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ABSTRACTS OF PROCEEDINGS
1988 Mojave Desert Quaternary Research Symposium

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by

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SAN BERNARDINO COUNTY MUSEUM

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Quaternary History of the Manix Fault,
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ABSTRACT

The Manix fault, in the eastern Mojave Desert, California, is a 38-kilometer-long, east-northeast-trending structure of uncertain sense of movement. Most evidence indicates that the predominant type of movement has been strike-slip, but geologic and geomorphic data that bear on the long-term sense of strike-slip movement are inconclusive.

Deformation related to movement on the fault is recorded by Plio-Pleistocene, Pleistocene(?) and middle and late Pleistocene lacustrine and fluvial sediments. Vertical movement on the fault resulted in local uplift and produced at least six local angular unconformities within the stratigraphic section. The positions of these angular unconformities within the section indicate that activity on the Manix fault began before the middle Pleistocene, and occurred throughout the middle and late Pleistocene and possibly later as well. Minor historical surface displacement across the Manix fault suggests that activity on the Manix fault has continued until the present.

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[1] Contribution No. 4732

INTRODUCTION

The Mojave province is a wedge-shaped block bounded by the left-lateral Garlock fault to the north and by the right-lateral San Andreas fault to the west. Within the Mojave block a majority of the faults trend northwesterly, parallel to the San Andreas fault, and have a right-lateral sense of movement. However, a significant number of faults, particularly in the northeast corner of the Mojave block, trend east or east-northeast parallel to the Garlock fault and have been conjectured to be left lateral (Garfunkel, 1974). The Manix fault, located in the east-central part of the Mojave block, is one of these east to east-northeast trending faults. It is exposed discontinuously for a length of 38 kilometers from the Calico fault on the west to Afton Canyon on the east (Figure 1).

A magnitude 6.2 earthquake occurred on or near the Manix fault on April 10, 1947. One to two inches of left-lateral displacement occurred along a two-mile surface trace of the Manix fault in association with this event (Buwalda and Richter, 1948). However, because the aftershocks of that earthquake aligned along a northwesterly trend, oblique to the Manix fault (Richter, 1947; Richter and Nordquist, 1951), it is not clear whether the earthquake was caused by rupture of the Manix fault or by rupture of an unidentified, northwest-trending, subsurface fault. The Pisgah fault (Figure 1), a northwest-trending fault exposed 19 kilometers southeast of the epicentral region, would nearly pass through the aftershock alignment if it were projected to the northwest (Keaton and Keaton, 1977). Gravity and magnetic surveys conducted by Hamilton (1982) indicate the presence of the Manix fault at depth, but the studies do not extend far enough east to determine whether or not there might be a deep, northwest-trending structure along the aftershock alignment. First motion data from the 1947 earthquake are consistent with either left-lateral strike-slip motion along the Manix

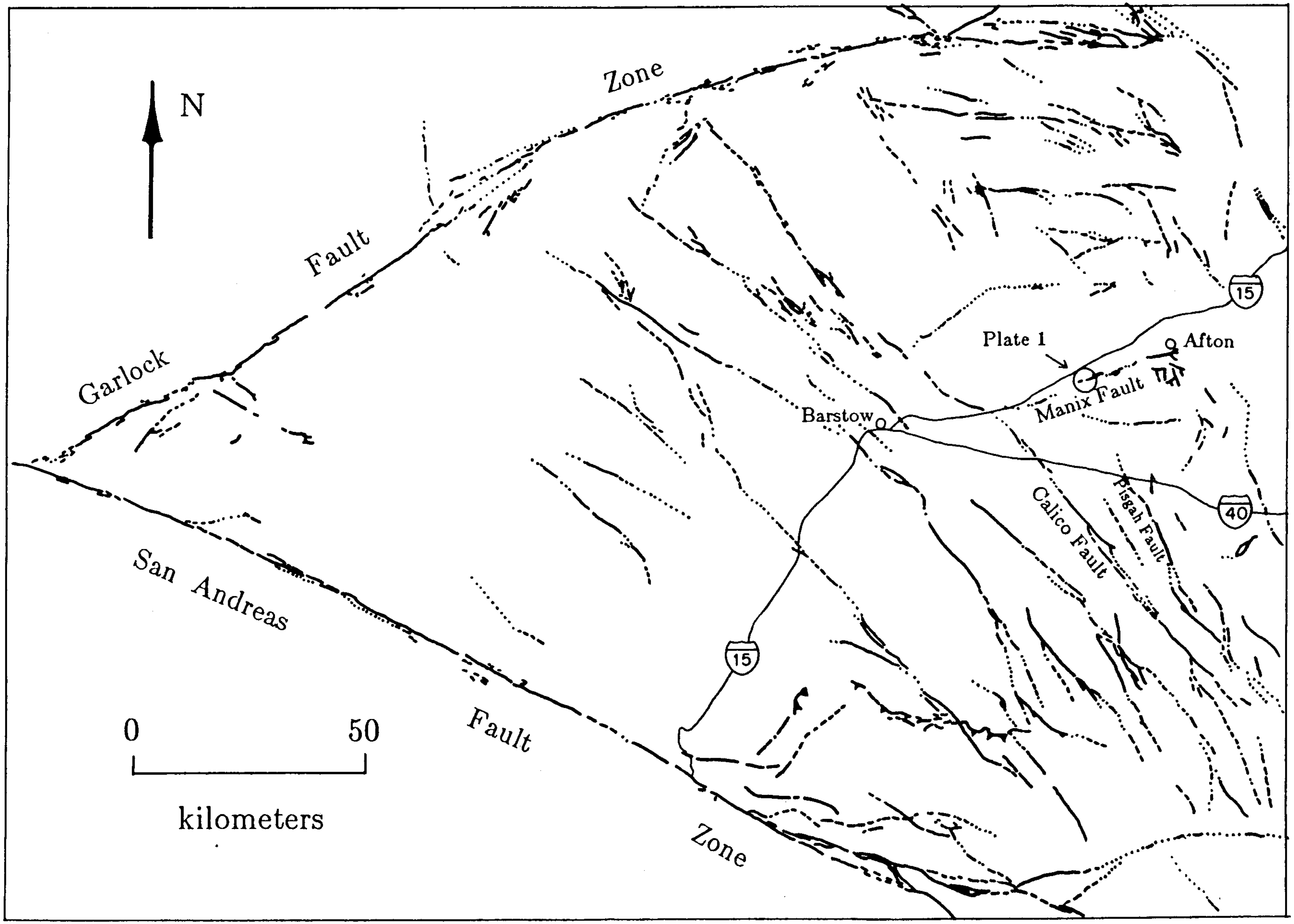


Figure 1: Quaternary faults of the Mojave block. (After Jennings, 1975).

fault, or with right-lateral strike-slip motion along a hypothetical, buried, northwest-trending fault (Richter, 1947; Richter and Nordquist, 1951).

The Manix fault passes through the basin of Pleistocene Lake Manix. The middle and late Pleistocene sediments within this basin partially record the history of movement on the Manix fault. The Mojave River and its tributaries have dissected this area, providing excellent exposure of the lake beds and of the Manix fault.

The Lake Manix beds were first recognized by Buwalda (1914). He suggested that two lakes had successively filled this basin and that changes in lake level were due to climatic and/or tectonic activity. Blackwelder and Ellsworth (1936), mapping in Afton Canyon, also suggested two lake events. They further implied that the first lake-stand ended due to dessication and that the second lake drained after down-cutting of Afton Canyon. They correlated these two lake-stands with glacial stages (Tahoe and Tioga) as did Winters (1954), although he inferred different stages (Illinoian and Tahoe). Jefferson (1968) described the Lake Manix beds in detail and informally named them the Manix Formation, a terminology which we here adopt. Jefferson (1985) suggested correlations between parts of the members of the Manix Formation and the marine oxygen isotope stages. His tentative correlations favor Winters's (1954) chronology.

Although the Manix Formation has been studied in a fair amount of detail, less attention has been paid to the Manix fault, which traverses the formation. The fault was first mapped by Buwalda (1914). The most comprehensive recent study of the fault was done by Keaton and Keaton (1977). They mapped the eastern half of the fault and described the relationships between units broken by the fault at a number of places along the fault zone, documenting the amount and sense of vertical offset at these sites. As with previous investigators, they found no consistent evidence for the sense of lateral displacement across the Manix fault zone.

This paper presents the results of a detailed study of the deformation of the Manix Formation in a small but critical area where the Quaternary record is both preserved and well-exposed. The study area lies near the epicentral location of the 1947 earthquake, and includes a portion of the segment of the Manix fault that exhibited minor, left-lateral displacement associated with that earthquake. This is the area surrounding Manix Wash, a tributary to the Mojave River, located southeast of the Manix railroad siding, 32 kilometers east of Barstow, California. Detailed mapping of individual members of the Manix Formation (Jefferson, 1968, 1985) in this area has provided information on the timing and style of deformation related to the Manix fault. In particular, a number of local angular unconformities were discovered within and between members of the Manix Formation that indicate repeated deformation before, during and possibly after deposition of the Manix Formation.

