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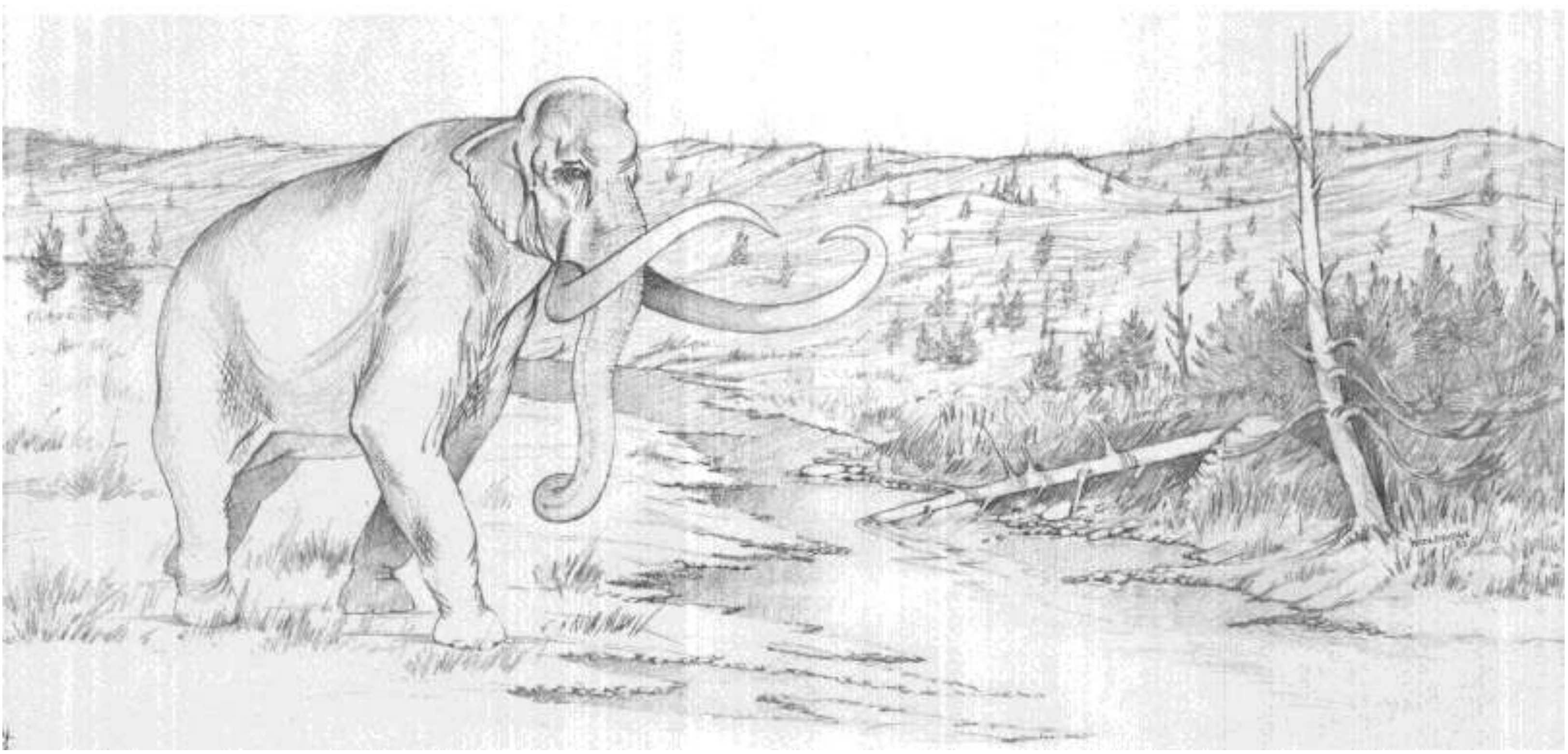
by H. L. Fleischhauer, Jr. and W. J. Stone



New Mexico Bureau of Mines and Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

QUATERNARY GEOLOGY OF LAKE ANIMAS, HIDALGO COUNTY, NEW MEXICO

Cover—LARGE MAMMOTH BROWSING ALONG A TRIBUTARY OF LAKE ANIMAS DURING THE LATE **P**LEISTOCENE.

FRONTISPIECE-AERIAL VIEW OF STUDY AREA (see fig. 1) Note giant desiccation polygons outlined by vegetation in largest of playas and meandering distributary channels (vegetated by mesquite) in delta complex at bottom. See geologic map (in pocket at back) for identification of other features. (U.S. Department of Agriculture, Soil Conservation Service photo-mosaic, 1936).

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Preface

This report on Lake Animas is based on M.S. thesis research conducted at New Mexico Institute of Mining and Technology by the senior author, under the supervision of the junior author. Although the work was done in the period 1975-1977, every attempt has been made to incorporate results of pertinent subsequent works.

Quantitative information in the text of this report is given in English units alone, whereas that in the descriptions of soil profiles (appendix) is given in metric units followed by English equivalents in parentheses. These English units are generally rounded to the nearest whole number so that precision of English and metric units agrees. The following conversion factors may be used for converting from one system to another:

Multiply English units	by	to obtain metric units
inch (not abbreviated)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

ACKNOWLEDGMENTS—We wish to thank **J. R.** MacMillan, Geoscience Department, New Mexico Institute of Mining and Technology, and R. H. Weber, New Mexico Bureau of Mines and Mineral Resources, for their input during the early phases of the work. Thomas Calhoun, Soil Conservation Service, Deming, assisted with soil descriptions. A special thanks is extended to J. W. Hawley, New Mexico Bureau of Mines and Mineral Resources, for suggesting the study, helping with discussions during its course, and reviewing drafts of the manuscript. The thesis was supported through a research assistantship from the New Mexico Bureau of Mines and Mineral Resources. Excavation of soil pits was made possible by a grant from the New Mexico Geological Society.

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Socorro, New Mexico
April 1981

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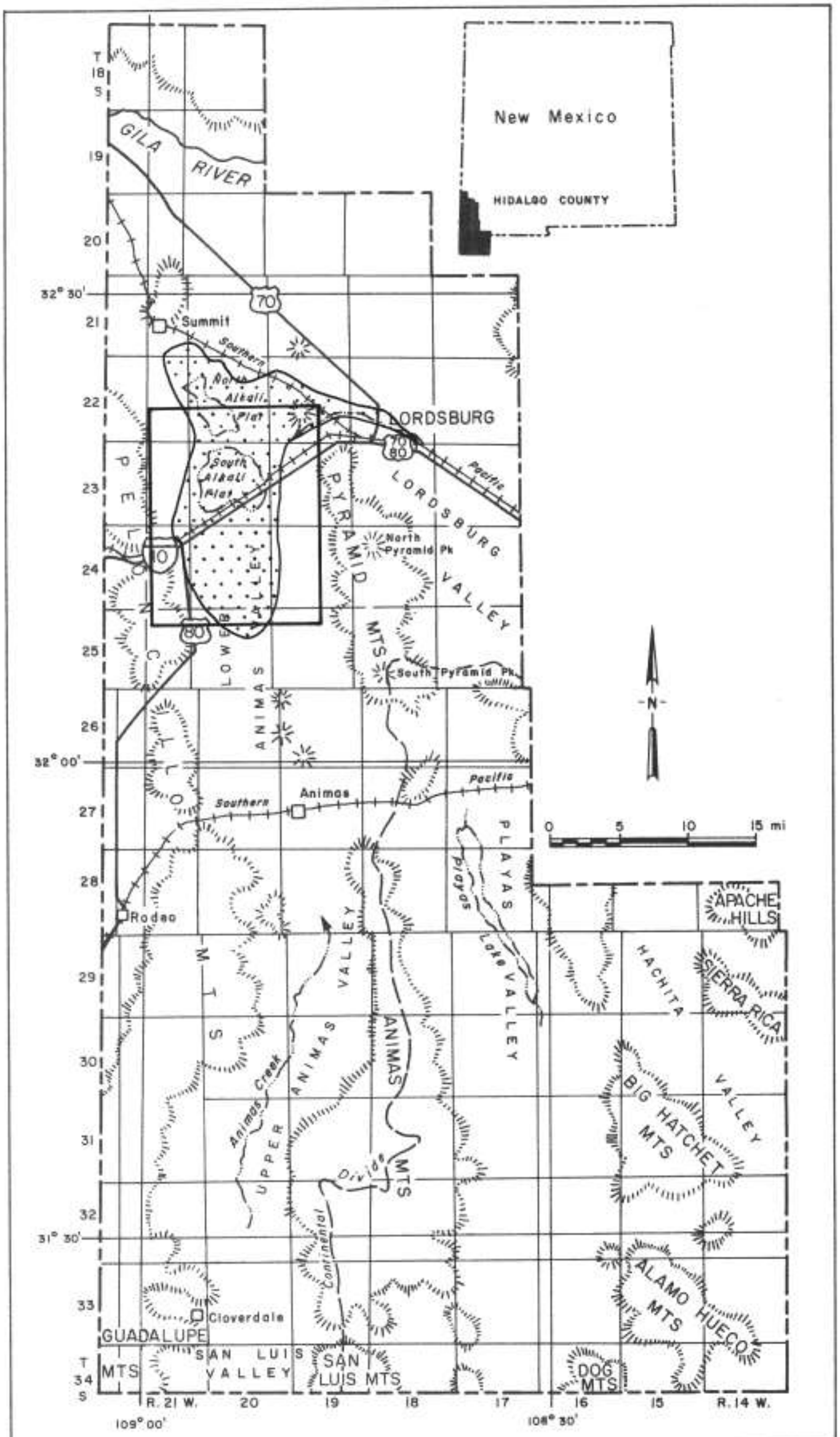

FIGURE 1—Location of study area in Hidalgo County; stippled pattern shows extent of Lake Animas.

ABSTRACT

The mapping of shoreline features in the Lower Animas Valley indicates three stages for Lake Animas. Estimated elevations of the high, intermediate, and low shorelines are 4,190-4,195 ft, 4,185 ft, and 4,175-4,180 ft, respectively. At an elevation of 4,195 ft (high stage), Lake Animas was approximately 17 mi long, 8 mi wide, 50 ft deep, and covered approximately 150 sq mi. Most of the shorelines are marked by low ridges that consist of homogeneous sand and gravel deposited on beaches. The stratigraphy of thicker sections suggests the presence of offshore bars and barriers along some stretches of the low shore ridge and further suggests that these stretches of the low shore ridge may have formed during higher stages of the lake. Haplargids and Camborthids have developed on the shoreline deposits. The low and intermediate shorelines have identical soils with morphologies comparable to Holocene soils in the Las Cruces area. A Holocene age for soils of these two shorelines is supported by limited archeological evidence; the inferred Holocene age for Lake Animas at these levels is consistent with radiocarbon chronologies of other western lake basins and with local and regional paleoclimate reconstructions. The age of the soil and material of the high shore ridge is probably Pleistocene.

Introduction

At least three small lakes occupied closed intermontane valleys in southwest New Mexico during the late Quaternary. The largest of these, Lake Animas, has the most continuous and best preserved shoreline features. The lacustrine origin of these features was first recognized by Schwennesen (1918) who traced them around the playas in the lower end of the Animas Valley. However, he postulated a high-stage elevation of 4,390 ft on the basis of ridges near Animas, New Mexico, approximately 20 mi south of the playas. A lake at this level would have submerged the divide at Summit railroad siding to a depth of 150 ft and would have extended far into the Duncan Basin to the north.

Later workers investigating adjacent mountains have made brief references to shoreline features of Lake Animas. Gillerman (1958) mapped shore gravel on the west side of the valley at elevations below 4,200 ft; Flege (1959) mapped a high-shore position on the east side at elevations ranging between 4,225 and 4,250 ft. Morrison (1965a) mapped lake gravels at high elevations in the Duncan Valley to the north. The highest of these gravels occurs below the divide at Summit (4,240 ft), which led him to conclude that the two valleys had never been connected in a single lake (Roger Morrison, personal communication, 1977).

The Animas Valley has also been regarded as the sump of the ancestral Gila River. Kottlowski and others (1965), citing a personal communication from R. H. Weber, suggested that the combined San Francisco River and Gila River drainages may have emptied into Lake Animas in the middle Pleistocene(?). Hawley (1975) and Hawley and others (1976) indicated this on maps of early and middle Quaternary paleodrainages of New Mexico.

