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QUATERNARY GEOLOGY OF THE TULE SPRINGS AREA, CLARK COUNTY, NEVADA

by

C. Vance Haynes, Jr.

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF GEOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by Caleb Vance Haynes, Jr. entitled Quaternary Geology of the Tule Springs Area, Clark County, Nevada be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

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After inspection of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

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SIGNED: C. Vance Haynes Jr.

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Dr. Willard F. Libby prompted initiation of the Expedition by offering unlimited use of the radiocarbon dating facilities at the University of California, Los Angeles. With the help of Prof. Gordon J. Fergusson and Erv Taylor over 80 radiocarbon dates were provided by Dr. Libby's Laboratory.

Distinguished scientists who visited the excavations and offered constructive comment included William Benson, J. Desmond Clark, Emil Haury, Robert H. Heizer, Alex D. Krieger, Willard F. Libby, Chester R. Longwell, A. L. Spaulding, and H. M. Wormington, all of the National Science Foundation Advisory Committee; Gordon J. Fergusson, Mark R. Harrington, Carl L. Hubbs, Tomas Humphry, C. B. Hunt, J. D. Jennings, George F. Kennedy, John F. Lance, Robert C. Euler, Hansjurgen Muller-Beck, George B. Maxey, Rodger Morrison, Bruno Sables, G. I. Smith, and Claude N. Warren.

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Pollen analysis over and above that done to determine the past vegetation was successfully tested as a method of correlating sediments. These additional efforts of P. J. Mehringer, Jr. are much appreciated.

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ABSTRACT

At the Tule Springs Site, located 10 miles north of Las Vegas, Clark County, Nevada, extinct animal bones and artifacts have been found in fine-grained sediments forming the surficial deposits of the Las Vegas Valley. Over 7,000 feet of bulldozer trenches and archaeological excavations provided an unusual opportunity to study the late Quaternary sediments of the valley and to determine the chronostratigraphic position of artifacts, faunas, pollen samples, and radiocarbon samples.

Major depositional units are separated by paleosols which have been eroded prior to the deposition of overlying units. The earliest unit (A) exposed at the site is alluvial clay and silt of undetermined thickness that contains a very strong pedocalic paleosol (S1) which was truncated prior to deposition of unit B. Silt, sand, and gravel of unit B is subdivided into units B_1, B_2, and B_3 on the basis of paleosol S2 at the top of B_1, paleosol S3 at the top of B_3, and an interbedded lacustrine mudstone (unit B_2)

which contains fossil evidence of mammoth, horse, camel, bison, sloth, and panther. Carbonized plant remains associated with buried springs in unit B_2 are beyond the limit of radiocarbon dating ($>$40,000 B.P.).

A channel dissecting earlier units contains alluvial silt, sand, and gravel of unit C and is overlain by a lacustrine mudstone, unit D, from which C^{14} dates of 22,600 B.P. and 31,300 B.P. have been obtained. The top of unit D contains a paleosol (S4) superimposed upon a lacustrine carbonate bed that forms a resistant floor over much of the Las Vegas Valley. The lake beds (unit D) are dissected by a narrow channel associated with ancient springs and filled with fluvial silt, sand, and gravel of unit E_1. Buried springs in E_1 contain carbonized wood, lithoid tufa, and bones of extinct mammoth, horse, camel, and sloth dating between 14,000 and 11,500 years old. Another channel is cut into and coincides with the E_1 channel and is filled with alluvial silt and gravel of unit E_2 which overfilled its channel and contains the oldest (9,000 to 11,000 B.P.) indisputable artifacts at the site. Post E_2 degradation began some time after 7,500 years ago and formed the badland topography that characterizes the Tule Springs area today. Alluvial gravel units F and G in Tule Springs Wash are not being transported today,and slope-wash facies of unit G veneer the floor of Las Vegas Valley.