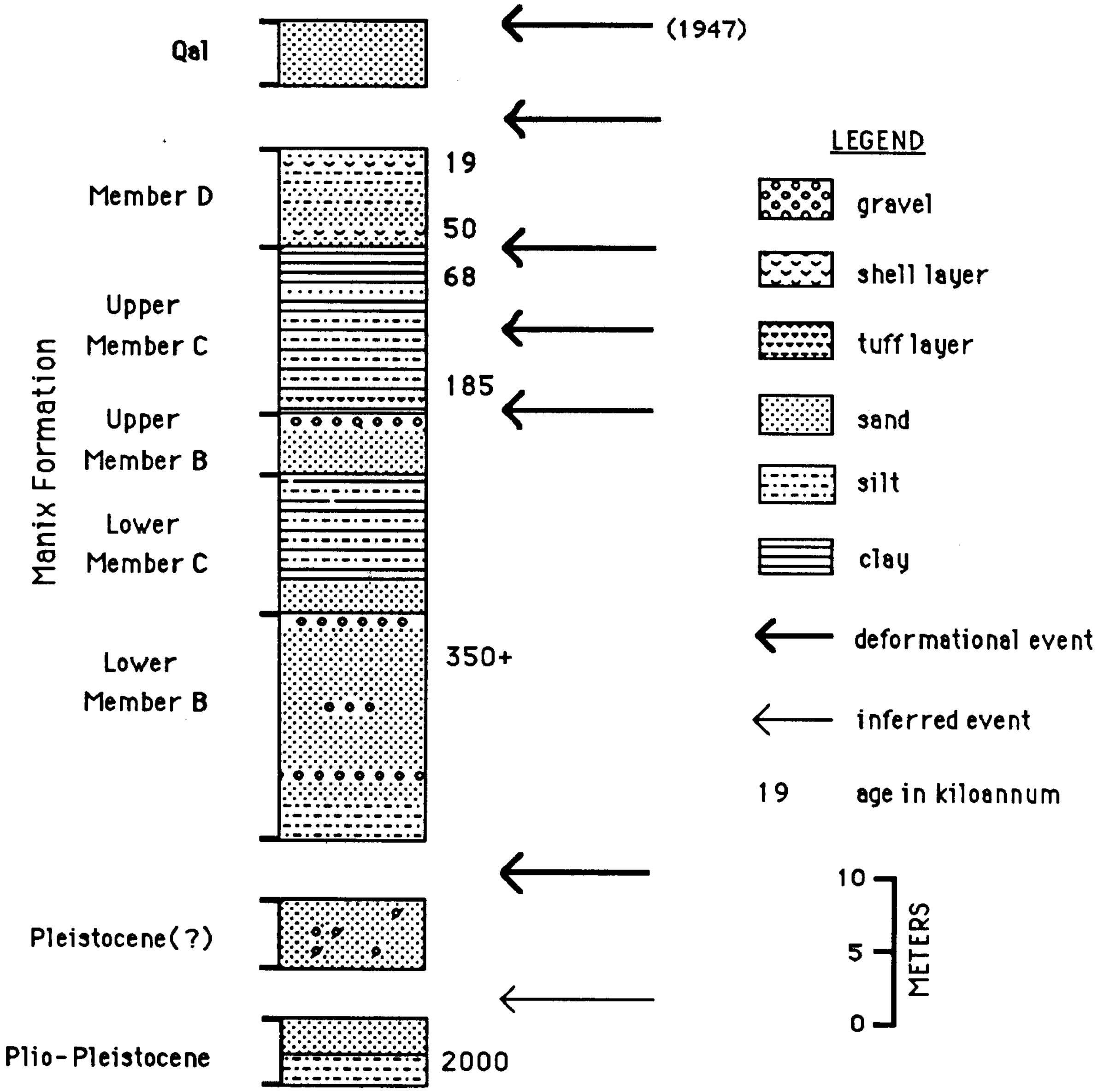
STRATIGRAPHY

The sedimentary rock units exposed in the mapped area include Plio-Pleistocene lacustrine deposits, Pleistocene(?) sediments, the middle and late Pleistocene fluvial and lacustrine Manix Formation, and younger fluvial, alluvial and aeolian deposits (Plate 1 and Figure 2). Since Jefferson (1968, 1985) described these sediments in detail only a brief summary is given below.

Plio-Pleistocene lacustrine sediments: The lower part of these sediments includes buff to red, gypsiferous siltstone. The upper part includes tan, medium- to fine-grained sandstone, with thin beds of white, well-cemented, calcareous, very coarse-grained, poorly-sorted sandstone, as well as minor amounts of interbedded brown, clayey slit, and gray-green silt. Three tuff beds are found in the

Figure 2

Stratigraphic column and events on the Manix fault system in the Lake Manix basin, Mojave Desert, California.



Reference column after Jefferson (1985).

Thicknesses of Qal, Pleistocene(?) and Plio-Pleistocene not to scale.

middle and upper part of the Plio-Pleistocene sediments (Jefferson, 1985). Two of these tuff beds have been dated at 2 million years BP (Christiansen and Black, 1972) and at 2.3 million years BP (Hay, 1966). Away from the Manix fault, the Plio-Pleistocene sediments are gently dipping, but they are steeply dipping near the fault.

Pleistocene(?) deposits: These deposits are composed of tan to light-green, medium- to fine-grained sand with minor pebbles. They crop out along the southwest side of Manix Wash, just north of the Manix fault zone. The Pleistocene(?) deposits underly lower Member B of the Manix Formation with slight angular unconformity and have uncertain relations to the Plio-Pleistocene sediments. However, within the fault zone, the Pleistocene(?) deposits have only a slight angular unconformity with lower Member B of the Manix Formation whereas the Plio-Pleistocene sediments underly the Manix Formation with a much greater angular unconformity. This difference in deformation indicates that the Pleistocene(?) deposits are probably younger than the Plio-Pleistocene sediments.

Manix Formation: The Manix Formation consists of interbedded lacustrine and fluvial sediments. Jefferson (1968, 1985) divided the Manix Formation into four, interfingering members, labeled A, B, C, and D. Members A and B consist primarily of coarse-grained sands and gravels. Member C interfingers with Members A and B and is composed of silt and clay. Overlying Member C is Member D, which is composed of silt and medium to coarse-grained sand (Jefferson, 1968, 1985). Jefferson's terminology is followed in this paper, but due to the interfingering of Members B and C, these two members have been divided into lower and upper parts, which are discussed separately. Member A is not exposed in the area covered by this study.

Manix Formation, lower Member B: This unit is widely-exposed in the mapped area, frequently forming broad terraces because of its greater erosional resistance than Member C of the Manix Formation. It is composed of moderately- to poorly-sorted, tan, arkosic, pebbly sand. It was probably deposited in a fluvial or deltaic environment. In many places, lower Member B is capped by a purplish-brown volcanic cobble layer. In some places the cobbles are tufa-coated, presumably marking the beginning of the first major filling of Lake Manix. An *Equus* ulna from about 9 meters above the base of lower Member B has been dated at >350 Kyr BP by U/Th techniques (Jefferson, 1985, via pers. com. from Bischoff, 1982, USGS 80-51). In the mapped area, lower Member B unconformably overlies both the Plio-Pleistocene sediments and the Pleistocene(?) deposits.

Manix Formation, lower Member C: Lower Member C is generally composed of light green silt that was presumably deposited during the first major filling of Lake Manix. Locally, however, lower Member C has a more varied lithology including red, blocky, gypsiferous claystone, green and white fine sand, and arkosic, pebbly sand, as well as laminated green silt. This more varied exposure of lower Member C, located on the southwest side of Manix Wash, just northwest of the mapped area, may represent a near-shore lacustrine environment, while the thick sequence of uninterrupted, green, silt beds exposed elsewhere may represent a deeper-water lacustrine environment. In most places lower Member C conformably overlies lower Member B, but just northwest of the northeast-trending fault strand in the northeast corner of the map (Plate 1) it overlies the Plio-Pleistocene sediments with angular unconformity.

Manix Formation, upper Member B: Upper Member B is composed of moderately- to poorly-sorted, tan, arkosic, pebbly sand. In some places it is cross-bedded. It was probably deposited in a fluvial or deltaic environment after the first stand of Lake Manix had drained or evaporated. In a few places upper Member B is capped by a volcanic cobble or pebble layer that is locally tufa-coated, but this layer is not as prevalent as the one capping lower Member B. Where present, this tufa layer probably records the initial filling of the second major stand of Lake Manix. Upper Member B conformably overlies lower Member C.

Manix Formation, upper Member C: Upper Member C is composed of light green silt, silty sand and fine-grained sand, that were probably deposited during the second major stand of Lake Manix. Locally it also contains some thin, oxidized sand layers, pebbly layers, and blocky clay layers. The presence of oxidized sand layers in upper Member C southwest of the mouth of Manix Wash (Jefferson, 1985), and the presence of gypsum in upper Member C near the south edge of the fault zone west of Manix Wash suggest that the lake level may have fluctuated during deposition of upper Member C, possibly causing brief periods of subaerial exposure.

A tuff layer near the base of upper Member C has been correlated, on the basis of trace element content, with volcanic vent rocks in the Long Canyon, Kern Plateau area of the southern Sierra Nevada (Sarna-Wojcicki, *et al.*, 1980). These vent rocks have been dated at 185 ± 15 Kyr BP (Sarna-Wojcicki *et al.*, 1980). This is consistent with a U-Th date of 183.8 ± 12.0 Kyr BP on a *Camelops* scapula fragment from 1.5 meters above the tuff (Jefferson, 1985 via pers. com. from Bischoff, 1982 USGS 81-30). In addition, a U/Th date of 68.0 ± 4.0 Kyr BP was obtained on a section of *Camelops* humerus found near the top of upper Member C (Jefferson, 1985, via pers. com. from Bischoff, 1982, USGS 81-51).

In many places upper Member C lies conformably on upper Member B, but near the southern edge of the Manix fault zone, west of Manix Wash, an angular unconformity separates the two units. There is also a local angular unconformity within upper Member C in this same area.