This study was conducted to resolve discrepancies of stage-elevation estimates through detailed mapping of shoreline features, to determine the geologic history of the lake, and to obtain more refined age estimates of the lake. Fig. 1 shows the location of the study area relative to Lake Animas and Hidalgo County.

Quaternary deposits

MAPPING UNITS

The units on the geologic map (in pocket) are regarded as morphostratigraphic (Frye and Willman, 1962) because they emphasize landform development or landscape setting. Most of the units have a degree of lithologic integrity as well, so they can also be regarded as rock-stratigraphic units. The chief purpose of mapping was to accurately portray the distribution of shoreline features of Lake Animas; accordingly, field checking was limited to shorelines. Other contacts were derived from airphotos, interpretation of county soil maps (Cox and others, 1973), and extensive field work. The geologic map encompasses most of the Gary, Mon-del, Steins, and Swallow Fork Peak 7.5-minute topographic quadrangles (fig. 1).

Eolian sand *(Qd)* covers the area between North Alkali Flat and Lordsburg Draw in the northern part of the map area. Older surfaces, soils, and sediments buried by the sand are exposed locally in small deflation basins. *Qd* occurs extensively on Lordsburg Mesa. Poorly developed longitudinal dunes north of the map area trend roughly N. 30 ° E.

Three playas *(Qp)* aligned on a nearly north-south axis occupy the lowest part of the Animas Valley (frontispiece). South Alkali Flat, the largest playa, with an area of approximately 16.2 sq mi, is notable for the giant desiccation cracks that form a polygonal network on its surface (Lang, 1943). No such cracks are visible on North Alkali Flat. This playa, however, has a pronounced beach or foreshore slope on its eastern and southern margins that is mantled with a lag of varnished gravel.

Shoreline features are associated with playa margins *(Qsy)*. The most prominent of these features is a ridge along the southern and eastern margins of North Alkali Flat. This ridge, rising 10 ft or more above the playa and composed of material resembling playa sediments, may have been formed in part by eolian deposition of deflation-derived playa sediments.

Other ridgelike features that occur along the northwest margin of South Alkali Flat are indicated by a special symbol on the map. On airphotos, the ridges appear as alternating dark and light bands. The swells are composed of playa materials; relief is 1 or 2 ft. Arcuate traces of crest lines broadly parallel present playa margins but do not strictly parallel topographic contours. Outer ridges are truncated by inner ones, indicating that the ridges become successively younger toward the playa. These ridges bear no relationship to shore ridges of Lake Animas and may represent former playa margins. The highest of these ridges lies as much as 10 ft above the present playa floor.

The valley *flat (Qvf)* is the level plain, exclusive of the playas, that occupies the central part of the valley. The surface consists mainly of those areas sloping down the basin axis, as opposed to those areas sloping toward the basin axis (piedmonts). The valley flat also includes gently sloping areas that are transitional between piedmont toeslopes and playas, and vegetated areas between playas. Surficial sediments of the valley flat consist of fine-grained sand, silt, and clay similar to playa sediments. Gravel is found at shallow depths within the delta of the ancestral Animas Creek. Sinuous groves of mesquite that indicate the positions of former channels are shown on the frontispiece.

The younger alluvial-fan complex *(Qfy)* is composed of surface elements of the fan piedmont that have formed since the construction of Lake Animas shore ridges. Therefore, the younger alluvial-fan complex designates areas of most recent deposition, primarily in active washes and piedmont toeslopes. As the term "complex" implies, *Qfy* includes several geomorphic units referred to as foreridge slope, interridge trough, and modern fan and wash. These units are illustrated in detail on fig. 2.

The foreridge slope **(R)** is a concave slope graded from the low shore ridge to the valley flat. Strata in the basal part of the shore ridge are truncated by this surface, indicating an erosional origin. This slope may have been cut by either wave erosion as the lake level receded, by alluvial processes, or by both. Interridge troughs (T)

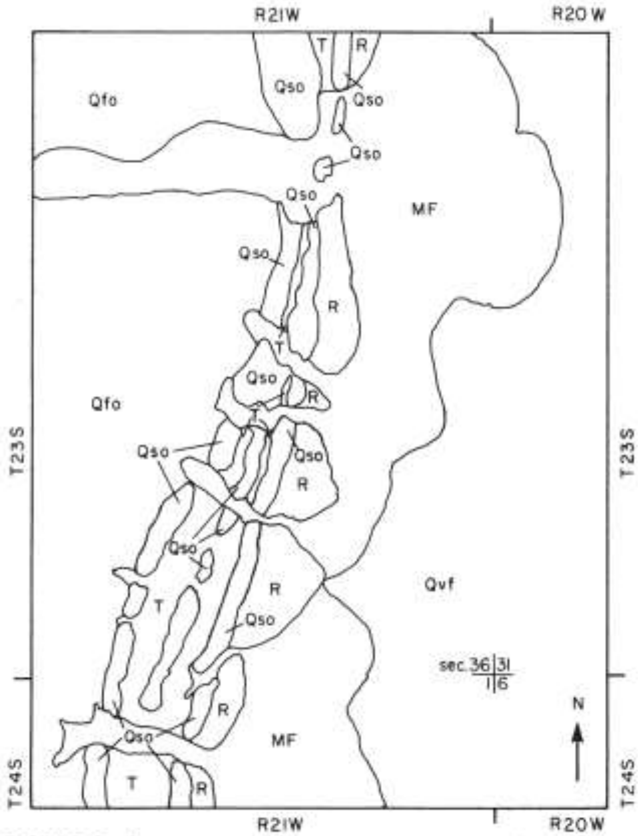

FIGURE 2—Detailed morphostratigraphic map of Lake Animas shore zone on west side of Lower Animas Valley near Robinson Windmill; *Qfo*, *Qso*, and *Qvf* are defined on geologic map (in pocket). Subunits of *Qfy* shown include: T = interridge trough, MF = modern fan and wash complex, and R = fore-ridge slope. Approximate scale is 1:16,800.

are flat, low-lying areas between shore ridges. Sediments filling the troughs consist of clayey silt. Small alluvial fans (MF) formed where washes breached the low shore ridge. Individual fans have surface areas of 0.25 sq mi and are coalescent where closely spaced. Sediments composing the fans are sandy gravel and gravelly sand.

Older shore ridges *(Qso)* marking shoreline positions of Lake Animas lie on piedmont toeslopes of the Pyramid and Peloncillo Mountains. In most areas, there are three such ridges, referred to in ascending order as the low, intermediate, and high shore ridges.

The low shore ridge is the most prominent, with relief up to 30 ft on the lakeward side and 10 ft on the landward side (Schwennesen, 1918). The profile of the ridge is asymmetrical with a gentle, concave, lakeward slope, a convex crest, and a steep, landward slope. Higher shore ridges, neither as conspicuous nor as continuous as low-shore ridges, form symmetrical, convex swells that often rise only a few feet above their surroundings.

The older alluvial fan complex *(Qfo)* consists of piedmont surfaces constructed prior to the high stage of Lake Animas. This older fan complex has a relatively stable surface undergoing slow erosion. Although this complex is probably not a single unit, we did not attempt to subdivide it. Sediments composing *Qfo* are sandy, cobble gravel and gravelly sand, often with a clayey, pedogenic matrix.

STRATIGRAPHY AND SOILS

The units on the geologic map and fig. 2 emphasize the geomorphic setting of surficial sediments in the Lower Animas Valley. The following discussion concerns the rock-stratigraphic character of these units. Informal rock-stratigraphic units are designated by letters in sequence of deposition (A, oldest). Subdivisions of the main units are designated by numerals in sequence of deposition (Al, oldest). Major soils associated with the sediments are designated by S followed by a numeral showing position in sequence of development (S1, oldest). Fig. 3 illustrates diagrammatically the strati-graphic relationships of lacustrine and alluvial sediments and soils in the Lake Animas shore zone. Table 1 shows the relationships among morphostratigraphic units (geologic map; fig. 2), rock-stratigraphic units, and soil units (fig. 3).

Localities 4 and 7 (geologic map) exhibit the stratigraphy portrayed in fig. 3. To summarize, a well-developed soil (S1 in unit A alluvium) is overlain unconformably by unit **B** alluvium. Unit **B** has a well-developed soil (S2) that is overlain by younger sediments on piedmont toeslopes but elsewhere lies at the surface of the piedmont *(Qfo).* Units C 1 , C2, and C3 are lacustrine sediments that form the shore ridges *(Qso).* Alluvium of unit **D** fills erosional depressions between shore ridges and mantles surfaces lakeward from the low shore ridge to form *Qfy.* The erosional unconformity at the base of unit **D** is most pronounced in the inter-ridge troughs where the unconformity cuts into unit **B.** This erosion may have produced the stratigraphic isolation of the shore ridges by removing any lacustrine sediments present between the ridges.

FIGURE 4—Exposure of unit C2 overlying unit B at locality 8. Unit A is exposed at base. See profile 6, Appendix, for description.

TABLE 1—Relationship of informal stratigraphic units associated with Lake Animas. Buried, weakly developed soils are observed in many exposures of unit D alluvium. Soil S5 generally refers to the variety of soils developed on unit D at the surface.

Morphostratigraphic unit	Rock-stratigraphic unit	Soil unit
Qfy	D	S5
Qso	C3	S4
	C2	S4
	C1	S3
Qfo	B	S2 (locally buried)
No landsurface counterpart	A	S1 (buried)

Unit A alluvium and its associated soil, S1, have not been identified in a land-surface position and have only limited exposures in arroyo walls. Few sedimentary features other than lentils and stringers of pebble gravel have been preserved. The distinguishing characteristics are mostly pedogenic. At locality 7 (geologic map and fig. 4), S1 has a high clay content and common, coarse, prominent mottles from soft masses of calcium carbonate (profile 6, 201-224 cm interval, appendix). Similar material overlies a stage III calcic horizon (Gile and others, 1966) at locality 8. Only a petrocalcic horizon in gravelly material is found at locality 9.

Unit **B** alluvium overlies unit A unconformably (fig. 4). Sediments consist of poorly stratified gravelly sand

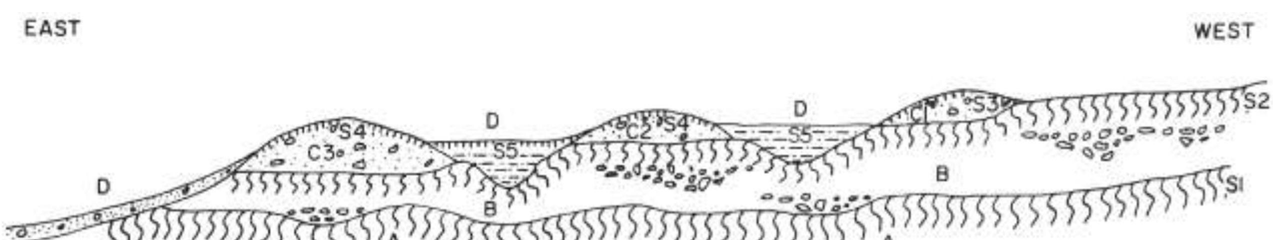

FIGURE 3—Diagrammatic cross section showing stratigraphic relationships of alluvial units A, B, and D, lacustrine units C1, C2, C3, and paleosols S1–S5. See table 1 for correlation with map units of geologic map.

with lenses of cobble-boulder gravel that probably represent former channel bars. The gravel of unit B is distinctly coarser than that of unit A. Soil S2, developed in unit B sediments, has an argillic horizon with angular blocky, and prismatic structure and clay content up to 35 percent. Calcium carbonate in gravelly C horizons has a stage II morphology (Gile and others, 1966). Detailed descriptions of S2 in both buried and land-surface positions are presented in the appendix (profiles 4, 71-104 cm; 5; 6, 107-201 cm). Soil S2 is shown in buried and land-surface positions in figs. 4 and 5, respectively.

Near locality 8, unit B has been physically traced from a buried position beneath unit C *(Qso)* to its land-surface position on *Qfo.* S2 has nearly identical morphologies in both buried and surface positions, indicating that its morphology was developed prior to burial by younger sediments. C1, corresponding to the high shore ridge, is the oldest unit overlying unit B. Therefore, *Qfo* had been stable for a long period of time prior to the high stage of Lake Animas.

Lacustrine sediments of unit C overlie S2 unconformably. S2, where buried by unit C, appears to have undergone only slight erosion, and the unconformity is smooth and nearly planar (fig. 4).