Four miles west of the site, two north-south alignments of springs, active in historic times, are believed to represent normal faults that have displaced unit D. The stratigraphy of mound springs reveals a history of abrupt emergence before 11,000 years ago and declining discharge since then. Correlations of the stratigraphy and weathered surfaces of alluvial fans with the finer grained units in the valley indicate that fan aggradation accompanied fluvial aggradation.

A prominent low-angle scarp south of the Tule Springs Site displaces unit D and contains numerous "extinct" springs with datable organic mats that indicate spring emergence before 11,000 years ago. A tectonically active block bounded by the spring alignments, the scarp, and Tule Springs Wash permits explanation of anomalous geomorphic features of the area. Spring alignments of the Corn Creek Springs area 15 miles northwest of the Tule Springs

Site have a similar history and define a small horst upon which buried aboriginal camp sites occur in dune fields that are 4,000 to 5,000 years old.

Analysis of 80 radiocarbon samples provides geochronologic control, permits geochemical evaluation of tufa formation, supports correlation of the Tule Springs beds with some other areas of the Southwest, and indicates that aquifers of the Las Vegas basin contain "fossil" water.

INTRODUCTION

Location and Geological Setting

The Tule Springs archaeological site occurs in a badland area along the right bank of what will be referred to as Tule Springs Wash at a point 10 miles north of Las Vegas and 5 miles east of Tule Springs Ranch, Clark County, Nevada (Fig. 1). The site datum stake (36° 19' 00" N. latitude and 115° 11' 23" W. longitude) is 2,307 feet above sea level. The Tule Springs Site is within the Las Vegas Valley, the northern portion of which is included in these investigations.

Approximately 8 miles northwest of Corn Creek Springs two large alluvial fans from opposite sides of the Las Vegas Valley coalesce to form the surface drainage divide between the Three Lakes Valley and the Las Vegas Valley which extends 35 miles to Frenchman Mountain at the southeastern end of the valley (Fig. 1). Here Las Vegas Wash intermittently drains the southern end of the valley, passes eastwardly between Frenchman and River Mountains, and empties into Lake Mead on the Colorado River. The upper end of the valley is drained