Manix Formation, Member D: Member D is composed of moderately-sorted, pink to orange, arkosic, pebbly sand. Just east of the mapped area the lithology changes somewhat to include a rounded-cobble conglomerate and a very well-sorted coarse sand. Member D is capped by a volcanic cobble layer near the eastern edge of the mapped area. East of the mapped area Member D was probably deposited in a beach environment, while elsewhere it may have been deposited in a fluvial or deltaic environment.

In many places Member D contains one or two layers with abundant *Anodonta* shells. Locally, however, more than two *Anodonta* layers are present. The shells are commonly stacked concentrically and may represent a storm surge deposit (Jefferson, pers. com., 1988). Where two *Anodonta* layers are present the lower layer has yielded two C-14 dates of >49 Kyr BP (Bassett and Jefferson, 1971) and >35 Kyr BP (Jefferson, 1985 via Berger, pers. com. 1982). In addition, U/Th dates on bone fragments from immediately below this *Anodonta* layer are 51.5 ± 2.5 Kyr BP and 47.7 ± 2.0 Kyr BP (Jefferson, 1985, via Bischoff, pers. com., 1982, USGS 81-49 and 81-48). Bischoff (pers. com., 1987, USGS 81-60) obtained a U/Th date of 74.5 $\pm^{2.9}_{2.5}$ Kyr BP on *Anodonta* shells from what was thought to be the same layer. However, the inconsistency of this date with the other dates mentioned above suggests that large uncertainties exist in the dates, that faulty correlations of the multiple *Anodonta* layers were made, or that the shells that provided the 74.5 Kyr age were redeposited along with the younger shells and bone fragments.

The upper *Anodonta* layer has been dated at 19.1 ± .250 Kyr BP by C-14 methods (Jefferson, 1985 via Pardi, pers. com., 1983, QC-1467).

Away from the Manix fault zone, Member D lies conformably upon upper Member C. Near the southern edge of the Manix fault zone west of Manix Wash, however, the two units are separated by an angular unconformity.

Quaternary alluvium: This unit includes fluvial deposits in the modern washes and in the modern channel of the Mojave River as well as wind-blown sand deposits. Near the west edge of the mapped area there may be a slight angular unconformity between the alluvium and the underlying Member D.

DEFORMATION

General description of deformation: Several strands of the Manix fault trend roughly east-west through the mapped area (Plate 1). Where exposed, these fault strands are vertical or dip greater than 65 degrees to the north. Within the mapped area, vertical displacement of the members of the Manix Formation across the Manix fault strands is typically less than 10 meters. However, locally (*e.g.* between two of the northern fault strands west of Manix Wash) gypsiferous beds of the lower part of the Plio-Pleistocene sediments are juxtaposed against the beds of the Manix Formation, suggesting that more than 20 meters of vertical slip probably occurred locally on these fault strands to produce the elevated fault slice of Plio-Pleistocene sediments.

The sense of vertical movement is recorded both by stratigraphic throw across the fault and by fault scarps. Both of these types of data indicate that the sense of vertical separation across the fault varies along strike. The sense of vertical separation also appears to have varied in time at a few locations, where the sense of vertical separation recorded by fault scarps is opposite that given by the stratigraphic throw. These variations indicate that either the sense of vertical slip on the fault has varied along strike and in time, or that an unknown component of lateral slip on the fault has produced variations in the apparent vertical offset across the fault. Despite the variable nature of apparent vertical offset, the general geometry of faulting in the mapped area is that of several south-side-up flexures and fault blocks, with fault planes dipping vertically or steeply to the north.

A series of gentle folds and warps, generally trending east-northeast, is also present within the Manix Formation within a narrow band parallel to the fault zone (Plate 1). Away from the fault, however, the lake beds are undeformed.

Sense of fault motion: The sense of motion on the Manix fault is still uncertain. However, the following lines of evidence suggest that the dominant mode of movement has been strike-slip. (1) The fault zone is long and relatively straight, with anastomosing strands. (2) The fault surfaces all have steep dips. (3) Vertical displacement is minor, and its sense changes both along strike and temporally. (4) There is no consistent topographic relief across the fault. (5) Small folds are present subparallel to the fault zone, with fold axes rotated by 15 to 35 degrees from the strike of the fault zone, as is typical of many wrench faults (Wilcox *et al.*, 1973).

Unfortunately, no good piercing points showing the amount and sense of horizontal offset across the fault have been found. Although many gullies and channels show peculiar drainage patterns where they cross the fault, they do not allow determination of the sense of horizontal displacement.

The folds present along the fault zone within the mapped area are consistently oriented with their axes rotated 15 to 35 degrees counter-clockwise from the strike of the fault zone (Plate 1). If the folds are the result of simple shear along a wrench fault zone, as described by Wilcox and others (1973), then the sense of shear implied by the fold orientations is *right* lateral. However, it is possible that the folds were produced by some other mechanism, such as convergence across the fault zone, as has been suggested for folds along the San Andreas fault zone (Zoback, *et al.,* 1988). It is interesting to note that folds in 600-Kyr-old sediments along the left-lateral Garlock fault in southern Searles Valley also have orientations consistent with either *right*-lateral shear parallel to the fault zone, or with compression directed at a high angle to the fault (Smith, 1986).

Although adequate geologic or geomorphic control on the sense of motion of the Manix fault is lacking, historical displacement across the fault has been left lateral. As mentioned earlier, Buwalda and Richter (1948) observed left-lateral slip of one to two inches on the Manix fault after the 1947 Manix earthquake. This historically-observed sense of slip may also be representative of the long-term sense of slip on the fault. Even if the left-lateral surface displacement was a secondary effect triggered by an earthquake on a buried, hypothetical, northwest-trending fault, the sense of such triggered displacement might still be expected to reflect the long-term sense of motion on the fault. In the Imperial Valley, California, where triggered slip has been observed a number of times on several different faults, the sense of the triggered slip has almost uniformly been the same as the long-term sense of slip on that fault (Allen *et al.,* 1972; Fuis, 1982; Sieh 1982; Sharp *et al.,* 1986; Williams *et al.,* 1988; McGill *et al.,* 1988).

Timing of deformation: Continued activity on the Manix fault before, during, and possibly after deposition of the middle and late Pleistocene Manix Formation is suggested by local angular unconformities near and within the fault zone between Plio-Pleistocene sediments and the Pleistocene(?) deposits (inferred), between the Pleistocene(?) unit and lower Member B of the Manix Formation, between upper Member B and upper Member C, within upper Member C, between upper Member C and Member D, and possibly after Member D but predating the Quaternary alluvium. In addition, numerous fault-related geomorphic features suggest recent movement on the fault. These include fault scarps, fault mounds, a graben, and ridges of clay gouge that protrude into gullies.

The strongest evidence for recent activity on the Manix fault is the 1947 Manix earthquake. Whether or not the earthquake actually occurred on the Manix fault, the occurrence of minor surface displacement along the Manix fault suggests that the Manix fault may be seismically active. In the Imperial Valley, where triggered slip is a common phenomenon, faults that have exhibited triggered slip have, in most cases, also ruptured in seismic events at other times (Allen *et al.,* 1972; Johnson *et al.,* 1982; Budding and Sharp, 1988; McGill *et al.,* 1988). Thus, even if the 1947 Manix earthquake did not occur on the Manix fault, the observation of minor displacement on the Manix fault related to the earthquake strongly suggests that the fault has been seismically active in the recent past and that it will continue to be active in the future.

CONCLUSIONS

The dominant mode of movement on the Manix fault has probably been strike-slip, but the sense of strike-slip movement is still uncertain. Historical displacement has been left lateral, but the orientation of fold axes is more suggestive of right-lateral shear or compression at a high angle to the fault zone. Geomorphic data bearing on the sense of horizontal slip are inconclusive. The minor, left-lateral, historical displacement on the Manix fault has been used to infer that not only the Manix fault, but also the other east-west-trending faults in the northeastern portion of the Mojave block are left-slip faults (Garfunkel, 1974). Although this is a reasonable hypothesis, no geologic or geomorphic evidence has been found to directly indicate the long-term sense of horizontal slip on the Manix fault.

Detailed mapping of individual members of the Manix Formation has elucidated the character and timing of movement on the Manix fault. The greater deformation of the Plio-Pleistocene unit than of the Manix Formation or the Pleistocene(?) unit suggests that deformation began at least as early as sometime before deposition of the Pleistocene(?) unit. The preservation of fault scarps and other fault-related geomorphic features suggests that movement may have occurred as recently as during the Holocene epoch. Vertical offsets resulting in local uplift and angular unconformity indicate at least six episodes of movement during this period of activity. This is undoubtably a minimum estimate, however, as several episodes of movement may be represented by a single stratigraphic break, and since not all events may have produced vertical offsets visible in the stratigraphic record. The occurrence of minor displacement on the Manix fault in association with the 1947 Manix earthquake suggests that the fault remains active today.