Subunits C1 and C2, composing the high and intermediate shore ridge respectively, consist of 3-4 ft of homogeneous, gravelly sand and sand. C3 corresponds to the low shore ridge and is identical to C1 and C2 at many localities but has a more complex stratigraphy in some areas. The thickness of C3 ranges up to 10 ft.

The following sequence of sediments of C3 is observed at locality 1 (geologic map; fig. 6): 1) gray,

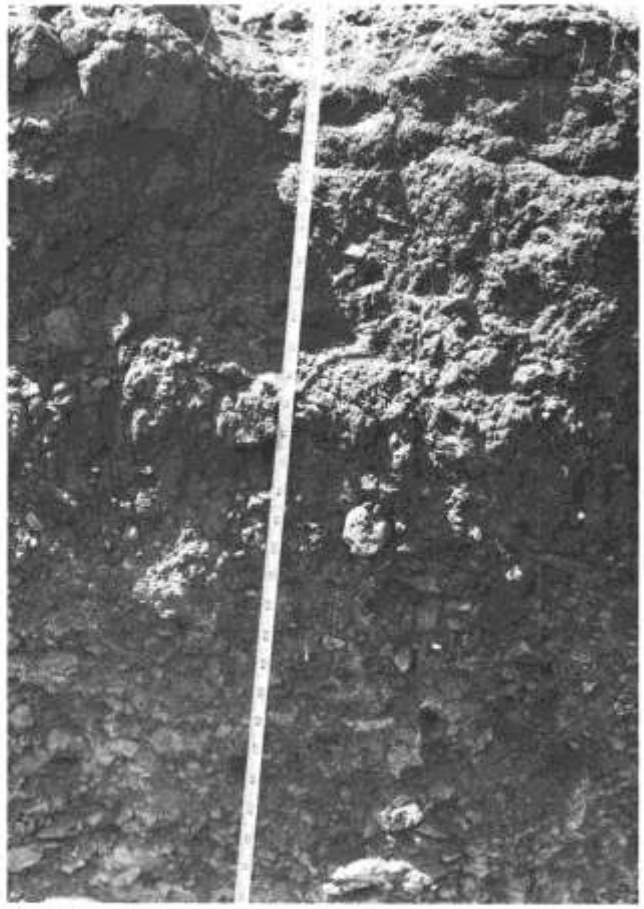

FIGURE 5—Typical profile of soil S2 in alluvial unit B. The soil shown here is probably Mohave Series; note the argillic and calcic horizons that characterize S2. See profile 5, Appendix, for description.

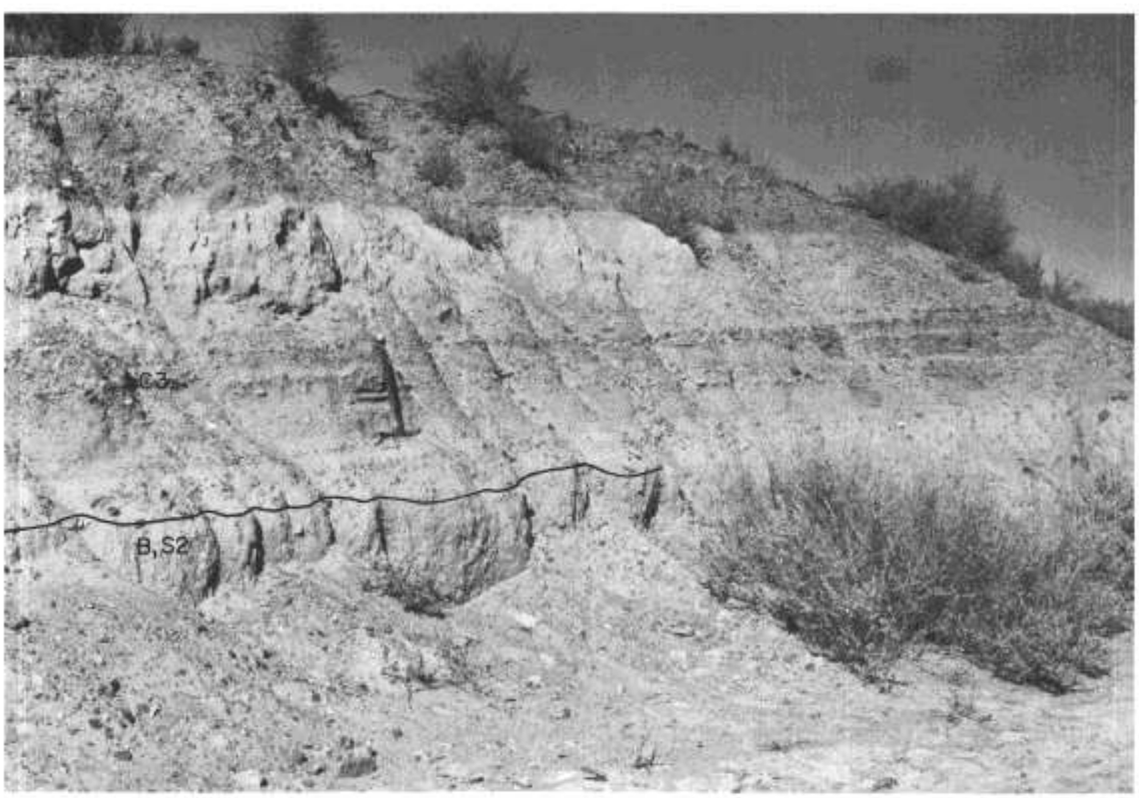

FIGURE 6—Unit C3 exposed in Banner Canyon Arroyo, locality 1. Soil S2 of unit B is exposed at base.

lacustrine silt overlying unit **B;** 2) stratified sand and gravel; 3) gray silt; and 4) homogeneous, gravelly sand. Parts of this sequence are observed northward from here along the ridge. At locality 2, unit **B** is overlain by a gray, lacustrine silt containing ostracods; the gray silt is in turn overlain by east-dipping, cross-stratified gravel. This same cross-stratified gravel is exposed at locality 3 where the gravel is overlain by a gray silt similar to the upper silt of locality 1. At locality 4, C3 consists of 3 ft of homogeneous, gravelly sand overlying unit **B.** Here, all lower units observed at localities 1 through 3 are missing.

Similar stratigraphic sequences and sediments are observed on the west shore. A basal, gray silt overlies unit **B** at localities 5 and 6. Landward-dipping, cross-stratified sand and gravel are found low in the sequence at localities 6 and 10. The upper silt observed at localities 1 and 3 was not observed on the west shore.

The thicker, more complex sections, such as those at locality 1, generally can be interpreted as representing a shallowing-upward sequence. The basal, gray silt overlying unit **B** is interpreted to be an offshore deposit. Landward-dipping cross-strata, interpreted to have formed in longshore bars, are similar in appearance to deposits in bars created in wave-tank experiments by McKee and Sterret (1961). The uppermost unit of homogeneous, gravelly sand and sand is interpreted to be a beach deposit; this interpretation is based largely on considerations of shoreline morphology discussed in the next section.

The upper silt overlying cross-stratified gravel at localities 1 and 3 could be interpreted to represent a second deep phase, but no parallel deposit is found in this position on the west side of the lake. Consequently, this unit probably represents local quiet-water or protected conditions along this stretch of the shore.

Two distinct soils, S3 and S4, are developed in unit C. Soil S3 is confined to unit C1 which composes the high shore ridge; soil S4 is found on both C2 and C3 which compose the intermediate and low shore ridges, respectively.

A representative profile of S3, described in the 0-71-cm interval of profile 4 (appendix), is shown in fig. 7. This soil has an argillic **B** horizon that contains about 20 percent clay and exhibits coarse, prismatic structure. The soil shows a slight reddening with a Munsell hue between 10YR and 7.5YR and is easily distinguished from S2 on the basis of color alone. The C horizon is massive, that is, it does not display any primary depositional features. In contrast to other soils, S3 is non-calcareous throughout.

Representative profiles of soil S4 are described in profiles 1 and 2, and in the 0-107-cm interval of profile 6 (appendix). Profile 6 is shown in fig. 4. This soil has a cambic **B** horizon containing up to approximately 8 percent clay. The **B** horizons are usually astructural, but some profiles have a fine crumb or granular structure. Locally, **B** horizons of S4 may border on incipient, argillic-horizon development. Calcareous C horizons consist of gravelly sand and sand containing less than 1

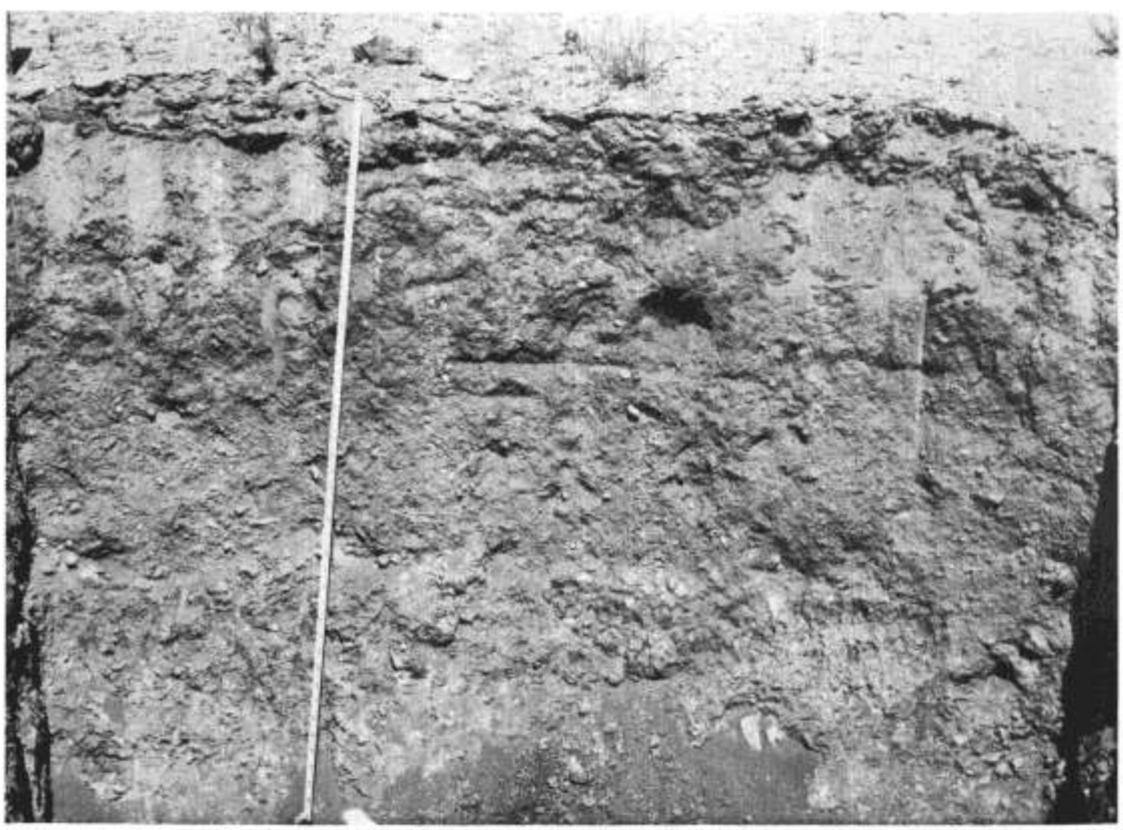

FIGURE 7—TYPICAL PROFILE OF SOIL S3 IN UNIT C1. This soil has an argillic B horizon and a noncalcareous C horizon. The buried soil is S2. See profile 4, Appendix, for description.

FIGURE 8—FINE-GRAINED ALLUVIUM OF UNIT D IN INTERRIDGE TROUGH AT LOCALITY 1.

percent clay. Calcium carbonate in these profiles has a stage I development; Munsell hues are 10YR without exception.

Unit **D** consists of alluvium deposited on the piedmont after deposition of unit C. The sediments composing this unit occur in a number of landscape settings of different ages (figs. 2 and 3). The only subunit of importance to shore-zone stratigraphy is the silty alluvium filling the interridge troughs (fig. 8). From all appearances, this sediment was deposited following a period of gullying in the interridge areas and overlies unit **B** alluvium; at locality 4, the sediment is inset against both unit **B** and unit C. Although the sediment appears homogeneous, unconformities are present within the subunit as evidenced by stonelines and buried, weakly developed soils.

