek fault zone was established in 1971 in the southern end of Fish Lake Valley north of Death Valley (not shown in Fig. 2). All the lines have been resurveyed several times since 1970 to evaluate bench mark stability, attainable precision and, of course, to determine whether or not systematic height changes have occurred that can be related to fault slippage or regional crustal tilt.

Each level line, ranging in length from 300 to 500 m, consists of a series of bench marks from 10 to 50 m apart. The bench marks are 1 cm diameter,1-1/2 m long copper-weld rods which are either driven their full length solidly into the ground, or are cut into 6 cm long sections that are cemented in holes drilled into large boulders (Fig. 3). The lines are oriented approximately perpendicular to the generally NNW-trending faults, so that they should record any E-W tilting of the major crustal blocks whose axes of tilt are nearly parallel to the faults, judging from structural and geomorphic evidence (Hooke, 1972).

The lines have been leveled with a shaded Wild N-3 precision tilting level (a Wild NAK2 automatic level was used on the two most recent surveys) and Wild GPL-3 invar leveling staves. Double-run surveying is done in the early morning or late afternoon when the air is cool. Heat waves in the middle of the day cause the numbers on the leveling staves to shimmer, precluding careful readings. With this instrumentation and using these techniques, the standard error is 0.2 mm as determined from replicate levelings - this is considered first-order survey precision (Sylvester,1986).

Eight resurveys of the level lines have been made since 1970, most recently in December, 1985. With the exception of line 50, the results of the relevelings show little systematic changes with time and for that reason are plotted as deviations from the mean in Figure 4. The ranges of the deviations, in general, are less than 1 mm and are not considered significant. In line 100 (Fig. 4B, bench marks in silty sediments floored by caliche, such as 105 and 106, have greater apparent bench mark motions than those established in sand and gravel or the alluvial fan. The lack of geomorphic expression of the fault scarps in the topographic profiles is due to the fact that the level lines were purposely established where gradients are even and as gentle as possible.

The results for line 50 are plotted as changes height of bench marks relative to the initial survey in 1970 (Fig. 5) and indicate that about 2 mm of vertical displacement has occurred across the Artist's Drive fault between 1978 and 1984, eastern block relatively upthrown (Fig. 5). In addition, bench mark 544 has been relatively displaced approximately 7 mm vertically since its establishment, suggesting movement on an as yet unrecognized fault located between bench marks 543 and 544. Some interpretators may be inclined to pass a least-squares fit line through the data and infer, thereby, regional crustal tilt to the west; we prefer not to stretch the interpretation that far without a longer period of observation.

In summary, the leveling results show that bench mark elevations are highly reproducible from survey to survey over a 15 year period, and only line 50 shows permissive evidence of systematic height changes over time indicating fault offset or tilting of a alluvial fan surface. The data also show that boulders, as small as one-half meter square, on the surface of alluvial fans are very stable and serve admirably as platforms for bench marks.

Clearly the value of this study will increase with time as a long-term record is built up over many years. If the fans are tilting as the geologic data (Hooke, 1972) and tiltmeter data (Greene, 1966) suggest, then future leveling should become increasingly significant. Inasmuch as fault slippage in general is commonly episodic elsewhere, it will certainly require more than 15 years to document the phenomenon conclusively, if, in fact, we are fortunate to note it at all in our own lifetimes.

ACKNOWLEDGMENTS

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Fig. 1. Scarp of Artist's Drive fault at the foot of the Black Mountains on the south side of Furnace Creek fan, 2 km south of Furnace Creek. The far (north) end of the scarp is buried by alluvial debris washed from a large canyon that has pirated the drainage from Furnace Creek Wash. The scarp is dissected by small gullies from small washes on the right. This scarp can be followed continuously for more than 5 km southward along the front of the Black Mountains. Locally Indian mesquite storage pits are built on colluvium that overlaps the scarp, showing the scarp is prehistoric (Hunt and Mabey, 1966, p. A100).