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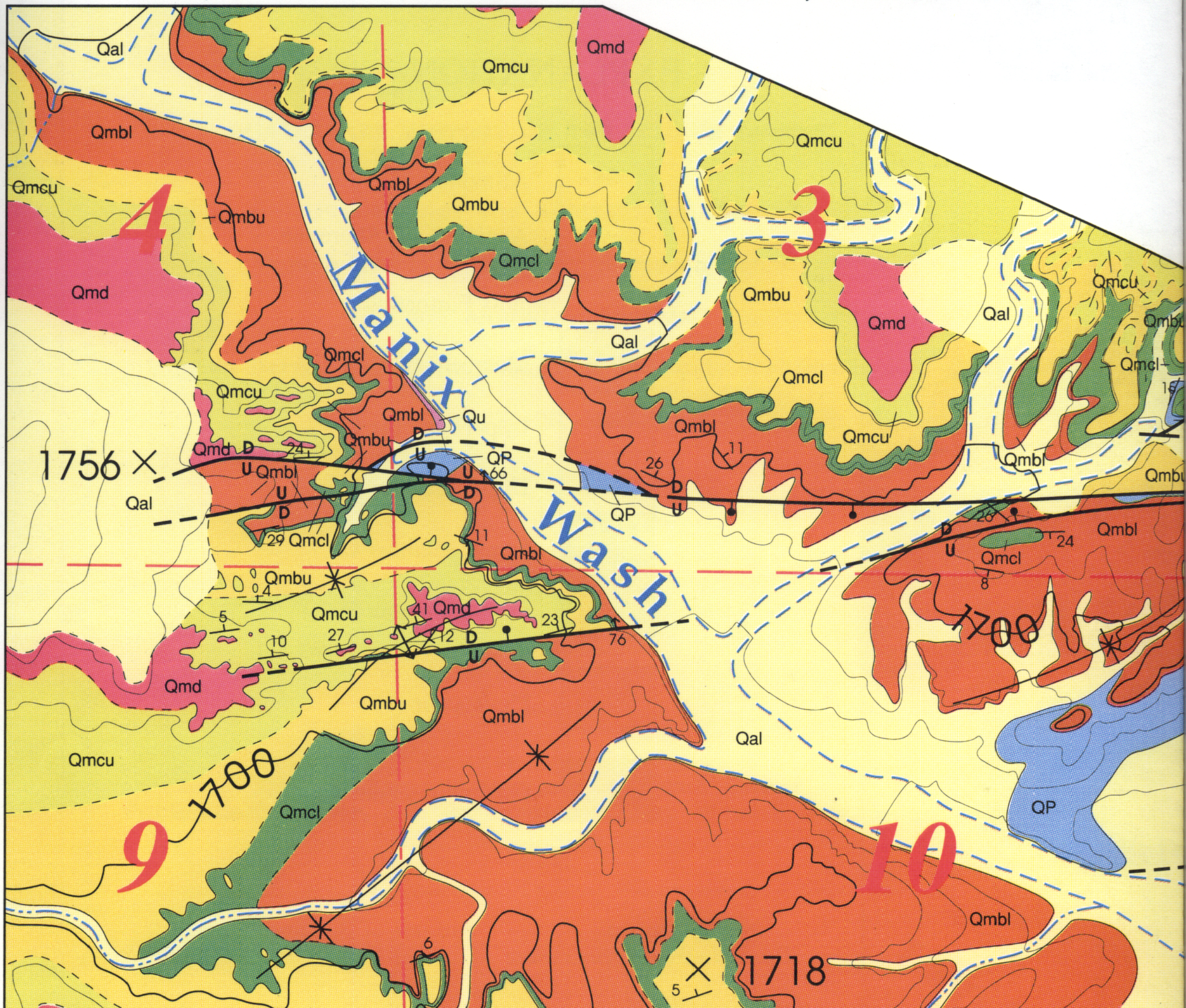
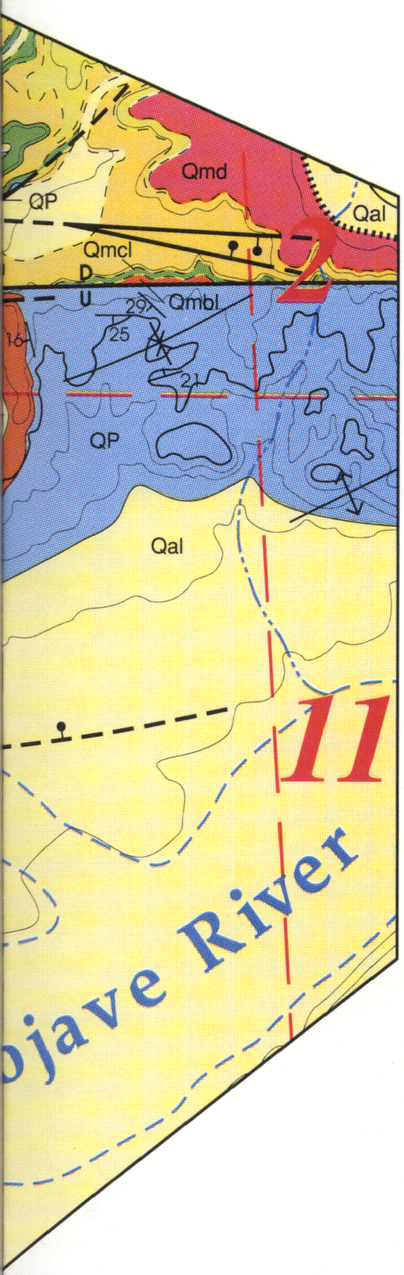
GEOLOGIC MAP OF THE MANIX FAULT AREA AT MOJAVE DESERT, CALIFORNIA



SCALE 1:10 000

0 500 1000 METERS

MANIX WASH,



Contour interval 20 feet

EXPLANATION

Qal	Alluvium
'''''''''''	Ancient Lake Shoreline

Manix Formation

Qmd	Member D
Qmcu	Upper Member C
Qmbu	Upper Member B
Qmcl	Lower Member C
Qmbl	Lower Member B
Qu	Pleistocene (?)
QP	Plio-Pleistocene

Contact
Dashed where approximate

25
Attitude of Bedding

U
D
Fault
Dashed where inferred; stratigraphic throw as indicated

65
Attitude of Fault

Folds
Syncline, anticline

Fault Scarp
Ball on downthrown side

3
Section Boundary and Number

QUATERNARY HISTORY OF THE MOJAVE DESERT

Proceedings and Abstracts of the

Mojave Desert Quaternary Research Center

Second Annual Symposium

San Bernardino County Museum, Redlands, California

June 25-26, 1988

compiled by

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MOJAVE DESERT QUATERNARY RESEARCH CENTER
SECOND ANNUAL SYMPOSIUM

San Bernardino County Museum
Redlands, California 92374

SATURDAY, JUNE 25

Registration 9:00 am

9:20 am Dr. A.D. Griesemer, Director, San Bernardino County Museum Introductory Remarks

SESSION 1: Chair: Bob Adams, MDQRC Library and Documents Program

9:30 am Meek, N., Department of Geography, University of California, Los Angeles. GEOMORPHIC AND HYDROLOGIC IMPLICATIONS OF THE RAPID INCISION OF AFTON CANYON, MOJAVE DESERT, CALIFORNIA.

9:50 am Murray, B., K.A. Maher, S.F. McGill, L. Rowan, J.H. Lieske, and F.E. Budinger, Jr., Department of Geological and Planetary Sciences, California Institute of Technology; California State University, San Bernardino. LATE PLEISTOCENE AND HOLOCENE HISTORY OF THE MANIX FAULT, MANIX LAKE BASIN, MOJAVE DESERT, CALIFORNIA.

10:10 am Roeder, M.A., Natural History Museum, San Diego. QUATERNARY DISTRIBUTION OF GASTEROSTEUS SPECIES IN SOUTHERN CALIFORNIA.

SESSION 2: Chair: Dr. Bruce Murray, Calif. Institute of Technology

11:05 am Castor, S.W., Nevada Bureau of Mines. GRAVELS OF PLEISTOCENE AND PROBABLE TERTIARY AGES IN THE MESCAL RANGE, CALIFORNIA.

11:25 am Reynolds, R.E., Division of Earth Sciences, San Bernardino County Museum. STRUCTURAL EVOLUTION OF THE SHADOW VALLEY BASIN.

11:45 am Brown, W.J., Y. Enzel, S.G. Wells, R.Y. Anderson, and L.D. McFadden, University of New Mexico. LAKE STANDS OF PLUVIAL LAKE MOJAVE: A RECORDING MECHANISM FOR CLIMATE; SILVER AND SODA LAKE PLAYA, MOJAVE DESERT, CALIFORNIA.

SESSION 3: Chair: George T. Jefferson, Page Museum, and Chairman, MDQRC

1:20 pm Jefferson, G.T., Page Museum of Rancho La Brea Discoveries. MULTIDISCIPLINARY APPROACHES IN QUATERNARY STUDIES.

1:40 pm Steinmetz, J.J., California Polytechnic, Pomona. OSTRACODE BIOSTRATIGRAPHY AND LATE PLEISTOCENE PALEOCLIMATIC RECORDS FROM LAKE MANIX.

2:00 pm Lander, E.B., Los Angeles County Museum of Natural History. FAUNAL EVENTS IN THE NORTH AMERICAN CONTINENTAL TERTIARY MAMMALIAN HERBIVORE RECORD AND THEIR IMPLICATIONS REGARDING THE CAUSES OF EXTINCTION AND DIMINISHING AVERAGE ADULT BODY SIZE IN LATE QUATERNARY MAMMALIAN HERBIVORES.

2:20 pm Tchakerian, V., Department of Geography, University of California, Los Angeles. GEOMORPHOLOGY OF THE DALE LAKE SAND SHEET AND ITS PALEOCLIMATIC IMPLICATIONS, SOUTHERN MOJAVE DESERT, CALIFORNIA.

<u>SESSION 4</u>: Chair: David Whistler, Natural History Museum of Los Angeles County

3:10 pm Miller, G.T., P. Remeida, J. Parks, B. Stout and V.E. Waters, Imperial Valley College Barker Museum. A PRELIMINARY REPORT ON HALF-A-MILLION-YEAR-OLD MARKS ON MAMMOTH BONES FROM THE ANZA-BORREGO DESERT IRVINGTONIAN.