Typical soils developed on unit **D** alluvium are Entisols. One profile examined in alluvium of the interridge trough is probably a Camborthid (profile 3, appendix). Cox and others (1973) have mapped soils of various taxa in this position including Natrargids and Torrerts.

Lake Animas

SHORELINE FEATURES

The map of shoreline features of Lake Animas indicates three distinct lake stages (geologic map). Locally, there are as many as five shore ridges, but not all of these appear to represent stabilized lake levels. All evidence of shorelines is confined to elevations between 4,200 and 4,165 ft. Ridges associated with playa margins occur between 4,160 and 4,150 ft.

Fig. 9 shows the frequency of occurrence of shoreline elevations rounded to the nearest 5 ft. Data were obtained from a preliminary map (scale 1:24,000) by tracing each shoreline and estimating an average elevation in each section where a shore feature occurred (Fleischhauer„ 1977, p. 26-27). Two elevation values were taken from the intermediate shore ridge in both sec. 28 and sec. 32, T. 22 S., R. 19 W. because of significant vertical changes along its length. One high-shore elevation of 4,195 ft from the east side of the lake was taken from a wave-cut bench; all other elevations were taken from the lakeward margins of shore ridges. This procedure essentially interprets all shore ridges as beaches; such an interpretation is not strictly valid at all localities.

Fig. 9 indicates that the vertical range increases in successively lower shorelines. The high shore ridge occurs between 4,195 ft and 4,190 ft. The narrow vertical range, considered with nearly parallel ridge development on both sides of the valley, precludes tectonism as the mechanism that produced the observed variability in the low and intermediate shore ridges. Instead, this variability can be accounted for by changes in depositional environments and shore processes along the length of the lower shorelines.

The intermediate shore ridge has a pronounced elevation mode at 4,185 ft. This is the lowest elevation of the shore ridge on the west side of the lake and is considered to be the best estimate of the stage elevation. Four of the six values deviating from the mode on the east side of the lake are from the mouth of Lordsburg Draw (secs. 29 and 32, T. 22 S., R. 19 W.) where the ridge descends from near 4,190 ft to 4,175 ft over a distance of approximately 1 mi. These elevation changes are inconsistent with a beach origin; if these values are disregarded, the 4,185-ft mode is considerably strengthened and variability reduced.

The assignment of the low-stage elevation is more difficult because of a vertical range of 20 ft on both sides of the valley. The internal stratigraphy of the low shore ridge indicates a more complex history than is evident in higher ridges. A variety of depositional environments, deduced from morphology and stratigraphy, seem to be represented here, so the assumption of a beach origin introduces the most error. However, some of the elevations can be discounted as representing true lake levels, and the range of values can be reduced to permit a reasonably accurate estimate.

A modal elevation of 4,180 ft occurs on each side of the valley. On the west side, four values less than the mode are localized at the distal part of Doubtful Canyon fan. The elevation of the low shore ridge climbs in both directions from this point. Likewise, three low values at 4,170 ft and below occur on the east side of the lake at the entrance to Lordsburg Draw where the low shore ridge parallels the descent of the intermediate shore ridge. The localization of these extreme values suggests the influence of local conditions or a change of depositional environment and a correspondingly low reliability for these elevations as stage indicators. Disregarding these values, the minimum elevation of low stage is 4,175 ft. The highest elevation on the east side of the valley, 4,180 ft, is the upper limit of the range in elevation; thus, the low stage lies between 4,180 ft and 4,175 ft.

Fig. 10 is revised from fig. 9 to show frequency occurrence of shoreline elevations from features that do conform to a beach interpretation. Mean elevations are not significantly different, but the variability is reduced.

No shoreline features or lacustrine sediments were found above the elevation of the high shore ridge (4,190-4,195 ft) within the study area. At this level, Lake Animas had a length of approximately 17 mi along the valley axis and a width of approximately 7 mi at the

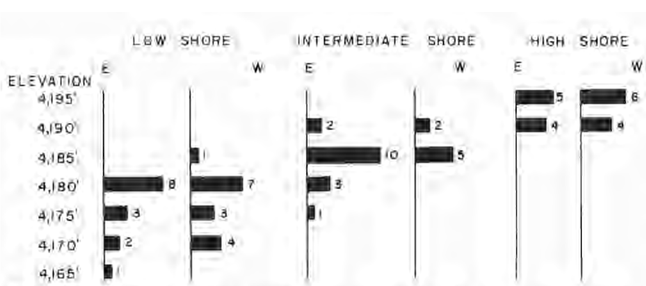

FIGURE 9—HISTOGRAM SHOWING FREQUENCY OF SHORELINE ELEVATIONS OF LOWER ANIMAS VALLEY. Elevations (one per section) are taken from lakeward toe of shore features without regard to depositional environment; E indicates east side of valley, W indicates west side.

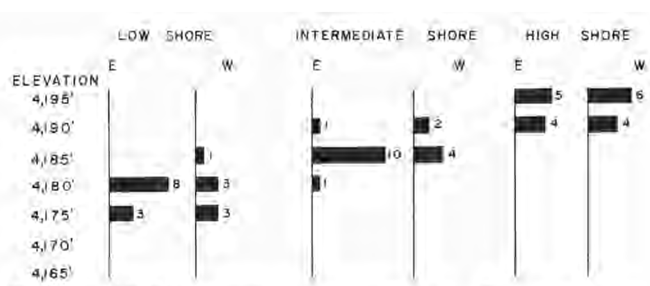

FIGURE 10—HISTOGRAM REVISED FROM FIG. 9 SHOWING FREQUENCY OF SHORELINE ELEVATIONS OF LOWER ANIMAS VALLEY. Elevations represented are associated with shore features that conform physiographically and stratigraphically to a beach or foreshore environment.

latitude of Robinson Windmill. Surface area was approximately 150 sq mi and maximum depth, estimated from present topography, was approximately 50 ft.

The scarp described as a wave-cut terrace by Flege (1959) is apparently a fault scarp. This feature lies between elevations of 4,230 and 4,270 ft and locally cuts sharply across topographic contours (geologic map). This relationship to topography, together with angular bends in its trace, is inconsistent with a shoreline interpretation. Furthermore, no shoreline occurs at a similar elevation on the opposite side of the lake.

As stated above, the assumption of a beach origin for constructional shoreline features is not strictly valid at all localities. The processes operating along a given stretch of shore and the types of shoreline features formed are strongly influenced by coastal physiography. In the Animas Valley, the low-lying area along the north side of Lordsburg Draw apparently gave rise to an embayed coast in which the action of currents dominated. In contrast, the comparatively smooth, regular shoreline along the piedmonts in the main body of the lake probably was strongly influenced by wave action.

Fig. 11 shows a possible interpretation of shoreline features on the north side of Lordsburg Draw, just off the northeast edge of the map. Wave erosion was sufficiently strong to oversteepen slopes on bedrock hillslopes and to form small wave-cut benches. Headland beaches and bayside beaches formed along the margins of the bay, while current-produced embankments extended into and across the bay. The baymouth bar is lower in the center than on the ends where it attaches to headlands, suggesting that longshore currents moved in two directions across the bay and that this bar was formed by the joining of two spits. An alternative explanation is that currents entering or leaving the bay could have eroded a saddle in the bar.

In the main body of the lake, shore ridges tend to parallel the topography of the piedmont, though the low shore ridge tends to become straighter with respect to piedmont topography. The ridges are widely spaced in topographic reentrants and closely spaced or mergent around topographic salients.

The high and intermediate shore ridges almost exactly parallel topographic contours of the piedmont (geologic map). This parallel alignment is a physiographic characteristic of beaches (Gilbert, 1885, 1890; Russell, 1885), and the topographic form of the ridges resembles that diagrammed by Gilbert (1890). This physiographic aspect led to the interpretation of the homogeneous, gravelly sand composing these ridges as a beach deposit. The simple stratigraphy and the preponderance of platy gravel in some localities (Landon, 1930) also point to this origin.

In some areas, the low shore ridge is also best interpreted as a beach on the basis of its morphology and stratigraphy. However, as shown by stratigraphy, portions of this ridge are more complex in origin. Between

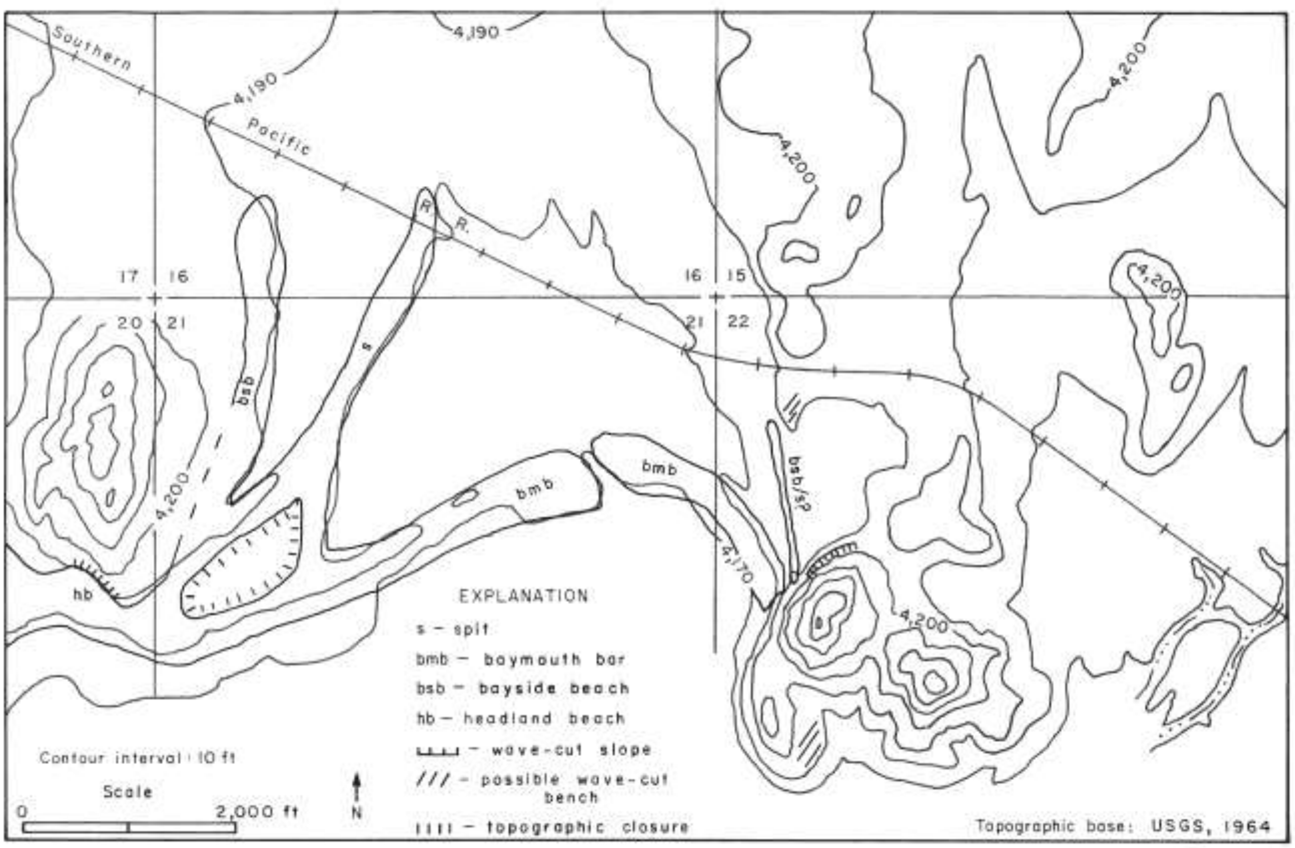

FIGURE 11—Interpretation of shoreline depositional environments in an embayed coastal setting along north side of Lordsburg Draw, northeast of study area. The area lies in secs. 15, 16, 17, 20, 21, and 22, T. 22 S., R. 19 W.

Braidfoot Tank and Butterfield Tank, the low shore ridge is straight, and locally its crest rises above 4,190 ft, the minimum elevation of the high shore ridge (geologic map), suggesting a barrier bar or island and the presence of a lagoon behind it. From the point of highest crest elevation, the toe and crest of the ridge decrease in elevation toward Butterfield Tank. Coupled with this elevation decrease is a decrease in maximum clast size from cobble to pebble. These facts probably indicate that sediment transport direction was north-northeast along this part of the shore and that the barrier became submerged laterally.