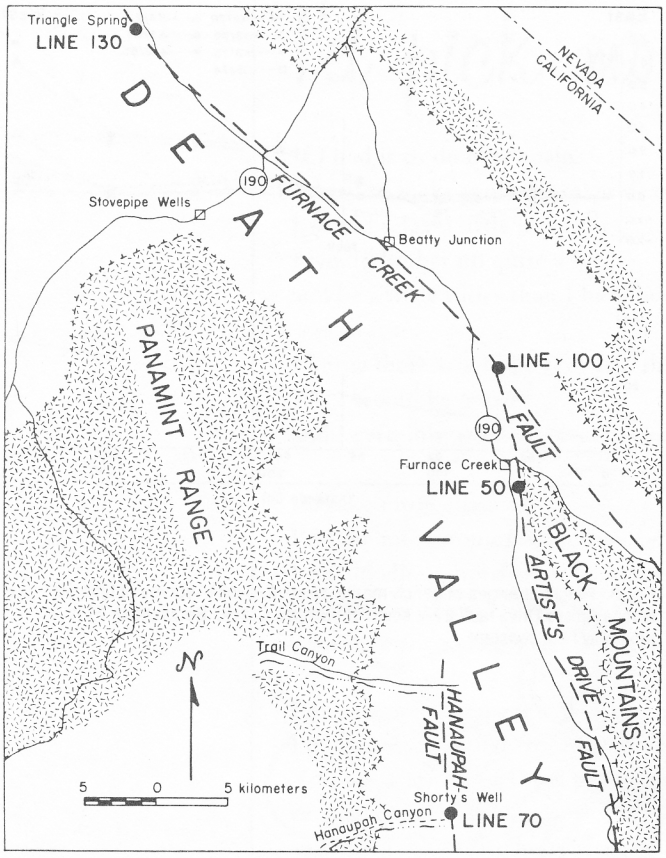

Fig. 2. Location map of principal faults and UCSB precision level lines in Death Valley.

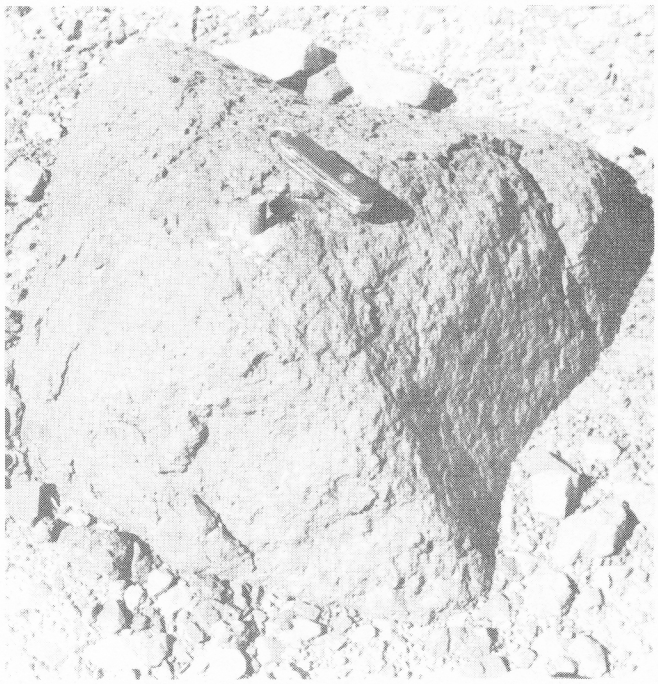

Fig. 3. Top of short, copper-jacketed weld rod projects 2 cm above the surface of a boulder on the surface of alluvial fan. This kind of bench mark is quite stable. Pocket knife for scale.

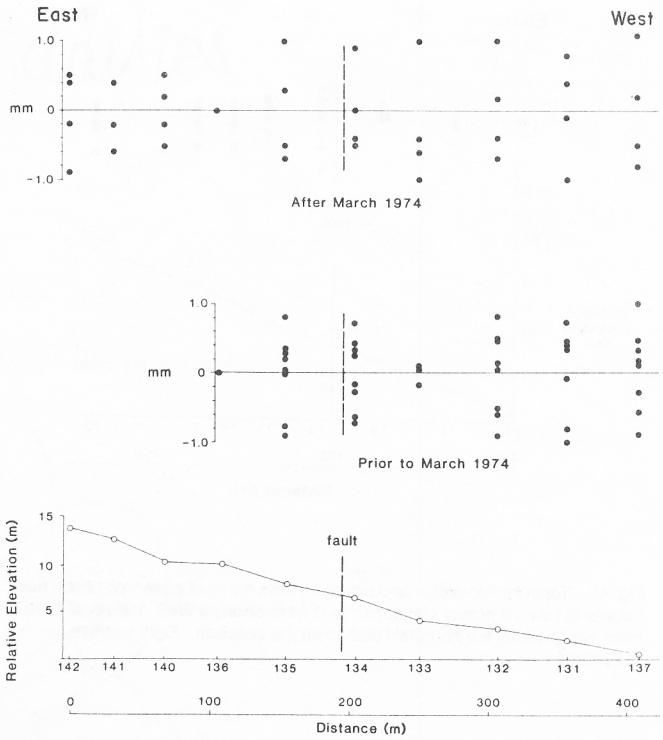

Fig. 4A. Topographic profile and deviation from mean of observed bench mark heights of Line 130 across Furnace Creek fault at Triangle Spring. Individual bench mark designations are numerals plotted on the abscissa. Eight surveys, 1970-1985.