3:30 pm Duane, P.B., A.K. Taylor and M. Subburaman, Pettis Hospital; Loma Linda University. DETERMINATION OF OSTEOCALCIN CONTENT IN ANCIENT BONES.

4:00 pm Budinger, F.E. Jr. and G. Stewart, Central Mojave Research, Yermo; Desert Research, Laguna Beach. GEOARCHAEOLOGY OF THE BASSETT POINT ARCHAEOLOGICAL SITE, LOWER MOJAVE VALLEY, SAN BERNARDINO COUNTY, CALIFORNIA.

EVENING SESSION

7:00 pm Dr. John M. Harris, Chief Curator of the Earth Sciences Division, Natural History Museum of Los Angeles County, and former Director of Paleontology, National Museum of Kenya: THE SEARCH FOR EARLY MAN IN NORTHERN KENYA.

SUNDAY, JUNE 26

SESSION 1: Chair: Dr. Walter C. Schuiling, San Bernardino County Museum Association

9:10 am Walker, J., IKON Minerals, Long Beach. PAOHA ISLAND PHOSPHATES.

9:30 am Goodwin, H.T., Natural History Museum, University of Kansas. *MARMOTA FLAVIVENTRIS* FROM THE CENTRAL MOJAVE DESERT.

9:50 am Spencer, L. and G.T. Jefferson, San Bernardino County Museum; Page Museum of Rancho La Brea Discoveries. QUANTITATIVE PLEISTOCENE MAMMALIAN PALEOPROVINCIALITY OF THE NORTH AMERICAN WEST.

10:10 am Minnich, R.A., Division of Geography, University of California, Riverside. FIRE AND THE ARRIVAL OF CREOSOTE BUSH SCRUB IN CALIFORNIA DESERTS AT THE PLEISTOCENE-HOLOCENE TRANSITION.

SESSION 2:

10:45 am Roth, B. and R.E. Reynolds, University of San Francisco; San Bernardino County Museum. LATE PLEISTOCENE NONMARINE MOLLUSCA FROM KOKOWEEF CAVE, IVANPAH MOUNTAINS, CALIFORNIA.

11:10 am Fife, D.L., Fife and Associates, Irvine. THE DESERT PLAYA--A DYNAMIC ENVIRONMENT FOR GEOLOGIC RESEARCH.

11:30 am Contributions from the floor, research in progress, and announcements.

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GEOMORPHIC AND HYDROLOGIC IMPLICATIONS OF THE RAPID INCISION OF AFTON CANYON, MOJAVE DESERT, CALIFORNIA

Norman Meek
Department of Geography, University of California, Los Angeles CA 90024-1524

Afton Canyon is a >150 m deep canyon that formed as a result of overflow and drainage of Lake Manix, an (approx.) 215 km^2 late Wisconsinan pluvial lake in the central Mojave Desert. Because the canyon age is within the range of conventional radiocarbon dating, it is possible to provide a time-based chronology of events and resultant landscape changes due to a >120 m base-level drop.

Analysis of erosion volumes upstream of Afton Canyon, and a review of public and private well logs downstream of the canyon mouth indicate that late Wisconsinan surfaces are deeply buried downstream of Afton Canyon. Burial depths are approximately 55 m at the mouth of Afton Canyon, 27 m in Cronese basin, and 18 m at Crucero. The well logs also indicate that Soda lake was far more areally extensive prior to the late Wisconsinan.

Stratigraphic and geomorphic evidence suggests that Afton Canyon was cut rapidly sometime after 14,230 ± 1325 yr B.P. The rapid draining of Lake Manix and subsequent basin dissection have important implications for late Quaternary lake fluctuations in Death Valley, base-level changes and resultant alluvial-fan adjustments in Cronese basin, the sand source for the Kelso Dunes, and the absence of old artifacts in Cronese basin and the Mojave River Wash region.

Revised and updated 09/22/88

QUATERNARY DISTRIBUTION OF GASTEROSTEUS SPECIES IN SOUTHERN CALIFORNIA

Mark A. Roeder
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Sticklebacks are small fish with distinctive rigid dorsal and pelvic spines. The family, Holarctic (above 30 degrees North latitude) in distribution, inhabits marine and brackish waters and coastal streams. The threespine stickleback (Gasterosteus aculeatus) usually frequents the quiet waters of inland streams, estuaries and the coast of southern California.

Recent paleontologic salvage operations in southern California have added new fossil records of threespine sticklebacks. San Bernardino County Museum investigations at the Solid Waste Site, Daggett (dated 12,210 +/- 430 years) and Coyote Dry Lake (possibly 100,000 years old) in San Bernardino County have documented the occurrence of Gasterosteus aculeatus in the Mojave River drainage during the late Rancholabrean land mammal age. In the Los Angeles Basin, threespine stickleback remains have been recovered from late Rancholabrean sites at Ralph Clark Park (possibly as old as 70,000 years) and Rancho La Brea (4-40,000 years). Stickleback spines have been collected in a deposit of the San Pedro Sand at the Naval Fuel Reserve near San Pedro (300,000 years). Gasterosteus, reported from Irvingtonian deposits in the San Timoteo Badlands (San Timoteo Formation) of Riverside County, have recently been found at Murrieta in the Unnamed Sandstone which contains Bishop Tuff ash (700,000 years) and at a site near Corona.

In addition to these Quaternary records of the threespine stickleback, there are a number of late Tertiary occurrences in southern California rock units, including the Ridge Route Formation (Blancan land mammal age) in northern Los Angeles County and the Sisquoc Formation, (Clarendonian land mammal age) near Lompoc, San Luis Obispo County.

Probably one of the most interesting finds as a result of recent paleontological work by the San Bernardino County Museum is a late Hemingfordian–early Barstovian record of a stickleback from the Toomey Hills in the Barstow Formation, Yermo, San Bernardino County. Stickleback spines recovered during screening of large bulk samples of sediment appear to be a species different from the Gasterosteus aculeatus and possibly a new species. This remarkable find pushes the record of sticklebacks in southern California and the world back to 16 million years and has important implications for the origin of the stickleback family. Although ichthyologists had speculated, based on the modern stickleback family distribution in the Holoartic region, that sticklebacks probably originated in the Northern Atlantic Ocean, fossil evidence in southern California argues for a northern Pacific origin. Southern California has a very good fossil record of this family at least back to the late Hemingfordian. The fossil record of sticklebacks is poorly known in areas outside of southern California.

GRAVELS OF PLEISTOCENE AND PROBABLE TERTIARY AGES IN THE MESCAL RANGE, CALIFORNIA

Stephen Castor
Nevada State Bureau of Mines, Reno, NV 89557

Pre-Holocene gravels occur in terraces and in large channels at Mountain Pass in the Mescal Range, southeastern California. Drilling indicates total gravel thicknesses in excess of 200 m. These gravels are typically poorly indurated, and locally contain hard calcite cement. They are mostly poorly sorted with clayey matrices, resembling modern alluvial fan material. No fossils or contemporaneous volcanics have been found in the gravels; past workers assumed them to be of Pleistocene age.

Detailed mapping at Mountain Pass supports subdivision of pre-Holocene gravel deposition into at least four episodes based on distinctive clast lithologies and on transport directions. Gravels deposited during the early episodes are devoid of Paleozoic carbonate clasts which are very abundant in more modern gravels. Tertiary ages are inferred for the older episodes, which must have been deposited before the formation of the Paleozoic carbonate highlands that dominate modern drainage patterns in the area.

STRUCTURAL EVOLUTION OF THE SHADOW VALLEY BASIN

Robert E. Reynolds, Division of Earth Sciences
San Bernardino County Museum, Redlands CA 92374

Structural events approximately 13 million years ago (mya) and 0.3 mya are recorded in continuing depositional records of Shadow Valley Basin and the Valley Wells Basin in the eastern Mojave Desert of San Bernardino County, California. The start of Tertiary extension between 13 and 11 mya in the Halloran Hills is indicated by deposition of fine-grained sediments in Shadow Valley Basin. After deformation of the fine-grained sediments, the basin received large breccia blocks of Paleozoic limestone and fanglomerates of distinct lithologies from the Mescal Range, 30 km distant. This event marks the elevation of the southeastern basin margin and indicates activity on the Clark Mountain Fault. Uplift of the southwestern basin margin is indicated by north-spreading granitic debris underlying 5.12 Ma basalt flows. Eastward tilting of blocks of the Tertiary section along northeast-trending faults continued through 4.5 mya.

At Valley Wells in southern Shadow Valley, more than 7 m of lacustrine and fluviatile sediments were deposited on Mesozoic granitic rocks and on the Tertiary fanglomerates and monolithologic Paleozoic carbonate breccias which had been shed westward from the Mescal Range. The elongate, northeast-trending configuration of the basin developed during the Pliocene, perhaps 3 mya. The age of the lacustrine section is based on tephrochronology and biostratigraphic correlation. The Huckleberry Ridge Ash, which has yielded a radiometric date of 2.02 Ma, occurs 2 m above the base of the section. A lower third molar of Mammuthus meridionalis, an Irvingtonian land mammal age taxon, was recovered approximately 2.5 m above the base of the section. Fragmentary teeth referable to M. columbi, a Rancholabrean land mammal age form, were found 2.5 m higher in the section. These taxa bracket the transition from the Irvingtonian to the Rancholabrean land mammal age that occurred approximately 0.5 mya. Between 2 and 0.5 mya, sediment deposition reflects upward displacement of the east side of the basin along a north-south axis. After 0.4 mya, the Pleistocene lacustrine sediments on the west side of the basin were tilted eastward and uplifted approximately 60 m relative to correlative facies on the east.