Speculation arises from the absence of the intermediate shore ridge along this reach of the shore. The sheltering effect of a barrier when the lake was at intermediate stage may have prohibited the development of the beach. The importance of the speculation lies in the implication that parts of the low shore ridge were constructed during higher stages of the lake. Unfortunately, no available data compel this conclusion, although two facts are consistent with it: 1) the absence of the intermediate shore ridge just described, and 2) the internal stratigraphy of the low shore ridge. At localities 5 and 6, between Braidfoot Tank and Butterfield Tank (NE1/4 sec. 24 and SE'/ sec. 13, T. 23 S., R. 21 W.), gravelly sediments of the barrier overlie offshore muds; this indicates that initial construction of the ridge began in deep water, but implies nothing about which stage the lake occupied at the time.

Several deductions emerge from the above discussion. Stage elevations obtained by applying a uniform interpretation of origin to constructional shoreline features may yield results that vary substantially (fig. 8), thereby reducing confidence in the estimates. This variability results from multiple origins of shoreline features. Shoreline features also may have developed during two or more lake stages. The best estimates of stage elevations are obtained through the combined use of stratigraphy and shoreline morphology.

Soil ages of shoreline features

Accurate dating of shorelines is an important aspect of any study of Quaternary lakes because of their important paleoclimatic and geomorphic implications. In the case of Lake Animas, conclusive dating by radiometric, archeologic, or paleontologic methods has not been possible. Instead, age estimates were obtained by studying the soils developed in shoreline sediments and comparing aspects of their morphology with the morphology of dated soils in the Las Cruces area. Such an approach yields an estimate of minimum age because soil formation occurs after deposition of the parent material and stabilization of the surface. As a check, age estimates were compared with radiocarbon chronologies of other lakes in the western United States and with regional paleoclimatic reconstructions, as described in the following sections.

In the semiarid regions of the southwestern United States, soils tend to become redder, more calcareous, and more clay rich with age; processes of pedogenesis result in the formation of calcic, cambic, and argillic horizons (Soil Survey Staff, 1975). The rates at which these processes operate vary temporally as a result of climate changes and vary spatially as a result of changes in other factors such as texture and composition of parent material, and landscape setting. The underlying assumption in using soils for dating is that rates of pedogenesis are equal at the sites being compared. The assumption seems valid in this instance because of the proximity of the study area to Las Cruces and the similarity of climate, geology, vegetation, and landscape. Furthermore, many of the same soil series are found in the two areas (Maker and others, 1970, 1971; Cox and others, 1973).

Soil color, the least dependable property for age determination, is perhaps best used to show trends or relative ages. Gile (1975, p. 338, 350) noted that soils with Munsell hues as red as 5YR form in rhyolite-derived alluvium of Fillmore age (Holocene). At Las Cruces, Holocene soils have not been observed to be redder than 5YR or to have chromas higher than 4. Soils with Munsell hues of 2.5YR are invariably of Pleistocene age in the Las Cruces area.

Calcium-carbonate accumulation is one of the most time-sensitive properties of soils in semiarid and arid regions. Gile and others (1966) described the morphogenetic sequence of carbonate accumulation, noting differences resulting from texture of parent material. Table 2 summarizes the chronology of pedogenic carbonate accumulation.

In soils developed on low-carbonate parent material, clay accumulation results in the development of cambic and argillic horizons. Gile (1975) has presented a chronology for the development of these horizons (table 3). Cambic and argillic horizons can form in as little as 1,000 to 2,000 yrs. A strong influence is exerted by the texture of parent material, with coarser textures favoring more rapid clay accumulation. After a period of

TABLE 2—Chronology for the development of pedogenic carbonate; **NG**, nongravelly soils; **G**, gravelly soils (modified from Gile, 1975, table 2, p. 324).

Age	Geomorphic surface	Stage of $CaCO_3$ accumulation NG	G
100–7,500 yrs. B.P.	Fillmore, Organ	I	I
before 7,500 yrs. B.P.	Leasburg, Isaacks' Ranch	II	II, III
late Pleistocene	Picacho, Jornada II	III	III, IV
late-middle Pleistocene	Jornada I	III	IV, Multiple laminar horizons
early-middle Pleistocene	La Mesa	IV	

TABLE 3—CHRONOLOGY OF PEDOGENESIS FOR HOLOCENE SOILS IN LOW-CARBONATE MATERIALS, LAS CRUCES AREA, NEW MEXICO (from Gile, 1975, table 10, p. 356–357).

Age (yrs B.P.)	Diagnostic horizon Nongravelly	Gravelly	Carbonate
1,100	Cambic	Argillic	Discontinuous coatings on pebbles
4,000 (?)	Cambic, incipient argillic		Continuous coatings on pebbles
7,000 (?)	Argillic horizons continuous through nongravelly and gravelly material		Coatings on sand grains in non-gravelly alluvium

approximately 7,000 yrs or more, argillic horizons probably are continuous through facies changes from gravelly to non-gravelly parent materials (Gile, 1975, p. 358).

Table 4 lists the time-significant properties of the soils of the Lake Animas shorezone along a transect in sec. 36, T. 23 S., R. 21 W. Stratigraphic relationships provide relative ages of sediments and soils (fig. 3) as well as constraints on absolute ages assigned by soil morphology.

Soil S2, developed in unit B alluvium of the older fan surface *(Qfo),* has a calcic horizon and a strongly developed argillic horizon. This soil is buried beneath shore-ridge sediments where it displays the same properties (that is, this morphology developed prior to construction of the oldest shore ridge of Lake Animas). The fan surface and unit B are interpreted to be of Pleistocene age; however, no more precise estimate is possible from soil morphology alone.

The argillic horizon and color of soil S3 in unit C1 of the high shore ridge mark this soil as the oldest of soils developed on the shore ridges. This interpretation is consistent with the observation that the high shore ridge is less continuous and more eroded than the low and intermediate shore ridges. The absence of calcium carbonate is puzzling, and the presence of the argillic horizon alone is not sufficient to estimate an age based on Gile's chronology; this soil is possibly of late Wisconsinan age.

TABLE 4—SUMMARY OF AGE-SIGNIFICANT PROPERTIES OF SOILS OF THE LAKE ANIMAS SHOREZONE, SEC. 36, T. 23 S., R. 21 W. Stages listed under Carbonate are morphogenetic stages of Gile and others (1966).

Soil position	Munsell hue	Diagnostic horizon	Carbonate
Low shore ridge	10YR	Cambic	Stage I
Intermediate shore ridge	10YR	Cambic	Stage I
High shore ridge	7.5YR	Argillic	Noncalcareous
Fan surface	5YR	Argillic, calcic	Stage II
Interridge trough	10YR, 7.5YR	Cambic	No macroscopic accumulation

In May 1961, partial remains of two mammoths were discovered in Lordsburg Draw, 1 mi north of Lordsburg (Kipp, 1962). The bones were uncovered during excavation of a borrow pit (SE 1/4 SW 1/4 NW 1/4 sec. 28, T. 22 S., R. 18 W.) for construction of US-70. Descriptions of the site by the Soil Conservation Service (made available by John W. Hawley) indicate the following:

1) the bones occurred in lacustrine clay beds at an elevation of 4,177 ft
2) a paleosol is developed in these clay beds
3) the clay beds and associated paleosol are overlain by the alluvial-fan toe-slope deposits that form the modern surface and in which the modern soil is developed
4) detailed dating of the mammoth material was not done.

Stratigraphic relationships between the mammoth site and the area we studied are not clear, and additional study is hampered by the flooded condition of the borrow pit. Shore ridges do not appear to occur in this arm of the lake; they may have been destroyed by later alluvial activity or may never have formed. At high stage, the lake in this area would have been less than a mile wide. The fetch would not have been sufficient to permit large waves to form, and the resulting low-energy conditions would not have fostered construction of ridges.

Interpretation of the mammoth remains in terms of the chronology of Lake Animas depends on the correlation of the overlying fan-toe deposits with the alluvial sequence of the study area. If the overlying deposits correlate with unit B *(Qfo),* then the remains predate the high shore ridge and point to the existence of an earlier lake. If the overlying deposits correlate with unit D *(Qfy),* then the remains may relate to one of the lake stages associated with shore ridges in the study area. Lacking further details, we interpret the remains as providing a maximum age of Pleistocene for Lake Animas in general and the high shore ridge in particular.

Soil S4, developed on the lower two shore ridges, has calcium carbonate with a stage I morphology (Gile and others, 1966); on this basis, the soil may be no older than 7,500 yrs B.P. Only cambic horizons have been identified, so the soil could be younger than 7,000 yrs B.P. and as young as 4,000 yrs B.P. A Holocene age for these soils is supported by the discovery of a metate, or grinding stone, in sediments of unit C2. The artifact might be intrusive (R. H. Weber, personal communication, 1976), in which case it postdates deposition of the sediments. However, a fairly typical S4 soil is developed in overlying material so the artifact has some antiquity.

Soils developed in sediments of the interridge troughs display varied profile characteristics. In some areas, profiles may even display more highly developed properties than stratigraphically older, shore-ridge soils. However, differences in texture of parent materials do not permit strict comparison of the two soils. These soils are probably Holocene in age. Indian pottery fragments are found on the surface at several localities in the interridge troughs, establishing a minimum age of less than 2,000 yrs.

To summarize, soil S2 developed on *Qfo* is Pleistocene in age and had developed much of its present morphology by the time Lake Animas rose to its highest stage. Soil S3 of the high shore ridge is possibly late Wisconsinan in age. A Holocene age seems likely for the soils of the low and intermediate shore ridges. The soil ages point to the possibility of two middle Holocene lake stands in the lower Animas Valley.

Correlations and paleoclimate reconstructions

The ages of Lake Animas shore ridges given above represent little more than best guesses. However, the chronology is not entirely unreasonable in light of existing chronologies of Quaternary lakes and paleoclimate reconstructions in the western United States.

CHRONOLOGIES OF OTHER WESTERN LAKES

Van Winkle (1914, p. 118, 123) was one of the earliest to advance the idea of a Holocene lacustral cycle. By measuring lake areas, composition of influent water, salt concentrations, and local evaporation rates, Van Winkle estimated the maximum age of Summer Lake and Lake Albert in Oregon to be perhaps no greater than 4,000 yrs B.P. He concluded that Summer Lake and Lake Albert could not be remnants of Pleistocene lakes that had occupied the basins and that the lakes had risen to their present levels following complete desiccation of the earlier water bodies.

Gale (1915, p. 264) obtained a similar age for Owens Lake, California, using the same methodology; however, his interpretation was fundamentally different. He viewed Owens Lake as the remnant of the deeper Pleistocene lake in that valley and interpreted the age to represent the time elapsed since the cessation of overflow. Antevs (1938) rejected this interpretation on the basis of data from the basin of Lake Lahontan, favoring the explanation given by Van Winkle (1914).

Early radiocarbon dating of sediments from Searles Lake, California, which received overflow from Owens Lake, indicated a lacustral period extending from about 23,000 yrs B.P. to about 10,000 yrs B.P. (Flint and Gale, 1958). The younger date actually represents the onset of deposition of the upper salt layer and is more accurately interpreted as the time when lake waters reached trona saturation. They concluded that desiccation actually began somewhat prior to this date. Dating of Holocene materials yielded inconclusive results.

Stuiver (1964) reported additional radiocarbon dates, and Smith (1968) presented a reconstruction of the history of Searles Lake. The radiocarbon dates of Searles Lake sediments have been reevaluated by Smith (1979).

The base of the parting mud, which represents the onset of the late Wisconsinan lacustral period, yielded dates of approximately 24,000 yrs B.P. Stuiver and Smith (1979, p. 74) felt that this date probably is too old and suggested that the probable date lies between 23,500 yrs B.P. and 21,500 yrs B.P. Seven dates from the top of the parting mud average 10,500 yrs B.P. Again, they regard this date as too old, suggesting a correct date between 10,000 yrs B.P. and 8,000 yrs B.P.

An interpretive time-space diagram shows four maxima during the parting-mud interval (Smith, 1979, p. 109, fig. 41). The earliest maximum spanned the period after 24,000 yrs B.P. to before 15,000 yrs B.P. The remaining three maxima are closely spaced between 13,000 yrs B.P. and 10,000 yrs B.P. and are separated from the earliest maximum by a prominent lake recession.