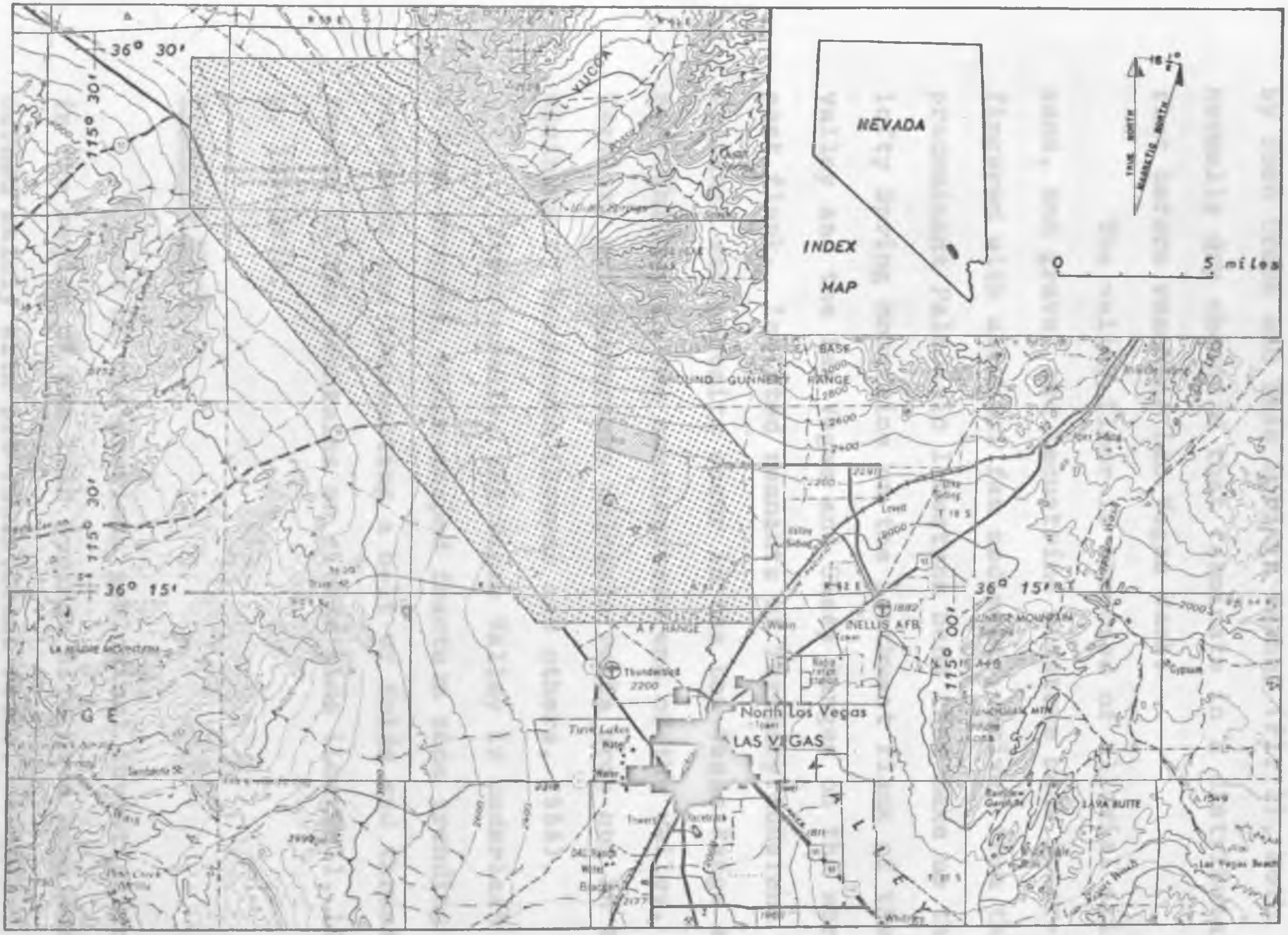


Figure 1. Location map showing areas of Plate 1 (large dots), Figure 2 (small dots), and Plate 5 (solid area within Fig. 2).

by Corn Creek and Tule Springs Washes (Pl. 1), both normally dry channels that terminate in a distributary flat before reaching Las Vegas Wash.

The valley floor is composed of alluvial silt, sand, and gravel and lacustrine mudstone beds interfingered with alluvial fan sediments derived from the predominant Paleozoic limestone beds that make up the lofty Spring Mountains on the southwest flank of the valley and the Las Vegas and Sheep Ranges on the northeast flank. Isolated remnants of Tertiary mudstone and volcanic ash deposits occur in the Las Vegas Range and near Whitney in the southeastern end of the valley. Tertiary and Quaternary volcanic rocks crop out in the vicinity of Henderson (Bowyer and others, 1958).

Structurally, Las Vegas Valley is underlain by a down-dropped, wedge-shaped fracture zone trending northwest and transecting a belt of folds and thrust faults in the mountains on either side (Longwell, 1960, p. 192-203).

Previous Work

Most of the previous geological investigations in the region of the Tule Springs Site have been concerned mainly with pre-Pleistocene rocks. A useful bibliography of the investigations is provided by

Maxey and Jameson (1948, p. 12-15). Of particular interest to Pleistocene geologists are the ground-water reports of Carpenter (1915) and Maxey and Jameson (1948). A Pleistocene study reported by Rose (1938) in abstract apparently was not completed. Longwell provided a brief description of the geology of the Las Vegas Valley in the archaeological report by Harrington and Simpson (1960, p. 47-50), and he is presently mapping and defining the Pleistocene Las Vegas formation (personal communication).

Historical Background

Archaeological investigations have shown that the Las Vegas Valley was occupied by aborigines as long as 10,000 years ago (Harrington, 1933; Harrington and Simpson, 1961; Shutler and Shutler, 1962). Probably its chief attraction to man and animals in prehistoric times, as in early historic times, was the abundance of springs within the valley. The concentration and variety of artifacts associated with springs attest to the heavy utilization of the springs by man. Early settlers found evidence of ancient irrigation works in the form of canal remnants around some of the larger springs (Carpenter and Youngs, 1928, p. 243).