LAKE STANDS OF PLUVIAL LAKE MOJAVE: A RECORDING MECHANISM FOR CLIMATE, SILVER AND SODA LAKE PLAYAS, MOJAVE DESERT, CALIFORNIA

William J. Brown, Yehouda Enzel, Stephen G. Wells, Robert Y. Anderson, and Leslie D. McFadden.
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During the last 20,000+ years, Silver and Soda lake playas, the remnants of pluvial Lake Mojave, have been the termini of the Mojave River. Unusually well-preserved sedimentological features in cored lake deposits reveal a complex lacustrine history. Fining upwards sequences of silt-clay with interbedded thin carbonate and sulfate layers, and desiccation cracks were used to measure the amplitude of major flooding, lake lowering and total drying episodes. Many of these events can also be correlated from core to core. These data, combined with information from a prominent series of beach ridges at the north end of Silver Lake, reveal two major high and persistent lake stands separated by intermittent lake phases containing numerous drying events. The highest of the continuous lake phases occurred from about 18.5 Ka to 17 Ka and was probably responsible for the most extensive and highest wave-cut and beach ridge features. Erosion of the outlet spillway at the northern margin of Silver Lake resulted in the formation of shoreline features at progressively lower elevations. The second persistent lake phase occurred from 14.5 Ka to about 12 Ka when a significant loss of water storage due to spillway downcutting and sedimentation of the basin made this later lake even more sensitive to climatic fluctuations. A loss of effective moisture accompanying a major climate change at about 8 Ka resulted in a dry playa phase which has continued to the present. Three short-lived lake stands are found within this period and are tentatively inferred to represent brief intervals of increased effective moisture during the mid to late Holocene.

OSTRACODE BIOSTRATIGRAPHY AND LATE PLEISTOCENE PALEOCLIMATIC RECORDS FROM LAKE MANIX

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and
George T. Jefferson
George C. Page Museum, Los Angeles CA 90016

Analyses of ostracode assemblages from lacustrine sediments of the Manix formation provide a data base for the interpretation of regional late Pleistocene climates. A preliminary examination of assemblage composition shows that the relative abundance of individual ostracode species fluctuates with a periodicity that apparently parallels a 23 kyr Milankovich cycle.

The 24 m thick lacustrine sequence consists primarily of clays, silts, and fine-grained sands. Based on direct stratigraphic correlation with the dated section of the Manix formation, the top of the sampled section is about 50 kyr old and the base approaches 400 kyr B.P. Sediment samples were excavated at 0.3 meter intervals from eroded exposures along the Mojave River. Each sample was processed by standard paleontologic techniques. Three extant and one extinct species of limnic ostracodes have been identified. Relative abundance of individual ostracode species was determined by a standardized density measurement. Random samples were tested for coherence by statistical analyses.

Two major biostratigraphic zones have been defined on the basis of the dominant ostracode taxon in each sample. The lower 3 meters of the sequence are dominated by Lymnocythere platyforma. Limnocythere robusta appears in moderate abundance intermittently throughout this zone. Ostracode assemblages from the top 3 to 24 meters of the section are dominated by L. ceriotuberosa. The modern ecology and biogeographic distribution of these ostracodes is relatively well known.

Given the effects of sedimentation rates and other taphonomic biases on the content of ostracode assemblages, fluctuations in the relative abundance of ecologically sensitive lacustrine ostracode taxa evidently reflects regional paleoclimatic conditions. An observed periodicity in the appearance of peak ostracode populations warrants further investigation of possible Milankovich-timed oxygen isotope stages in continental lacustrine depositional systems.

FAUNAL EVENTS IN THE NORTH AMERICAN CONTINENTAL TERTIARY MAMMALIAN HERBIVORE RECORD AND THEIR IMPLICATIONS REGARDING THE CAUSES OF EXTINCTION AND DIMINISHING AVERAGE ADULT BODY SIZE IN LATE QUATERNARY MAMMALIAN HERBIVORES

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The late Quaternary land mammal record is characterized by extinction of larger-bodied herbivore species and concurrent diminution in average adult body size (up to about 25% in terms of linear dimensions in some cases) through successive generations of smaller-bodied herbivores. Controversy has arisen regarding the probable cause of the observed faunal changes. The pronounced climatic shift and accompanying habitat alteration that occurred at the end of the Pleistocene, increased human predation, or a combination of both phenomena are usually considered the factors primarily responsible for these faunal events. Analysis of the North American continental Tertiary mammalian herbivore record allows documentation of faunal events similar in type and magnitude to those observed at the end of the Pleistocene, but without the influence of human predation.

Many Tertiary faunal sequences are characterized by small or diminishing average adult body size in oreodonts (Oreodonta, Artiodactyla) and other comparatively small ungulates during the early Uintan to late Clarendonian Land Mammal Ages (approximately 49 to 9 M.Y.B.P.). A period of small or decreasing size is usually followed by a period of large or increasing size in the same lineage (in some cases the first and/or last appearance of a lineage is characterized by relatively small size.) Small or diminishing size is documented during 17 intervals, including the middle Uintan; middle Duchesnean; post-Duchesnean, pre-Chadronian; middle Chadronian; late Chadronian to early Orellan; early Whitneyan; earliest late Whitneyan; latest Whitneyan and/or earliest Arikareean; earliest Arikareean; middle early Arikareean; latest early Arikareean to earliest late Arikareean; post-Arikareean, pre-Hemingfordian; middle early Hemingfordian; middle Hemingfordian; earliest late Hemingfordian; post-Hemingfordian, pre-Barstovian; and the post-Barstovian, pre-Clarendonian; or an average of once every 2.29 M.Y. *Leptauchenia* increased and subsequently decreased in size at least six times during the early Chadronian to early Hemingfordian. In some faunal sequences, three or four oreodont lineages decreased in size in parallel fashion. During the late Chadronian to early Orellan, *Oreonetes gracilis*, *Prodesmatochoerus periculorum*, and *Leptauchenia eiseleyi* decreased in size (up to 31% reduction in P1-M3 length in stratigraphically superposed samples of *O. gracilis*), but, along with *Agrichoerus antiquus* and possibly *Eucrotaphus jacksoni*, increased in size (nearly 45% in stratigraphically superposed samples of *O. gracilis*) during the late Orellan. Diminishing size in these taxa occurred concurrently with extinction of some larger mammalian herbivores (large rhinoceros, *Trigonias*; last titanothere, *Menodus*) and development of redbeds and caliche (nodular zones). The lithologic changes reflect increasing aridity, at least on a seasonal basis, and may have been accompanied by a major vegetational alteration that resulted in replacement of forest by grassland. Periods of small or decreasing body size may correspond in time to extinction events in land mammals, these events having recently been documented as occurring on a cyclic basis every 2.33 M.Y.

Oreodonts existed in North America during a period of transition from tropical forest to savanna, this transition reflecting development of a seasonal climate characterized by summer drought. However, fluctuations in average adult body size in many oreodont lineages throughout this period suggest that a pattern of fluctuating climate, habitat, and available forage was superimposed on this transition. Summer drought could have resulted in a reduction of forage during the growth stage of an oreodont and might have served as a factor limiting the size attained by a mature individual. However, the ability of oreodonts and other relatively small-bodied ungulate species to reduce body size during a period of limited resources might have been an adaptive advantage that typified smaller herbivores and allowed the total biomass of a population to adjust to a diminishing resource base while maintaining the size of the population. Reduction in linear dimensions would have led to a proportionately greater reduction in biomass. Reduced body size, as well as the shorter generation time and lifespan that characterize comparatively small ungulates, would have allowed a rapid turnover of individuals, larger ancestors being replaced by progressively smaller descendants. A comparatively large-bodied ungulate species, because of the longer generation time and lifespan that accompany larger size, could adjust the total biomass of a population during a period of rapid and severe climatic deterioration only by reducing population size, a severe reduction ultimately resulting in extinction.

The Tertiary record suggests that climatic change, particularly increasing aridity as manifested by seasonal drought, rather than human predation, is the factor primarily responsible for the late Quaternary faunal events.

GEOMORPHOLOGY OF THE DALE LAKE SAND SHEET AND ITS PALEOCLIMATIC IMPLICATIONS, SOUTHERN MOJAVE DESERT, CALIFORNIA

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The purpose of this research is a) to analyze the geomorphology and stratigraphy of the Dale Lake sand sheet in the southern Mojave Desert of California and b) to examine the potential of using scanning electron microscopy (SEM) as a relative dating method based on weathering of quartz grains. This study is part of a larger project which has as its primary objective the nature and frequency of late Quaternary aeolian sedimentation and erosion in the Mojave Desert of California.

The Dale Lake sand sheet, located about 45 km east of the town of Twentynine Palms, consists of a series of climbing dunes deposited at the foot of the Sheephole Mountains. The sand sheet is currently stabilized by vegetation and mantled by talus from the adjoining mountains. Since the cessation of aeolian activity, incision by streams has exposed thick sequences of aeolian units, in places up to 40 m in height.

Mechanical analysis, paleosol development, relative weathering data from scanning electron microscopy, and principal component analysis on quartz grain surface microfeatures indicate at least 5 major aeolian depositional units. Based on these results, as well as data from the Cronese Basin and the Kelso Dunes in the eastern Mojave Desert, it is proposed that the majority of the aeolian units were deposited during the last half of the late Wisconsin (18,000 to 10,000 yr B.P.). Recent paleoecological studies by Spaulding (1984) indicate that the southern Great Basin was characterized by drier and colder conditions. Supporting evidence from other arid regions of the world also indicate that the late glacial maximum (18,000 ± 3,000 yr B.P., Climap Project Members,

1976) was characterized by drier and colder conditions, leading to the development of extensive dune systems (Williams, 1985).