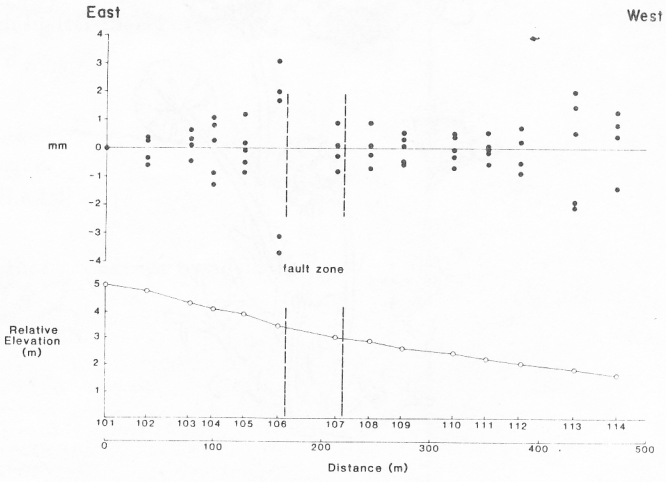

Fig. 4B. Topographic profile and deviation from mean of observed bench mark heights of Line 100 across Artist's Drive fault, 7 km north of Furnace Creek. Individual bench mark designations are numerals plotted on the abscissa. Five surveys, 1970-1985.

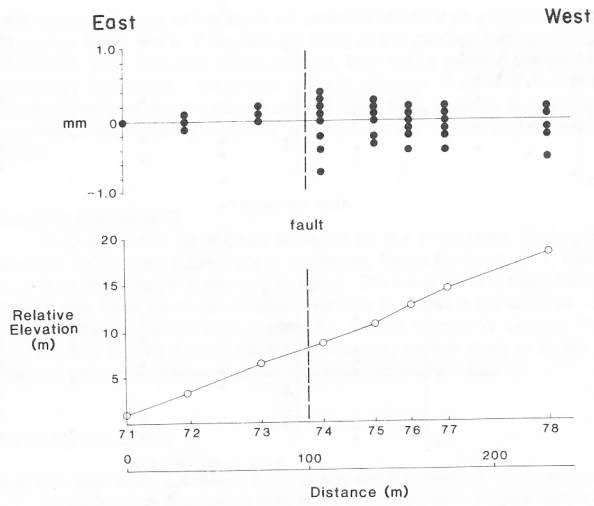

Fig. 4C. Topographic profile and deviation from mean of observed bench mark heights of Line 70 across Hanaupah fault near Shorty's Well. Individual bench mark designations are numerals plotted on the abscissa. Eight surveys, 1970-1985.

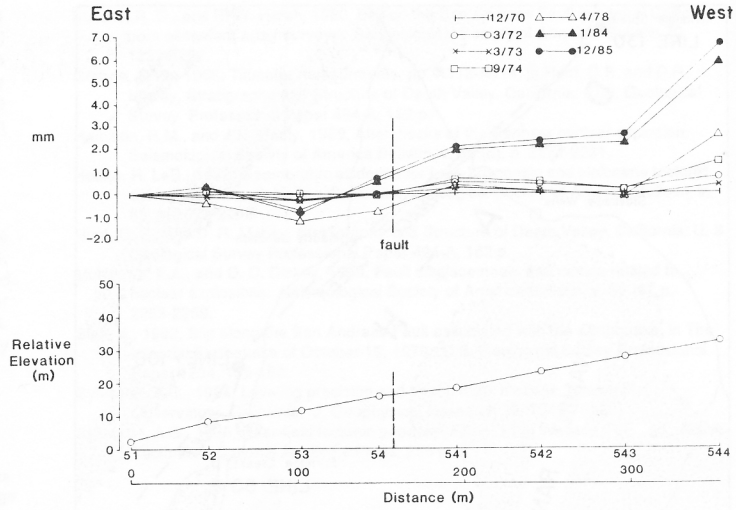

Fig. 5. Height changes of bench marks relative to initial survey of Line 50 across Artist's Drive fault 2 km south of Furnace Creek. Bench mark 51 is arbitrarily held constant.