Exploration of the area began about 1770 with Spanish exploring parties under the direction of Father Junipero Serra. They journeyed up Las Vegas Wash from the Colorado River and discovered an oasis of spring-fed meadows or vegas at the present site of Las Vegas. John C. Fremont and his party camped at Las Vegas Springs in 1844 (Fremont, 1845), and explorer Kit Carson passed through the region at about the same time. These explorations were followed in 1847 by a wagon train en route to southern California from Salt Lake City and led by Captain Jefferson Hunt, a Mormon missionary.

During the early 1850's, Mormons led by William Bringhurst established Las Vegas and constructed an adobe fort north of the present city. They successfully farmed this part of the valley and mined lead in the mountains until 1857 when they were recalled to Utah by Brigham Young because of troubles with the U. S. Government.

After 1857, several large cattle ranches operated in the valley, but the State Land Act of 1885 made agricultural lands cheaply available,and farmers again prospered. The alfalfa industry became dominant after the discovery of artesian water in 1905, the same year that the Union Pacific Railroad was completed through Las Vegas.

Rapid decline of ground water levels since 1905 has almost eliminated ranching and farming in the valley. Hoover Dam, Lake Mead, military installations, mining and milling, and the casinos are all responsible for the rapid growth of Las Vegas since the 1930's. The Tule Springs and Gilcrease Ranches no longer raise cattle and are the only operating farms in the valley north of Las Vegas. Fields of alfalfa are irrigated by pumping from wells over 500 feet deep. The springs on these farms as well as those around Las Vegas are now extinct. The only active springs in the area investigated are at Corn Creek Springs, and here the flow from all but one is insignificant. A description of the springs near Las Vegas as they appeared in the nineteenth century is given by Lyle (1878).

Vertebrate fossils from the Las Vegas Valley were reported first by R. B. Rowe of the U. S. Geological Survey in 1901 when mastodon remains were discovered in lacustrine deposits between Corn Creek Springs and Tule Springs (Spurr, 1903, p. 157). Subsequent finds by government surveyors led to paleontological investigations by the American Museum of Natural History in the early 1930's;whereupon an obsidian flake of human manufacture was found in deposits containing the remains of an extinct camel (Simpson, 1933). Evidence of early man's association with extinct ground sloths had already been found by M. R. Harrington, of the Southwest Museum, in Gypsum Cave some 25 miles southeast of Tule Springs. The possibility of man's association with extinct camel led the Southwest Museum to conduct archaeological excavations in 1933 and during the years 1954-56 (Harrington, 1934; Harrington and Simpson, 1961) at what became known as the Tule Springs Site. Two radiocarbon dates suggesting man's presence at the site more than 23,000 years ago (Libby, 1955, C-914; Olson and Broecker, 1961, p. 170) gave American archaeologists cause for renewed interest in the Tule Springs Site. Ample evidence supports the presence of man in the New World about 11,500 years ago, but evidence for his earlier presence remains controversial (Wormington, 1957, p. 197-198). The Nevada State Museum Tule Springs Expedition, of which the present investigations are a part, was organized to establish independently the geochronological position of the artifacts and the fauna in the Tule Springs Site area and to bring all pertinent scientific disciplines to bear on the problem.

Purpose

The purpose of the geological investigations of the Tule Springs Site has three objectives: (1) to determine the stratigraphic relationships of its artifacts and fossils, and, in so doing, to establish its stratigraphic framework for correlations, and for the placement of samples collected by various disciplines in their true chronostratigraphic relationships (Haynes, 1964); (2) to determine the relation of the Tule Springs Site geology to that of the surrounding region; and (3) to place the Tule Springs data in proper perspective with late Pleistocene events in North America.