A PRELIMINARY REPORT ON HALF-A-MILLION-YEAR-OLD MARKS ON MAMMOTH BONES FROM THE ANZA-BORREGO DESERT IRVINGTONIAN

George J. Miller[1], Paul Remeikā[2], Julia Parks[3], Betty Stout[4], and Vern E. Waters[5]
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Bones of an adult male mammoth (Mammuthus sp.) closely related to the Imperial mammoth have been discovered in the Anza-Borrego Desert State Park, San Diego County, California. The nearly complete skeleton was in situ in Irvingtonian land mammal age sediments (Late Pleistocene). A rib bone with V-shaped cuts was found 251.5 centimeters below the top of the Pleistocene beds. Studies of the cuts show that they were made with a chopping motion. It is suggested that the cuts were made by early hominids using a primitive stone chopper or hand axe. Radiometric, faunal and paleomagnetic dates show the site to be from 300,000 to 500,000 years old.

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[4] Research Assistant, Imperial Valley College Museum, El Centro, CA
[5] Field Assistant, Imperial Valley College Museum, El Centro, CA

DETERMINATION OF OSTEOCALCIN CONTENT IN ANCIENT BONES

Peggy Backup Duane, Subburaman Mohan, Arch K. Taylor, and David J. Baylink
Loma Linda University and Pettis VA Hospital, Loma Linda, CA 92357

The past few decades have witnessed the development of many new techniques capable of detecting minute quantities of protein-based material. The present study reports on measurement of a specific bone matrix protein, osteocalcin, in prehistoric bone specimens, using a radioimmunoassay.

Three ancient bone specimens were donated by Robert Reynolds, Curator of Earth Sciences, San Bernardino County Museum:

Coyote, estimated > 13,000 years bp, Maricopa Asphalt Deposit
Marmot, estimated < 13,000 years bp, Antelope Cave
Artiodactyl, c^{14} dated at 9,850 years bp, Kokoweef Cave

For the positive control, a modern turkey bone was obtained from a grocery store.

Osteocalcin was extracted from the four bones by a crude extraction procedure consisting of formic acid demineralization and dialysis. The osteocalcin content of the bone matrix extract was measured using a radioimmunoassay for human osteocalcin developed by Dr. Arch Taylor and others at the Mineral Metabolism Laboratory, Pettis VA Hospital, Loma Linda. This assay is specific for the mid-molecular portion of human osteocalcin, and recognizes osteocalcin from several species, even though there are species differences in the osteocalcin molecule.

A radioimmunoassay works on the principle of competition between radio-labeled protein, i.e., osteocalcin tracer, and osteocalcin derived from the specimens being tested. Both forms of osteocalcin are antigenic, and bind to osteocalcin antibodies supplied in the assay. Osteocalcin content was calculated as microgram-equivalents human osteocalcin per gram dry weight bone because standard curves are not available for this assay using marmot, coyote, artiodactyl, or turkey bone. In general, values for the paired duplicates were comparable, and greater dilutions of bone extracts exhibited correspondingly less activity, indicating that pipetting errors did not contribute significantly to the osteocalcin activity measured by the assay.

The results showed that despite species and age differences, osteocalcin from the ancient specimens showed sufficient activity to displace bound osteocalcin tracer, especially for marmot bone extract. Marmot bone extract contained 250-fold more osteocalcin than modern turkey bone extract (4.771 vs. 0.019 microgram-equivalents human osteocalcin per gram dry weight bone).

These results demonstrate that the bone matrix protein, osteocalcin, is extremely resistant to degradation under a variety of conditions for long periods of time. Comparison of results using 13,000 year-old marmot bone and modern turkey bone suggest that species differences may be more important than specimen age in determining osteocalcin activity. Phylogenetically, the marmot osteocalcin is considerable closer to the human osteocalcin measured by this assay than is the turkey osteocalcin. Because of the relatively slow degradation of this protein, the possibility also exists of being able to use this assay to detect osteocalcin in bone specimens even more than 13,000 years bp. For example, bone extract can be concentrated before it is measured, whereas the present study used only unconcentrated extracts.

Differences in osteocalcin content found in this study could be due to combinations of at least five variables: conditions at the preservation site, animal age at death (young animals have relatively more non-collagenous protein than older animals), time elapsed since death, species variations in the initial percentage of osteocalcin per non-collagenous protein, and perhaps most important, species differences in cross-reactivity in the human osteocalcin radioimmunoassay. Additional studies need to be performed in order to further evaluate the effects of these parameters on osteocalcin content of ancient bone.

GEOARCHAEOLOGY OF THE BASSETT POINT ARCHAEOLOGICAL SITE, LOWER MOJAVE VALLEY, SAN BERNARDINO COUNTY, CALIFORNIA

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Geoarchaeology, the utilization of geological and geographical methods and perspectives in the service of archaeology, is a powerful new subdiscipline in anthropology. Its techniques are especially useful for determining site depositional history, stratigraphy, and other contextual patterns which, when considered in a systematic fashion, allow an investigator to generate a realistic paleoenvironmental reconstruction.

The Bassett Point Archaeological Site, located in the lower Mojave Valley of San Bernardino County, California, is a relatively new discovery of lithic artifacts which promises to play a role in the on-going controversy regarding Early Man in the New World. Geoarchaeological perspectives are being utilized to understand the environmental setting and age of an artifact bearing facies of alluvium which is interdigitated with lacustrine deposits of Pleistocene Lake Manix. Unifacially flaked artifacts of chalcedony and jasper have been found <u>in situ</u>. These were situated 16.43 feet below a 4 cm thick layer of 85,000 year old air-fall tephra which has been sourced to the Long Canyon area of the Kern Plateau of the Southern Sierra. Bassett Point lithic artifacts are quite probably on the order of 250,000 years old and would, therefore, be the oldest yet discovered in North America.

PAOHA ISLAND PHOSPHATES

James Walker
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Research Associate, San Bernardino County Museum, Redlands CA 92374

A number of unusual phosphate minerals of organic minerals were collected from an island in Mono Lake, Mono County, California. They included:

Newberyite $MgHPO_4.3H_2O$ (Cohen and Ribbe, 1966)

Monetite $CaHPO_4$ (Cohen and Ribbe, 1966)

Struvite NH $MgPO_4.6H_2O$ (Cooper and Dunning, 1969).

In addition, the presence of one other phosphate mineral--Brushite, $CaHPO_4.2H_2O$--at some point in the paragenetic sequence can be deduced.

In California, these minerals are unique to this locality. They are extremely rare worldwide, with about four other localities noted.

Geology

Paoha Island is approximately 2.0 by 1.5 miles in size and is situated just north of the center of Mono Lake. The island is an interbedded, varved series of sediments comprised of layers of sublacustrine volcanic tuffs interbedded with layers of diatomite, probably of Pleistocene age. Subsequent uplift exposed the island for use as a bird nesting site. Phosphate crystals formed. The island was submerged and more sediments were deposited; the island was again uplifted and/or lake levels dropped. The sediments were exposed to subaerial weathering and temperature extremes causing dehydration and further alteration of the mineral specimens.

Mineral Paragenesis

The paragenetic sequence is as follows. Struvite forms in guano. Struvite acquires a coating of brushite. Coated crystals are submerged and buried in diatomite. Slow loss of NH_3 converts most, but not all, of the struvite to newberyite. Uplift and a drop in the lake level expose the crystals to further dehydration and loss of NH_3 via weathering while converting the brushite coating tc monetite by dehydration.

Morphology

The specimens are epimorphs of monetite and pseudomorphs of newberyite after struvite. They are orthorhombic, pyramidal, and of the point group mm2. Twinning is common. Their size tends to be no larger than 7.5 cm by 3.8 cm for complete specimens. The exterior is a porcelaineous veneer of monetite over a friable aggregate of blade-like crystals of newberyite. In a few rare examples, there remains a core of grayish, transparent material resembling gypsum which in fact is the unaltered remains of the original struvite.

Access

Paoha Island is under the jurisdiction of the Los Angeles County Department of Water and Power and the U.S. Forest Service. It is off limits between April 1 and August 1 because of its continuing use as a gull rookery.

MARMOTA FLAVIVENTRIS FROM THE CENTRAL MOJAVE DESERT

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A late Quaternary faunal assemblage recovered from Newberry Cave in the central Mojave Desert includes remains of extralimital Marmota flaviventris, the yellow-bellied marmot. This record is the most southwesterly of known late Pleistocene records for the species; is one of the lowest in elevation (730 m); and is the first indication that the species colonized the presently dry mountains of the central Mojave Desert during the late Pleistocene. Long distance transport from known late Pleistocene populations in the eastern Mojave Desert is judged an unlikely explanation for the Newberry Cave record. Two colonization hypotheses are considered. The first involves westward expansion of a source population in the eastern Mojave Desert and requires that the species crossed 40 km of terrain below 914 m elevation and several km below 610 m elevation. The second requires the expansion of a Sierra Nevada population southward down the Tehachapi Mountains, westward across the Transverse Ranges, and northward into the central Mojave Desert. Though less direct, this route lies mostly above 914 m elevation and would involve less xeric habitat. The latter hypothesis, consistent with Recent biogeographic evidence, is here judged the most probable one.