BIGELOW COREOPSIS (left). Eight flat square-tipped yellow-orange petals, orange stamens, and small narrow shiny green bracts below petals. 6 to 16 in. tall. 2000-6000 ft elevation. Note the difference in leaves and triangular bracts above the olive green to pink stem of the CALIFORNIA COREOPSIS which has golden pleated petals and is 2 to 10 in. tall. -3600 ft elevation. It does not grow in the Monument. March-May.

I'd pick more daisies

If I had it to do over again . . .
I'd try to make more mistakes next time.
I would relax a little more,
I would limber up quite a bit,
and be a little sillier than I have been this trip.

I know there would be very few things I would take so seriously,
and I would be crazier,
and I certainly would be less hygienic.

I'd take more chances,
I'd take more nonsense journeys.
I would climb more mountains and swim more rivers and watch more sunsets.
I'd fuss less about myself and think a little more of the value of myself.
I would burn a great deal more gasoline.

I'd eat more ice cream and less beans.
I'd have more actual troubles and fewer imaginary ones.
You see, I'm one of those people who is highly organized . . .
very sane and sensible,
and that's why I live hour after hour and day after day.

Oh, I've had my moments . . . and if I had it to do over again,
I'd have more of them!
In fact, that's what I'd have most of . . . just moments . . . one after another,
instead of living so many years ahead of each day.

I have been one of those people who never go anywhere without a
thermometer, a raincoat, second this or that.
But if I had it to do over again,
I would go more places,
I'd get up and go quickly and travel much lighter than I ever have,
and I would go places I never dreamed I'd go.

If I had my life to live again,
I would start barefooted earlier in the spring,
and I would stay that way until later in the fall.
I would play hooky more,
and I wouldn't make such good grades either . . . except by accident.
I would ride more merry-go-rounds . . .
AND I'D CERTAINLY PICK MORE DAISIES.

Ah, if I had my life to live over again . . .
But, I do . . . . . each day!

Come with me . . . I want you to meet some daisies I know.

Poem by Nadine Stair
Stolen by Bonnie

MISSING LAKESHORES

A song on the subject of former lakes thought by some to have occupied Death Valley during the Pleistocene
By M. Reheis, J. Hardin, and A. Gillespie with the assistance of several others
(Sung to the tune of Poison Ivy")

He's been searching for those lake shores
Those mythical lake shores
He's been searching like a hound
For pebbles that should be semi-round

CHORUS:
Missing lake shores, missing lake shores
Every night while you're sleeping
Those waves come a' creeping
At your tent floor or or or ...

Nobody knows how big it grows
But everybody knows
That great Mojave River
Will set your mind all a' quiver

CHORUS:
Missing lake shores, missing lake shores
Every night while you're sleeping
Those waves come a' creeping
At your tent floor or or or...

Fans, they may be lumpy
Playas make you grumpy
Paleosols may make you jump and twitch
Carbonates may fool ya'
Ashfalls, they may cool ya'
But, Lord, those missing lake-shores are a bitch

You're going to need an ocean
Of water in commotion
You'll be searching like a hound
But we think they may never be found

CHORUS:
Missing lake shores, missing lake shores
Every night while you're sleeping
Those waves come a' creeping
At your tent floor or or or...

AN UNTITLED SONG HAVING TO DO WITH RESEARCH AND OTHER PURSUITS OF AN ACADEMIC NATURE (MORE OR LESS)

by
M. Reheis and J. Hardin with the assistance of several others
(Sung to the tune of "My Favorite Things")

Sitting in chairs and picking our noses
Cracking our knuckles and wiggling our toes-es
Flapping our arms when it's our turn to speak
My argument seems so pitifully weak

Sleeping through sessions and crossing our knees
Waking up only to backstab colleagues
Slandering friends and flattering foes
These are a few things that make my heart glow

CHORUS:
When I'm shown up, when I'm put down
When I look like a fool
I simply remember my favorite things
And then I just feel so COOL.

Ripping off rivals and publishing quickly
Others' ideas I package so slickly
Only my deans and my publishers know
This is the way that my stature grows

Feigning great interest in others' equations
Without understanding the whole situation
Missing the point and feeling quite glum
Frankly I'd rather be sucking my thumb
CHORUS:
When I'm shown up, when I'm put down
When I look like a fool
I simply remember my favorite things
And then I just feel so COOL.