Procedure

An area measuring 700 feet by 2,200 feet, hereafter called the Tule Springs Site (Pl. 5) and divided into 100-foot squares forming a grid coordinate system, was mapped in detail at a scale of 1:240 with the aid of low altitude aerial photographs, scale approximately 1:1,200. Other sites studied in similar detail are included with the site proper in what is called here the Tule Springs Site Area (Fig. 2). This area comprises 1.47 square miles and was mapped on a scale of 1:4,800 with the aid of Soil Conservation Service composite aerial photographs.

The geological studies were extended, on a reconnaissance basis, to include the Las Vegas Valley from 2 miles north of Las Vegas to 4 miles beyond Corn Creek Springs (Desert Game Range Headquarters) (Pl. 1 and Fig. 1). United States Geological Survey aerial photographs were used in conjunction with the Las Vegas, Gass Peak, and Corn Creek Springs 15-minute quadrangle sheets. Sites of special interest within the reconnaissance area were studied in greater detail and are referred to as the Eglington Scarp area, the Tule Springs Ranch and Gilcrease Ranch area, and the Corn Creek Springs area.

Within the Tule Springs Site Area, localities of particular scientific interest are given locality numbers 1 through 38, and localities outside of this area are designated by continuing the numerical sequence on the reconnaissance map (Pl. 1). Stratigraphic sections at pertinent localities are included in Appendix I.

The detailed stratigraphy of the deposits at the Tule Springs Site Area was obtained from 7,000 feet of bulldozer trenching, averaging approximately 15 feet in depth and mapped at a horizontal scale of 1 inch = 20 feet, and a vertical scale of 1 inch = 10 feet. The trench walls provided an unusual opportunity to construct precise stratigraphic cross sections showing greater detail than would be possible with only natural exposures. Particular attention was given to erosional contacts and to paleosols as these are the prime factors upon which subdivision of the strata into units is based. Soil descriptions are based upon the procedure presented in the Soil Survey Manual of the U. S. Department of Agriculture (Handbook No. 18, 1951). In the present paper the strength of soil development is described in relative terms (very strong, strong, moderate, weak, very weak, or incipient) based upon thickness, structure, and calcification of comparable horizons; i. e. a strong soil generally displays a thicker profile, stronger structure (as defined in the Soil Survey Manual), and Cca horizons with more calcium carbonate than moderate or weak soils.

The Tule Springs strata are considered informally and are subdivided into stratigraphic units with letter designations (A through G) and subscript numerals (1, 2, or 3). Soils are designated by the letter S with number designations (S1 - S6). Tule Springs beds are included in the Las Vegas Formation of Longwell (Longwell and others, in press, and personal communication).

Field investigations required four and a half continuous months (1962-63), and geological work, performed at the Geochronology Laboratories of The University of Arizona, consisted chiefly of C^{14} analyses, sediment studies, and preparation of maps and diagrams.