The upper salt, deposited during Holocene desiccation of Searles Lake, is overlain by the overburden mud deposited during the expansion of a shallow, saline lake no deeper than approximately 150 ft (Smith, 1979, p. 112). The base of the overburden mud is older than 3,520± 190 yrs B.P.

Broecker and Orr (1958) did not delineate a Holocene lacustral cycle for Lake Bonneville or Lake Lahontan. Their work showed that the late Wisconsinan lacustral interval occurred between 25,000 yrs B.P. and 11,000 yrs B.P., roughly coinciding with the interval of Searles Lake (Flint and Gale, 1958). According to the chronology of Broecker and Orr, Bonneville and Lahontan were generally at high levels from 25,000 yrs B.P. to 15,000 yrs B.P. From 15,000 yrs B.P. to 13,000 yrs B.P., these lakes were generally declining, but beginning about 12,500 yrs B.P. there was an abrupt rise that reached its maximum about 11,700 yrs B.P. No firm evidence supporting a post-11,000 yrs **B.P.** expansion was found, but the existence of such an expansion was postulated from four radiocarbon dates averaging approximately 9,700 yrs B.P. No evidence of carbonate exchange could be found, and the age could be raised no higher than 10,500 yrs B.P. by using the maximum control value (Broecker and Orr, 1958, p. 1,028). Following this postulated expansion, the lake levels declined abruptly and remained low for the remainder of the Holocene.

Broecker and Kaufman (1965) modified these earlier views with additional dating. Briefly, the late Wisconsinan lacustral interval was shifted forward in time to span a period from 18,000 or 20,000 yrs B.P. to approximately 8,000 yrs B.P. Two maxima occurred between 18,000 yrs B.P. and 14,000 yrs B.P.; two others occurred at 12,000 yrs B.P. and at 9,000 yrs B.P. The lakes were dry by 5,000 yrs B.P., and a minor cycle began after 4,000 yrs B.P. (Broecker and Kaufman, 1965, fig. 4).

Several objections were raised by Morrison and Frye (1965) and Morrison (1965b): 1) there were several clear age reversals in radiometric dating with regard to strati-graphic succession; 2) in some instances, samples from the same stratigraphic unit yielded ages differing by several thousand years; and 3) different chronologies could be constructed from the dates presented in Broecker and Orr (1958) and Broecker and Kaufman (1965) by selecting different sets of dates; the dates provided no unique solution.

Morrison and Frye (1965) advanced a different chronology based on regional correlation of geosols (Morrison, 1965c, 1978) and used radiocarbon dating of lacustrine samples as a secondary means of establishing a chronology. The overall history based on stratigraphy is complex and is marked by numerous fluctuations of the lake level. According to the scheme of Morrison and Frye, the late Wisconsinan lacustral interval began approximately 25,000 yrs B.P., with the highest maxima approximately 18,000 yrs B.P., 14,000-13,000 yrs B.P., and 10,000 yrs B.P. The lakes persisted after 10,000 yrs B.P. and disappeared completely approximately 7,000 or 8,000 yrs B.P. In the Lahontan Basin, the Toyeh Soil, with a radiocarbon age of 4,000 to 5,000 yrs B.P. confirmed by archeological evidence, is overlain by lacustrine sediments. The Midvale Soil in the Bonneville Basin is correlated with the Toyeh Soil (Morrison and Frye, 1965) and is overlain by the lacustrine Ridgeland Formation (Van Horn, 1979).

The area inundated by Lake Lahontan consists of nine separate basins that were united in a single body of water only after the water level rose above 4,290 ft. As the lake fell below this level, these basins became isolated one by one. Upon isolation, each basin behaved independently of its neighbor so that a climatic perturbation affecting one basin would not necessarily affect another in the same way (Benson, 1978). In view of the possibility of error introduced by time/space considerations, the stratigraphic approach of Morrison and Frye (1965) has more merit than the approach of Broecker and Kaufman (1965). However, as Benson (1978) pointed out, the approach of Morrison and Frye (1965) is merely an alternative. Correlation with the midwestern glacial sequences is based on the assumption of contemporaneity of continental glaciation and pluviation, or the interregional synchroneity of soil-forming intervals.

Benson (1978) presented additional information based on dating of Lahontan tufas; his study is more limited in scope and concentrates only on the basins occupied by modern Walker Lake and Pyramid Lake. Radiocarbon dates from tufa found above 4,290 ft cluster in two groups: 25,000 yrs B.P.-20,000 yrs B.P. and 12,600 yrs B.P.-11,000 yrs B.P. These dates suggest two separate stands at this level or higher. Benson presented data on ion concentrations in core samples from the modern lakes that he interpreted as an indication of Holocene drying prior to the expansion of the present lakes. Radiocarbon dates of Born (1972) from deltaic sediments of the ancestral Truckee River are also cited as evidence for drying of the lakes after 10,000 yrs B.P. and a post-5,000 yrs-B.P.-expansion.

A skeletal picture of the chronologies is shown in fig. 12. No clear consensus exists as to the timing of individual expansions and recessions, especially for Lake Bonneville and Lake Lahontan; it does not seem possible to resolve differences between researchers of individual lakes on the basis of available information. Because of uncertainty of the initial ^{14}C reservoir in lake waters and the difficulty in recognizing and compensating for post-depositional exchange of carbonate, the accuracy of the "C dates must remain in question, in spite of efforts of the various workers to address this problem.

The assumption of synchronous lake-level fluctuations between basins is questionable, but a general picture emerges. Perhaps as early as 25,000 yrs B.P., lakes in the western United States began to rise and may have reached high levels shortly thereafter. Numerous fluctuations (perhaps three or four major ones) occurred. Between 14,000 yrs B.P. and 10,000 yrs B.P., the lakes may have experienced a drastic expansion, but by 10,000 yrs B.P. they were dry or drying. Diminishing bodies of water may have persisted until approximately 7,000 yrs B.P., but evidence of this is not clear. Beginning approximately 4,000 to 5,000 yrs B.P., the lakes began to expand again.

PALEOCLIMATE RECONSTRUCTIONS

Fossil flora and fauna preserved in pack-rat *(Neotoma)* middens and cave deposits are an important source of information regarding climates of the late Wisconsinan. Although they do not yield unique reconstructions of paleoclimate, these deposits provide reliable material for documenting spatial and temporal changes in flora and fauna that occurred in response to climate. The time of climate changes has an especially important bearing on possible dates for fluctuations in lake levels.

Fossil flora in pack-rat middens indicate the presence of a stable piñon-juniper woodland from about 22,000 yrs B.P. to 11,000 yrs B.P. in basins of the southwest United States (Van Devender, 1977; Van Devender and Spaulding, 1979). Approximately 11,000 yrs B.P., the piñ°n-juniper woodland was succeeded by a juniper-oak woodland that persisted until approximately 8,000 yrs B.P. Shortly thereafter, modern floral assemblages appeared almost synchronously across the Mohave, Sonoran, and Chihuahuan deserts.

Thus, floral changes roughly parallel major lacustral

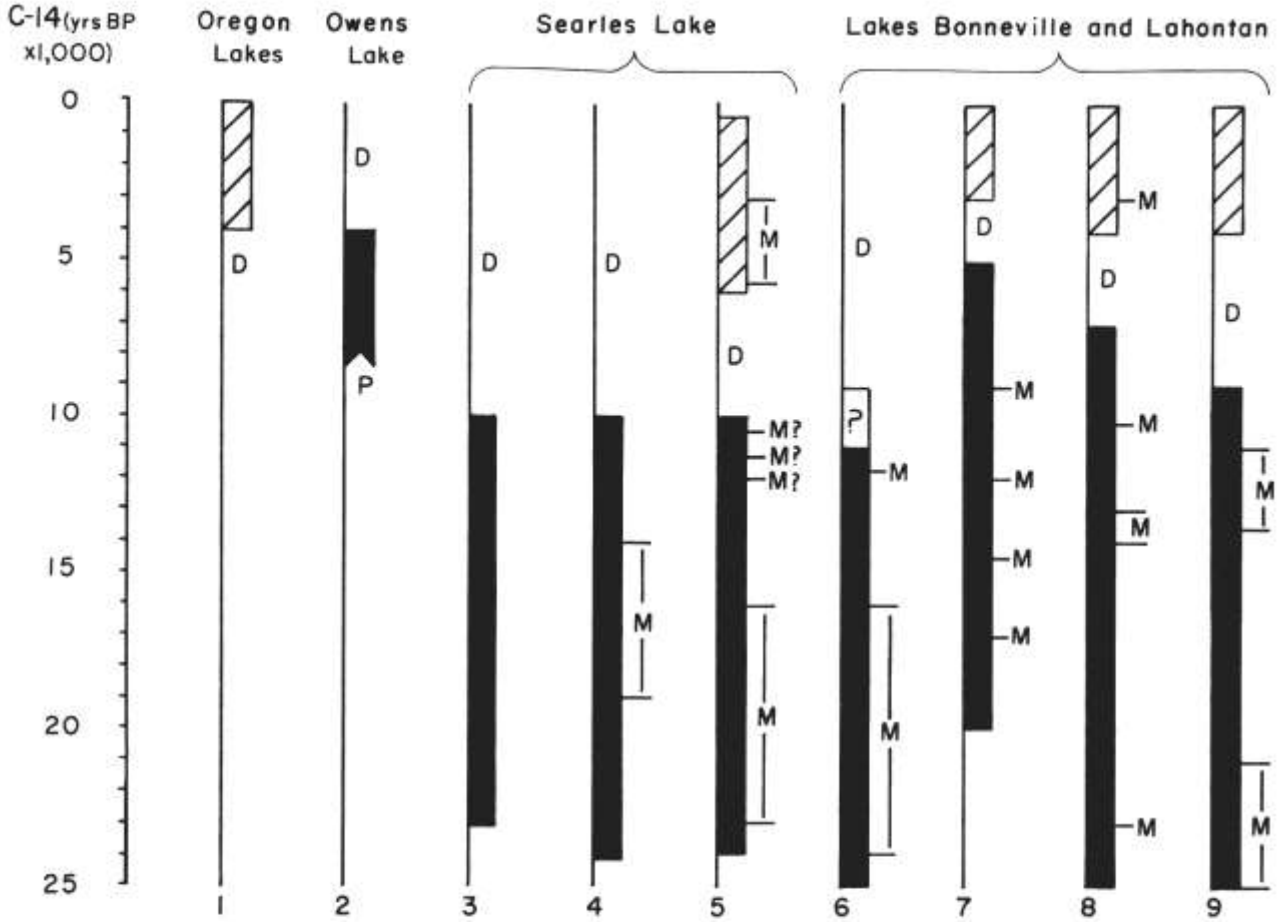

FIGURE 12—SYNOPSIS OF CHRONOLOGIES OF SOME QUATERNARY LAKES IN THE WESTERN UNITED STATES. Solid bars span the duration of the late Wisconsinan lacustral interval. Cross-hatched bars span the duration of the middle and late Holocene lacustral intervals. M represents maxima or culminations of lake expansions; D represents dry periods or periods of extremely low lake level. Sources by columns are: 1) Van Winkle, 1914, 2) Gale, 1915, 3) Flint and Gale, 1958, 4) Stuiver, 1964, 5) Smith, 1979, 6) Broecker and Orr, 1958, 7) Broecker and Kaufman, 1965, 8) Morrison and Frye, 1965, 9) Benson, 1978. Columns 5–9 are summarized from time-space diagrams in the respective papers.

events in the Great Basin. The piñon-juniper woodland that was stable in southwestern basins from 22,000 yrs B.P. to 10,000 yrs B.P. was contemporaneous with Great Basin lakes during the late Wisconsinan lacustral interval. The disappearance of piñon from this woodland and the onset of lake recessions are nearly synchronous. The latest possible date suggested by some workers for the disappearance of lakes (7,000 yrs B.P.) corresponds approximately to the appearance of essentially modern flora in southwestern basins.

Floral assemblages suggest that the late Wisconsinan climate (up to 11,000 yrs B.P.) was equable, with mild winters and cool summers (Van Devender and Spaulding, 1979; Wells, 1979). Van Devender and Spaulding (1979) infer greater winter precipitation prior to 8,000 yrs B.P. than occurs now in the Southwest. The essentially modern floral assemblage appearing after 8,000 yrs B.P. suggests the expansion of the present summer monsoonal climate. Wells (1979) agrees with the idea of increased precipitation but infers that enhanced, summer monsoonal rainfall occurred during the late Wisconsinan.