QUANTITATIVE PLEISTOCENE MAMMALIAN PALEOPROVINCIALITY OF THE NORTH AMERICAN WEST

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Quantitative mammalian provinces have been described for North America during historical times. We propose to use the same procedures to quantitatively analyse Late Pleistocene distributions. Because fossil locations are determined largely by non-biological processes (sedimentation processes, etc.), limitations imposed by using potentially abbreviated data need to be analysed before paleoprovinciality can be determined. Since historical mammalian distributions were originally used to define provinces, we will analyse the effect of fossil locality limitations by reconstructing the historical mammalian ranges as if extant species could only be collected from sites where fossils are preserved. New provinciality maps will be constructed based on the revised ranges; any differences in boundary locations will be due to data limitations, not biological parameters. Additionally, the recent provinciality represents an instant in time; fossil distributions require some level of time averaging. The effects of time averaging can be addressed by conducting the analysis over different time spans (Wisconsinan >50,000, total Wisconsinan, Sagamonian), and observing the differences.

FIRE AND THE ARRIVAL OF CREOSOTE BUSH SCRUB IN CALIFORNIA DESERTS AT THE PLEISTOCENE-HOLOCENE TRANSITION

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Plant migrations in the Southwestern Deserts at the Pleistocene-Holocene transition (12,000--8,000 B.P.) have normally been interpreted in terms of temperature and moisture aspects of climatic change. Because plants have complex physiological and adaptive modes, the effects of temperature and precipitation on equilibrial or dynamic plant distributions are often indirect. It has also become recognized that disturbance plays a vital role in plant biogeography. Many communities persist over time because taxa respond flexibly to disturbance through sprouting, fire resistant bark, seed scarification, fruit serotiny, and long distance seed dispersal. Moreover, fire is a continuous variable dependent upon the environment including climate, stand productivity, fuel accumulation rates, as well as plant life form and community structure. Thus, species migrations attendant on climatic change, such as the Pleistocene-Holocene transition, may have arisen partially from selective pressures produced by geographic shifts in fire regimes.

Relationships between fire and post-Pleistocene vegetation changes may be seen in recent fire history in California deserts. Fires are generally infrequent in deserts owing to limited biomass and discontinuous cover of shrubs and annuals. Unprecedented proliferation of European annuals (Bromus rubens, B. tectorum, Schismus barbatus, Brassica tournfortii) associated with abnormally heavy precipitation after 1976 resulted in widespread burning in California creosote bush scrub. Long-lived dominant species (Larrea tridentata, Ambrosia dumosa, Krameria grayii, Tetradymia spinescens, *Grayia spinosa*, *Opuntia* spp., *Edhinocereus* spp.) resprout poorly and recolonize burns by continuous reproduction over long spans of time. These are replaced by typically short-lived pioneer species with high reproductive capacities, many occurring along washes or high rocky places (*Hymenoclea salsola*, *Stipa speciosa*, *Hilaria rigida*, *Salvia mohavensis*, *Eriogonum fasciculatum*, *Happopappus linearifolius*, *Viguiera deltoidea*, *Bebbia juncea*, *Encelia virginensis*, *E. farinosa*). Other mostly uncommon perennials (*Ephedra* spp., *Beloperone californica*, *Acacia greggii*, *Hyptus emoryi*, *Lycium* spp., *Yucca schidigera*, *Salazaria mexicana*) persist through sprouting. Since European exotics invading deserts are relatively recent introductions and have not equilibrated in distribution, changes in fire regime engendered by increasing herbaceous fuels appear to be modifying the distribution and composition of creosote bush scrub.

Similarly, high vegetal productivity and fuel accumulation rates during the more mesic Pleistocene climates, in particular the combination of wetter winters and cooler, dry summers, probably resulted in extensive burning in the Southwestern Deserts. Decline in burning during the Pleistocene-Holocene transition contributed to vegetation changes recorded in woodrat middens. Temporal and geographic data from middens indicate that many of the latest arrivals in the creosote bush scrub in the Southwestern Deserts are taxa most poorly adapted to fire. Some well-adapted species persist in the region through the Pleistocene-Holocene transition. It is concluded that some aspects in the development of creosote bush scrub correspond with the cessation of burning with the development of modern climate.

The results bring to question some aspects in the interpretation of midden data. Most surviving middens come from rock shelters on cliffs and rocky slopes which are more immune from fire than other habitats. Thus, Neotoma samples may reflect a bias toward fire-free environments and thus overrepresent fire-sensitive species such as Pinus monophylla and Juniperus californica. The interpretation of middens is also obscured by the fact that Neotoma prefer wooded cover and will not sample open vegetation per se. It is possible that intervening bajadas and pediments between scattered ranges harboring ancient middens were covered with more flammable communities during the late Pleistocene, such as Great Basin sage scrub and perennial grasslands. Fire regimes supported by these communities would probably be selective against nonresiliant desert taxa such as Larrea tridentata.

LATE PLEISTOCENE NONMARINE MOLLUSCA FROM KOKOWEEF CAVE, IVANPAH MOUNTAINS, CALIFORNIA

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An assemblage of one freshwater and seven terrestrial mollusk species was collected in Kokoweef Cave (elevation 1800m), Ivanpah Mountains, San Bernardino County, California, associated with vertebrate remains of Rancholabrean (late Pleistocene) age. All but one of the molluscan taxa are extant. The present vegetation in the environs of Kokoweef Cave is juniper scrub. Most of the land mollusks indicate an environment like that of modern pine and fir forest now found at elevations above 2200 m in the Spring Range, Nevada. There is also a xerophilic element characteristic of the modern Lower Sonoran Zone. In the time interval represented by the fossils, the pine and fir forest zone probably extended 500-1000 m lower than at present. The freshwater species, <u>Tryonia</u> sp., may have lived in a shallow pluvial lake outside the Ivanpah Range or in the outflow of a thermal spring within the range itself; it may have been transported to the cave in the stomachs of fish, the bones of which occur in the cave deposit.

THE DESERT PLAYA—A DYNAMIC ENVIRONMENT FOR GEOLOGICAL RESEARCH, MILITARY USE, RECREATION, CONSTRUCTION AND TOXIC WASTE DISPOSAL

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Playa is the Spanish word for shore or beach. In English it has lost its original meaning and is used to describe the dry lakes in the closed basins of arid regions. Playas often slope less than 0.2 m per kilometer and are among the flattest of all land forms. In the western North American desert there are hundreds of playas greater than 5 km^2 in area. The flat broad surface of a playa has important military as well as recreational uses. The Space Shuttle may use these vast natural features as scheduled or emergency recovery areas throughout the arid regions of the earth. In addition to these important uses, many playas overlie valuable accumulations of lacustrine or evaporite minerals (Blanc and Cleveland, 1961).

Playas usually consist predominantly of clay minerals, carbonates, salines and zeolites with silt size particles of quartz, feldspar and other clastic sediment (Droste, 1961).

Playa sediments underlie many arid closed basins, including large alluvial plains adjoining active playa surfaces. Natural arid climatic conditions or pumping may lower the water table. As water levels in aquifers in contact with the clayey playa sediments are lowered, the arid environment allows the clay and hydrous minerals above the capillary fringe to desiccate, building up stress. Giant polygons are formed when cohesion in the desiccating sediments is overcome by tensional forces. Explosive and seismic forces can trigger the initial rupture.

Playa fissures frequently gain attention when ephemeral flood waters exhume large conspicuous gullies or fissures. The origin of most large playa fissures can be traces to smaller inconspicuous breaks related to: 1) faulting, 2) subsidence, 3) uplift, 4) massive desiccation, or 5) a combination. The first two causes are generally recognized by geologists and engineers working in the playa environment. However, in the author's experience, massive desiccation forming giant desiccation polygons is the most common cause and the least recognized original source of playa fissuring. Massive desiccation is defined as the moisture loss from clayey sediments or evaporites sufficient to produce giant desiccation polygons and fissures.

As playas are relatively homogeneous sedimentary bodies and normal stress and ultimate shear from massive desiccation can be predicted from the stress-strain elipsoid for individual playas, the geometry of playa fissures may be used to identify regional stress patterns if they were significant at the time of formation of the giant fissures (Fife, 1980).

Surface waters have been observed to recharge the water table directly through giant fissures. Reservoirs built over fissures may be rapidly drained after water establishes a connection with openings at depth. This tends to degrade the ground water quality and allows the fissures to erode to spectacular dimensions. They may be greater than 1 m wide at the surface, and 0.5 m at depths of 6 m. During wet periods the fissures tend to "heal" and all surficial evidence may be erased during a single storm season. However, under favorable conditions, old fissures may be detected by geophysical methods, such as shallow refraction. Once desiccation is resumed, fissures tend to reopen along pre-existing polygon boundaries. With extreme desiccation, the polygons tend to divide into smaller and smaller polygons.

Fissures have the potential to store water which may become hazardously perched above tunnels or excavations in the playa. Fissures are commonly observed filling with windblown sand, and, where they pass beneath sand dunes, running sand can form "sand-stone dikes" which become semipermanent conduits to the water table.

As playas have been proposed for disposal of radioactive and/or toxic wastes (Burnett and Taylor, 1973), the potential for fissures providing a conduit to the water table must be recognized. The fissures are hazardous to surface transportation and landing aircraft. When they occur beneath a structure, they may cause severe damage. The propensity for fissure development can be a danger to pipelines and power transmission towers. Fissures tend to originate in the weakest vertical zone, which may be an excavation, tower footing, or boring. Mitigation measures include awareness, avoidance, structural compensations and control or stabilization of moisture content.

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