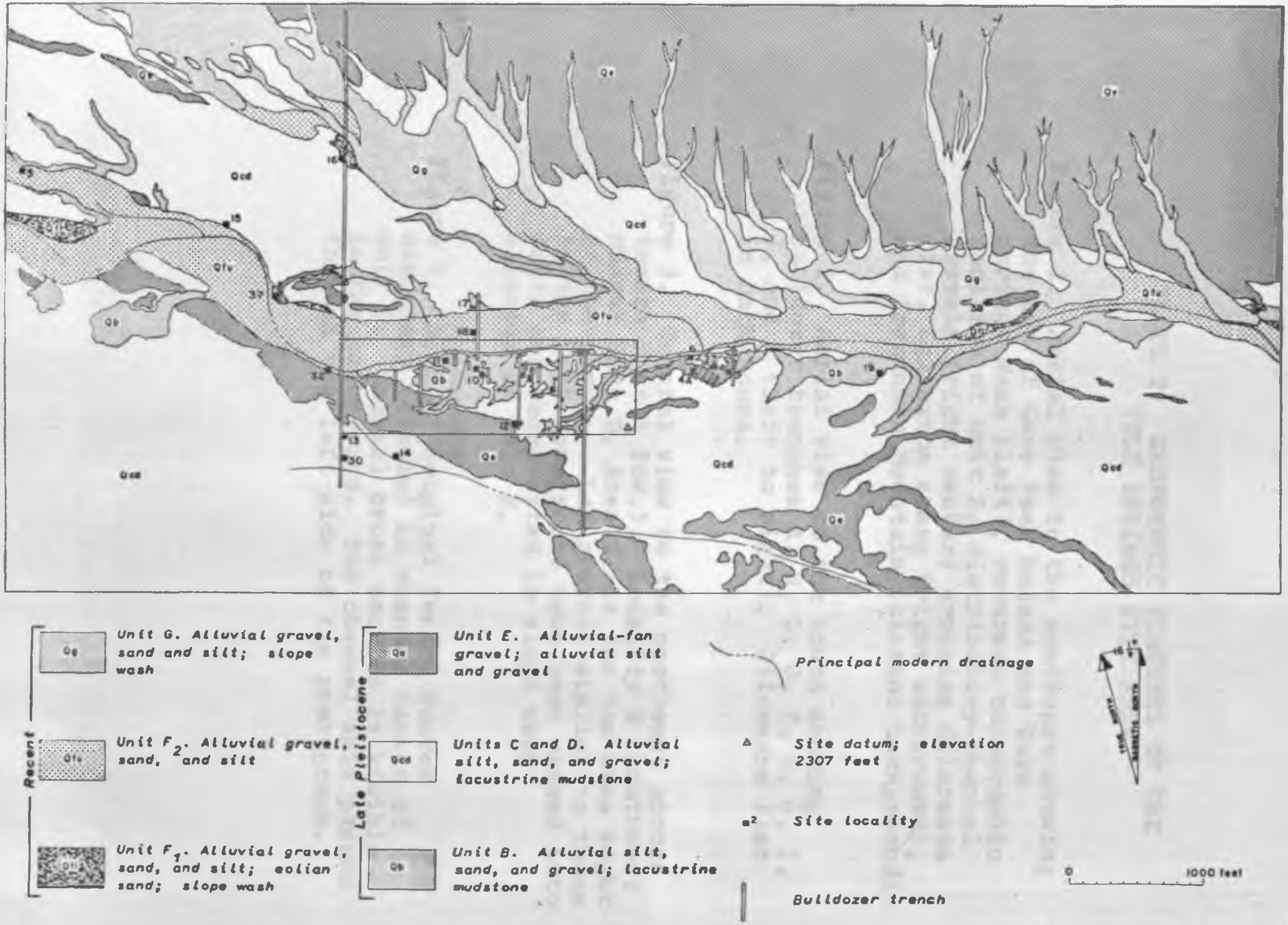


Figure 2. Geologic map of Tule Springs site area. Grid survey of Plate 5 outlined.

PLATE 2. GEOMORPHIC FEATURES OF THE TULE SPRINGS SITE AREA

Figure 1. Aerial view to the southeast showing the toe of Gass Peak bajada and Tule Springs Wash (left), reversed topographic position of unit E_2 distributary-channel gravels (right center) crossing Gilcrease flat, Eglington scarp (right background), and Frenchman Mountain (distant background).

Figure 2. Aerial view to the south showing bulldozer trenches A, B, C, D, F, G, H, I, J, and K (left to right). Gilcrease flat in background.

Figure 3. General view to the northeast across trench D (8 + 50W.). Locality 9 (southwest Museum Site D, Area 2) is the low area right of the person. Lag gravels similar to those in the left foreground have been washed into rills and redeposited in slope wash alluvium of unit F.

Figure 4. Site of original Fenley Hunter discovery (circle) in channel facies of unit E. Channel cross section is visible in the background. The channel axis passed through the left side of the photograph.