Van Devender and Wiseman (1977) obtained a succession of fauna from a 2-m section of Holocene deposits in Howell's Ridge Cave in the Little Hatchet Mountains of southwest New Mexico. The Little Hatchet Mountains are on the eastern divide of the Playas Valley, the valley east of the Animas Valley. The paleoclimate represented by the assemblage should apply to the Animas Valley as well.

Three species are especially important to the paleoclimate reconstruction. *Ambystoma tigrinum* (tiger salamander), which occurs thorughout the lower meter but only sporadically in the upper meter, requires relatively permanent water for larval development; therefore, its presence suggests conditions wetter than those at present (Van Devender and Wiseman, 1977, p. 20). *Gila robusta,* a freshwater minnow, is associated with *A. tigrinum* in the upper meter. The occurrence of *Microtus sp.* (vole) implies mesic grasslands.

The sequence of fauna in the 2-m section suggests the presence of a lake in the Playas Valley until approximately 4,500 yrs ago and recurring about 3,000 yrs ago and 1,100-500 yrs ago (Van Devender and Wiseman, 1977, p. 20). Age reversals in the lower meter suggest contamination with younger materials, but the degree to which these reversals cast doubt on the accuracy of dates in the upper meter was not addressed.

Discussion

The stratigraphic isolation of the shore ridges from each other and the lake floor makes the exact reconstruction of the history of Lake Animas difficult. For instance, did the lake experience a single rise to the high level followed by a single recession with temporary stabilizations at the intermediate and low shorelines (one cycle), or do the three shorelines represent three separate expansions and recessions of the lake (three cycles)?

The contrast in morphology between soils S3 and S4 indicates that a greater time separation exists between the high and intermediate stages than between the intermediate and low stages. Soil morphology suggests that the time interval separating the latter stages is quite short. Thus, a major lake recession may have followed the high stage, whereas the intermediate and low stages may have been part of a single lake cycle. The absence of the intermediate shore ridge in the area between Braidfoot Tank and Butterfield Tank suggests that the low shore ridge existed as a barrier during the intermediate stage, reinforcing the idea of a single lake cycle for the lower two shorelines.

Soil morphology and archeology suggest a Holocene age for the lower two shorelines. If the Holocene phase of Lake Animas paralleled that of Great Basin lakes, then 6,000 yrs B.P. is a possible maximum age. Local fossil evidence from Howell's Ridge Cave suggests ages of 4,500 or 3,000 yrs B.P.

The age of the high shore ridge is even more problematic. The maximum possible age is probably 24,000 yrs B.P., corresponding to the beginning of the late Wisconsinan lacustral interval. The minimum possible age is approximately 8,000 yrs B.P., corresponding to the appearance of modern floral assemblages in the Southwest; the minimum probable date is approximately 11,000 yrs B.P., marking the disappearance of piñon from southwestern basins and corresponding to postulated lake maxima in the Great Basin.

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Appendix

Detailed profile descriptions of selected soils are included here to illustrate soil characteristics. Additional information, such as results of textural analyses of these soils, was given by Fleischhauer (1977, appendix **III).** Terminology used is that of the Soil Conservation Service (Soil Survey Staff, 1975). Soil-color designations used here and in the text are based on a Munsell Soil Color Chart (Munsell Color Co., Inc., 2441 Calvert St., Baltimore, Maryland). Locations of profiles are plotted on the geologic map (in pocket).

Profile no. 1

Location: North of stock tank, NE 1/4 SE 1/4 R. 21 W.
Physiographic setting: East-facing slope just below crest of lowest shore ridge at toe of alluvial fan
Parent material: Lacustrine sand and gravel derived from andesite, latite, and rhyolite
Classification: Typic Camborthid

Al — 0-4 cm (0-1.5 inches). Pale-brown to brown (10YR 5.5/3), sandy loam, dark-grayish-brown (10YR 4/2) when moist; weak, medium, platy structure; soft (dry), slightly sticky and slightly plastic (wet); noncalcareous; abrupt, smooth boundary; 2.5-4 cm (1-1.5 inches) thick

B1 — 4-25 cm (1.5-10 inches). Pale-brown (10YR 6/3), loamy sand, very dark-grayish-brown (10YR 3/2) when moist; massive; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); noncalcareous; abrupt, smooth boundary; 15-30.5 cm (6-12 inches) thick

B2 — 25-64 cm (10-25 inches). Dark-grayish-brown (10YR 4/2), sandy loam, very dark-grayish-brown (10YR 3/2) when moist; massive; slightly hard (dry), very friable (moist), slightly sticky and nonplastic (wet); noncalcareous; few clay coatings on coarse sand grains; clear to gradual, wavy boundary; 33-40.5 cm (13-16 inches) thick

CI ca — 64-107 cm (25-42 inches). Light-brownish-gray (10 YR 6/2) sand, dark-grayish-brown (10YR 4/2) when moist; massive to single grain; soft (dry), loose (moist), nonsticky and nonplastic (wet); calcareous with thin, continuous to discontinuous, carbonate coatings on grains and pebbles; gradual, irregular boundary; 41-43 cm (16-17 inches) thick

C2ca — 107-135 cm (42-53 inches). Light-brownish-gray (10YR 6/2), gravelly sand; single grain; loose (dry), loose (moist), nonsticky and nonplastic (wet); calcareous with thin, continuous to discontinuous, carbonate coatings on grains; boundary not exposed

Profile no. 2

Location: West of stock tank and south of road, SE'/ SW'/ SW'/ sec. 36, T. 23 S., R. 21 W.
Physiographic setting: Crest of intermediate shore ridge at toe of alluvial fan
Parent material: Lacustrine sand and gravel derived from andesite, latite and rhyolite
Classification: Typic Camborthid

Al — 0-5 cm (0-2 inches). Light-yellowish-brown (10YR 6/4), loamy sand, dark-brown (10YR 3/3) when moist; massive, upper 0.6-1.0 cm having weak, medium platy structure; soft (dry), very friable (moist), nonsticky and nonplastic (wet); abrupt, wavy boundary; 2.5-8 cm (1-3 inches) thick

B1 — 5-25 cm (2-10 inches). Pale-brown (10YR 6/3.5), loamy sand, dark-brown (10YR 3/2.5) when moist; weak, very fine granular to massive; soft (dry), very friable (moist); nonsticky and nonplastic (wet); abrupt, irregular boundary; 18-28 cm (7-11 inches) thick

B2 — 25-56 cm (10-22 inches). Brown (10YR 5.5/3), gravelly, loamy sand, dark-brown (10YR 4/2.5) when moist; massive; soft (dry), very friable (moist), nonsticky and nonplastic (wet); thin, discontinuous, clay skins on pebbles; abrupt, irregular boundary; 25-38 cm (10-15 inches) thick

Cca — 56-140 cm (22-55 inches). Light-brownish-gray (10YR 6/2), gravelly sand, dark-grayish-brown (10YR 4/2.5) when moist; single grain, becoming stratified near base; soft (dry), loose to very friable (moist), nonsticky and nonplastic (wet); calcareous in upper half; boundary not exposed

Profile no. 3

Location: West of stock tank and south of dirt road, SW'/ SW 1/4 SE 1/4 SW'/ sec. 36, T. 23 S., R. 21 W.
Physiographic setting: Swale between high and intermediate shore ridges at toe of alluvial fan
Parent material: Fine-grained alluvium
Classification: Camborthid

Al — 0-15 cm (0-6 inches). Brown to light-brown (7.5YR 5.5/4), silty clay loam, brown to dark-brown (7.5YR 4/3) when moist; massive, upper 1.0 cm weak, medium platy structure; slightly hard (dry), very friable (moist), sticky and plastic (wet); noncalcareous; abrupt, smooth boundary; 13-15 cm (5-6 inches) thick

B2 — 15-38 cm (6-15 inches). Pale-brown to light-yellowish-brown (10YR 6/3.5), silty clay loam, dark-yellowish-brown (10YR 3/4) when moist; moderate, medium, subangular, blocky structure; hard (dry), firm to very firm (moist), very sticky and plastic (wet); noncalcareous; gradual, smooth boundary; 23-25 cm (9-10 inches) thick

B3b — 38-71 cm (15-28 inches). Brown (10YR 5/3), silty loam, very dark-grayish-brown to dark-brown (10YR 3/2.5) when moist; weak to moderate, very fine, subangular, blocky structure; slightly hard (dry), very sticky and plastic (wet); calcareous near base; clear, smooth boundary; 28-33 cm (11-13 inches) thick

C — 71-107 cm (28-42 inches). Light-brownish-gray (10YR 6/2), sandy loam, dark-grayish-brown (10YR 4/2) when moist; massive; slightly hard (dry), slightly sticky and plastic (wet); calcareous; abrupt, smooth boundary; 30-36 cm (12-14 inches) thick

IIBb — 107-114 cm (42-45 inches). Reddish-brown (5YR 5/4) loam, reddish-brown (5YR 5/3) when moist; massive in limited exposure; slightly hard (dry), very friable to friable (moist), sticky and plastic (wet); calcareous; boundary not exposed

Profile no. 4

Location: West of tank and south of dirt road, SE'/ SE'/ SW'/ SW'/ sec. 36, T. 23 S., R. 21 W.
Physiographic setting: East-facing slope below crest of high shore ridge on toe of alluvial fan
Parent material: Lacustrine sand and gravel derived from andesite, latite, and rhyolite
Classification: Typic Haplargid

Al — 0-8 cm (0-3 inches). Very pale brown (10YR 7/3.5), sandy loam, dark-brown (10YR 3.5/3) when moist; massive to weak, fine platy structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); noncalcareous; abrupt, smooth boundary; 8 cm (3 inches) thick

B21t 8-41 cm (3-16 inches). Dark-yellowish-brown to yellowish-brown (10YR 4.5/4) sandy clay loam, dark brown (10YR 3/3) when moist; weak, coarse prismatic to massive structure; slightly hard (dry), very friable (moist), sticky and plastic (wet); noncalcareous; clay skins on pebbles and clay bridges between sand grains; gradual, smooth boundary; 33 cm (13 inches) thick

C1 41-71 cm (16-28 inches). Pale brown (10YR 6.5/3), loamy sand, brown (10YR 4.5/3) when moist; single grain; loose (dry), loose (moist), nonsticky and nonplastic (wet); calcareous near base; abrupt, smooth boundary; 28-33 cm (11-13 inches) thick

IIB22tb 71-81 cm (28-32 inches). Reddish-brown to yellowish-red (5YR 5/5) clay loam, yellowish-brown (5YR 5/6) when moist; compound, moderate to weak, medium prismatic structure and moderate, fine-angular, blocky structure; slightly hard (dry), very friable (moist), very sticky and plastic (wet); calcareous with carbonate coatings on pebbles and soft carbonate lining and filling root tubes and pores; clear, smooth boundary; 8-13 cm (3-5 inches) thick

IIB23ca 81-104 cm (32-41 inches). Yellowish-red (5YR 4.5/6), sandy clay loam, yellowish red (5YR 4/6) when moist; weak to moderate, coarse angular blocky structure, breaking to fine-angular, blocky structure; slightly hard (dry), friable (moist), very sticky and plastic (wet); calcareous with thin, discontinuous coatings of carbonate (5YR 8/1) on pebbles, fractures, and root tubes; boundary not exposed

Profile no. 5

Location: West of stock tank and south of dirt road, SW 1/4 SE 1/4 SW 1/4 SW 1/4 sec. 36, T. 23 S., R. 21 W.