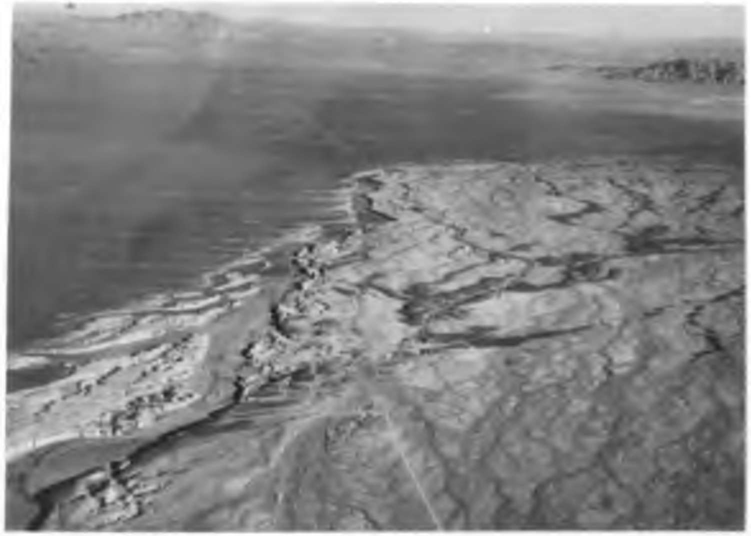


Figure 1.

Figure 2.

Figure 3.

Figure 4.

GEOMORPHIC FEATURES OF THE TULE SPRINGS SITE AREA

GEOLOGY OF THE TULE SPRINGS SITE AREA

Geomorphology

The Tule Springs Site is in a deeply eroded badland area along the right bank of Tule Springs Wash and opposite the toe of the Gass Peak bajada (Pls. 1 and 8). The normally dry wash, which is approximately 300 feet wide (Pls. 2 and 4), has a gravel bed (stratigraphic unit F_2) partially covered with fluvial sand dunes and riffles (unit G_2). A small channel 4 feet wide and 2 feet or less deep meanders across the wash floor and becomes a broad braided channel in some places.

A broad flat area extending southwesterly from Tule Springs Wash is covered by a resistant calcareous bed or "caliche cap" (unit D) that is drained by numerous small shallow rills forming a pronounced braided pattern over the area that will be referred to as Gilcrease flat (Pl. 1). Exposed caliche areas are covered by a rubble of angular, partially dissolved, caliche fragments. Relief on this surface is provided by discontinuous gravel-capped ridges (unit E_2) standing as much as 10 feet above the surrounding surface (pl. 2, fig. 1). Limestone pebbles on the ridges display solution features similar to those described by Bryan (1929), and siliceous rocks show variable degrees of desert varnish.

On the opposite side of Tule Springs Wash the Gass Peak bajada is formed by coalescence of several alluvial fans extending from canyons in the Las Vegas and Sheep Ranges. The lower bajada is dissected by numerous small channels that are tributary to Tule Springs Wash. Gravels of interfluvial surfaces display weathering features similar to those mentioned for gravel-capped ridges, while modern channel-bed gravels show freshly abraded surfaces.