Physiographic setting: Fan surface upslope from high shore ridge

Parent material: Alluvium derived from andesite, latite, and rhyolite

Classification: Typic Haplargid

A1 0-5 cm (0-2 inches). Light-brown (7.5YR 6/4) sandy loam, brown to dark brown (7.5YR 4/4) when moist; weak, medium platy structure; soft (dry), sticky and plastic (wet); noncalcareous; abrupt, smooth boundary; 2.5-6 cm (1-2.5 inches) thick

B2 lt 5-15 cm (2-6 inches). Reddish-brown (5YR 4/4) loam, reddish-brown (5YR 4/3) when moist; weak, fine-angular blocky structure; slightly hard (dry), very sticky and plastic (wet); noncalcareous; abrupt, smooth boundary; 5-10 cm (2-4 inches) thick

B22t 15-36 cm (6-14 inches). Reddish-brown (5YR 4/4) clay loam, reddish-brown (5YR 4/3) when moist; moderate, medium-angular, blocky structure; slightly hard (dry), sticky and plastic (wet); noncalcareous; thin, discontinuous clay coatings on pebbles; abrupt, smooth boundary; 20-33 cm (8-13 inches) thick

B23t 36-48 cm (14-19 inches). Reddish-brown (5YR 4/4) clay loam; reddish-brown (5YR 4/3) when moist; compound moderate, fine, prismatic and very fine angular blocky structure; hard (dry), very sticky and plastic (wet); noncalcareous; thin clay skins on ped faces and root pores; clear, discontinuous boundary; 0-15 cm (0-6 inches) thick

C1ca 48-76 cm (19-30 inches). Brown (7.5YR 5/4), gravelly, sandy clay loam, dark brown (7.5YR 4/4) when moist; massive; slightly hard (dry), very friable (moist), sticky and plastic (wet); calcareous, with thick, continuous coatings (7.5YR 7/4) on pebbles and local, strong cementation; clear, smooth boundary; 28 cm (121 inches) thick

C2ca 76-89 cm (30-35 inches). Pink (7.5YR 7.5/4), gravelly, sandy loam, light brown (7.5YR 6/4) when moist; massive; very hard (dry), firm (moist), sticky and plastic (wet); calcareous, with thick, continuous coatings on pebbles and interpebble fillings; boundary not exposed

Profile no. 6

Location: South bank of first arroyo north of dirt road leading to Robinson Windmill, NW'/ SE'/ NE'/ SW'/ sec. 36, T. 23 S., R. 21 W.

Physiographic setting: Crest of intermediate shore ridge on toe of alluvial fan

Parent material: Lacustrine sand and gravel derived from andesite, latite, and rhyolite

Classification: Typic (?) Camborthid

A1 0-8 cm (0-3 inches). Grayish-brown (10YR 5/2), sandy loam, dark-grayish-brown (10YR 3/2) when moist; massive; loose (dry), very friable (moist), slightly sticky and slightly plastic (wet); noncalcareous; abrupt, smooth boundary; 5-8 cm (2-3 inches) thick

B21 8-28 cm (3-11 inches). Brown (10YR 5/3), gravelly, sandy loam, very dark grayish brown (10YR 3/2) when moist; massive; soft (dry), very friable (moist), sticky and slightly plastic (wet); noncalcareous; some thin, discontinuous, clay skins on pebbles and clay bridges between sand grains; gradual, smooth boundary; 20-28 cm (8-11 inches) thick

B3 28-56 cm (11-22 inches). Brown (10YR 5/3), loamy sand, dark-brown (10YR 3/3) when moist; single grain; loose (dry), loose to soft (moist), nonsticky and nonplastic (wet); noncalcareous; gradual, smooth boundary; 25-28 cm (1011 inches) thick

Coca 56-89 cm (22-35 inches). Light-gray (10YR 7/2) sand or loamy sand, light-brownish-gray (10YR 6/2.5) when moist; single grain; loose (dry); loose (moist), nonsticky and non-plastic (wet); calcareous, with thin, discontinuous, carbonate coatings on pebbles; clear, smooth boundary; 38 cm (15 inches) thick

C2ca 89-107 cm (35-42 inches). Light-yellowish-brown (10YR 6/4) gravelly sand, yellowish-brown (10YR 4.5/4) when moist; stratified; loose (dry), loose (moist), nonsticky and nonplastic (wet); calcareous; abrupt, smooth boundary; 13-18 cm (5-7 inches) thick

IIB22tb 107-122 cm (42-48 inches). Reddish-brown (5YR 5.5/4), sandy clay, reddish-brown (5YR 5/4) when moist; compound, moderate coarse prismatic and weak fine prismatic structure, breaking to moderate fine angular, blocky structure; slightly hard (dry), very friable (moist), very sticky and plastic (wet); slightly calcareous; thick sand coatings, apparently from sandy horizon above, on faces of coarse prisms; clear, wavy boundary; 13-15 cm (5-6 inches) thick

IIB23ca 122-145 cm (48-57 inches). Reddish-brown (5YR 5/5), sandy clay; massive, in places moderate coarse angular, blocky structure; slightly hard (dry), very friable (moist), very sticky and plastic (wet); calcareous; clear, smooth boundary; 15-23 cm (6-9 inches) thick

IIC3ca 145-201 cm (57-79 inches). Light-reddish-brown (5YR 6/4), gravelly sand, reddish-brown (5YR 5/4) when moist; massive and stratified; slightly hard (dry), very friable (moist), nonsticky and nonplastic (wet); calcareous, with coatings (pink, 5YR 8/3) on pebbles and in inter-pebble fill; few mangans on pebbles; abrupt, smooth boundary; 46-56 cm (18-22 inches) thick

IIIBcab 201-224 cm (79-88 inches). Yellowish-red (5YR 4/6) when moist; clay or silty clay; massive; very friable (moist), very sticky and very plastic (wet); common, coarse mottles and nodules of CaCO,; pink to reddish-yellow (7.5YR 8/5) when moist; boundary not exposed

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References-8-pt. English Times, leaded one point
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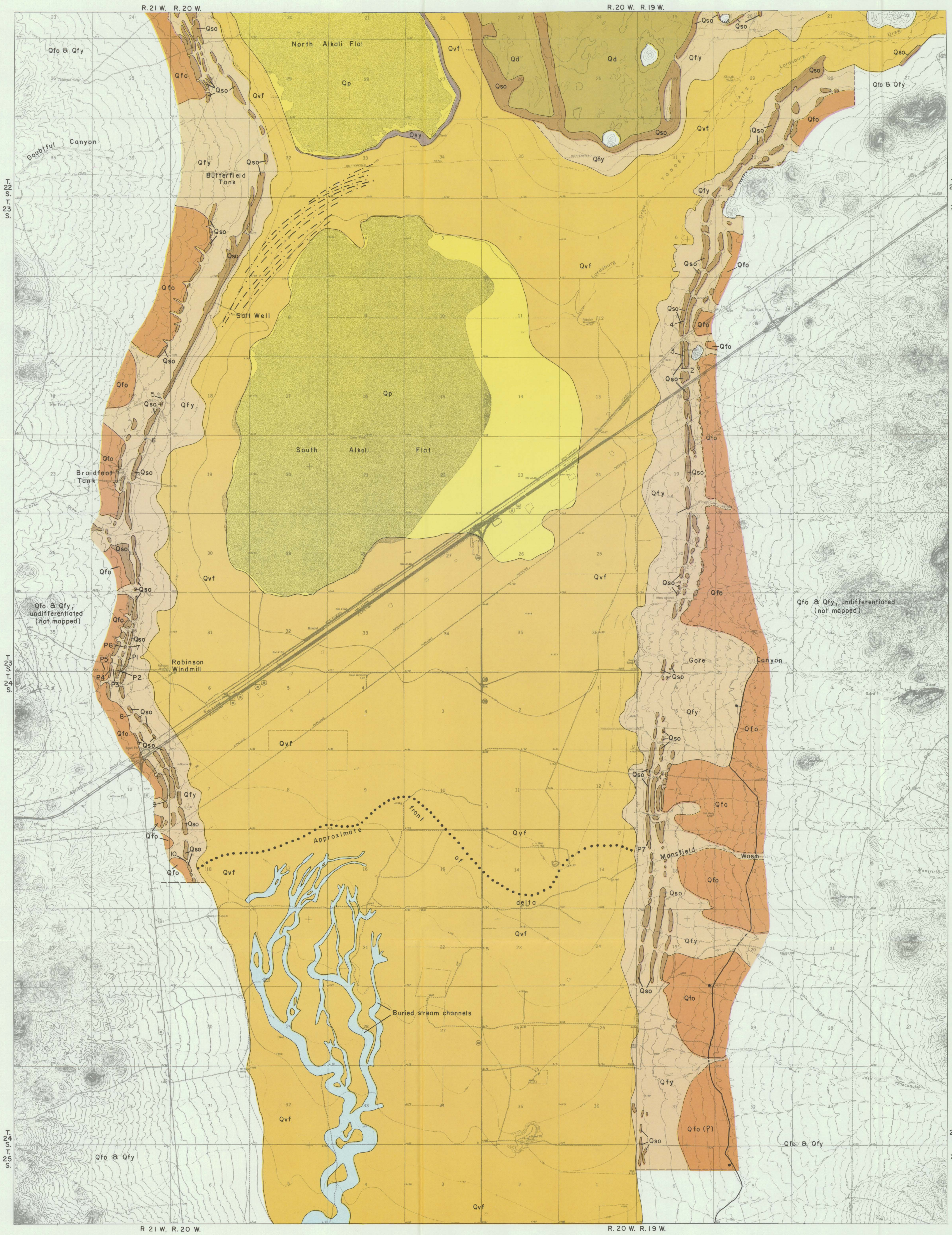
CONTENTS OF POCKET

Geologic map of Lake Animas,
Hidalgo County, New Mexico



Topographic base after USGS, 1964, 1965

Cartography by James C. Brannan

Geology by H. L. Fleischhauer, Jr., 1976

CORRELATION OF MAP UNITS

Qd, Qp, Qsy, Qvf, Qfy	HOLOCENE
Qso	LATEST WISCONSINAN TO MIDDLE HOLOCENE
Qfo	MIDDLE TO LATE PLEISTOCENE

DESCRIPTION OF MAP UNITS

Qd — DUNES AND COPPICE DUNES—Locally expose older sediments in deflation basins

Qp — PLAYA

Qsy — PLAYA SHORE RIDGE

Qvf — VALLEY FLAT—Includes alluvial flat and areas transitional from fan toe to playa; in part, a former delta plain of ancestral Animas Creek

Qfy — YOUNGER ALLUVIAL-FAN COMPLEX—Includes interridge trough, ridge-front slope, and post-lake alluvial fan; locally exposes sediments of older alluvial-fan complex

Qso — SHORE RIDGE OF ANCESTRAL LAKE ANIMAS

Qfo — OLDER ALLUVIAL-FAN COMPLEX—Locally includes sediments correlative with younger alluvial-fan complex

VEGETATION BELTS—Mark position of buried stream channels in delta of ancestral Animas Creek

SYMBOLS

WAVE-CUT SLOPE—hachures point upslope

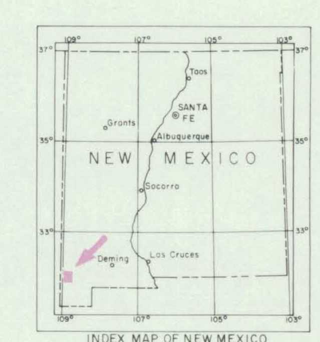
CRESTLINE OF LOW RIDGE OR SWELL—marks former playa margin or receding lake shore

CONTACT—dashed where approximate or queried

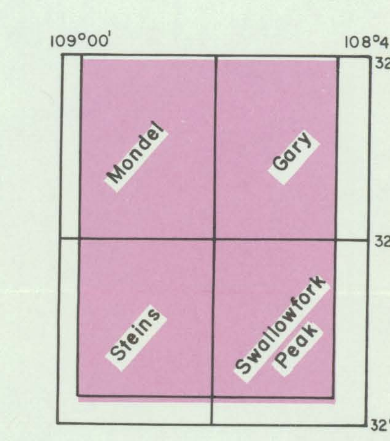
POSITION OF FAULT SCARP—dashed where eroded or obscure; dotted where concealed; ball and bar on downthrown side

P1, P3 — SOIL-PROFILE NUMBER (*see appendix*)

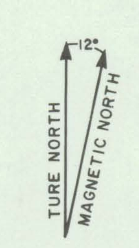
1, 2 — LOCALITY NUMBER REFERENCED IN TEXT



INDEX MAP OF NEW MEXICO



Location of map area in USGS 7½-min quadrangles



APPROXIMATE MEAN DECLINATION, 1970

Quaternary geology of Lake Animas, Hidalgo County, New Mexico

by H. L. Fleischhauer, Jr. and W. J. Stone

1982

(see frontispiece for aerial photomosaic of map area)

scale 1:48,000

2 1.5 1 .5 0 2 mi

2 1 .5 0 1 2 km