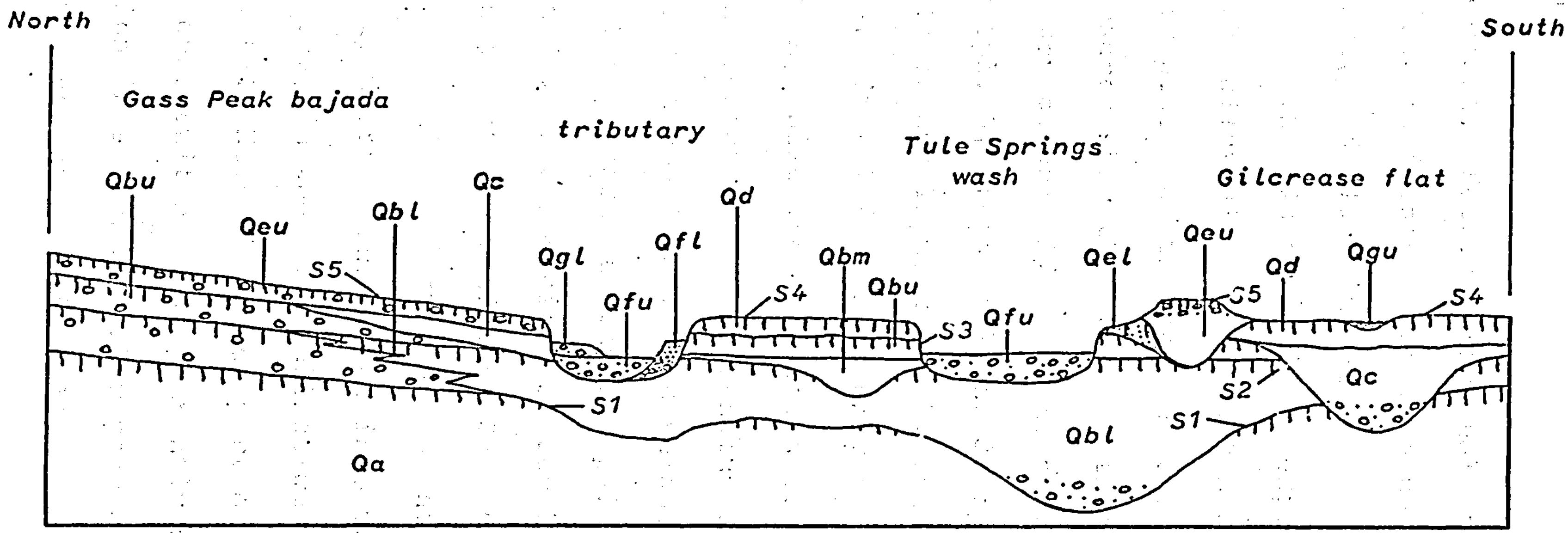
Today, the drainage area of Tule Springs Wash in the site area is only about 55 square miles and comprises the adjacent bajada and the southwesterly slopes of the Las Vegas Range; whereas the wash between Corn Creek Springs and Tule Springs Ranch drains approximately 4,500 square miles and is here called Corn Creek Wash (Pl. 1). At a point 2.5 miles northwest of Tule Springs Ranch the wash, in recent time, has abandoned the channel leading past the Tule Springs Site and instead splayed into a myriad of braided distributary rills covering Gilcrease flat (Pl. 8).

Farther to the northwest, beyond Corn Creek Springs, additional thousands of square miles of drainage area (Three Lakes Valley) have been isolated from the Corn Creek Wash system by juncture of opposing fans. From the present geomorphology it is apparent, as Hubbs and Miller (1948, p. 101) have suggested, that the ancestral "Las Vegas River" at one time made a substantial contribution to the Colorado River. As will be seen, the sediments shed additional light on the history of the Las Vegas Valley.

Stratigraphy

The walls of the wash and bulldozer trenches reveal a sequence of alluvial and lacustrine sediments separated by soils and erosional contacts (Pl. 3 and Fig. 3). The sediments and soils are described in Table 1; their areal distribution is shown in Figure 2 and Plate 5; their stratigraphic relations are shown in the trench profiles (Pls. 6 and 7). These data plus Appendix I constitute the evidence upon which the following discussions are based.

All of the gravels are composed mostly of limestone with minor amounts of sandstone, quartzite,



EXPLANATION

S5 — soil

Qgu - unit G_2
Qgl - unit G_1
Qfu - unit F_2
Qfl - unit F_1

Qeu - unit E_2
Qel - unit E_1
Qd - unit D
Qc - unit C

Qbu - unit B_3
Qbm - unit B_2
Qbl - unit B_1
Qa - unit A

Figure 3. Generalized stratigraphic cross section of the Tule Springs Site Area. No scale.

and chert. Petrographic analysis reveals the finer grained sediments to be made up mainly of calcite, quartz, and clay minerals.

The oldest sediment exposed in the site area is the alluvial silt of unit A which is exposed in only a few places at the base of the wash wall (Pl. 5). All exposures show the strong calichefication of soil S1 at the top of unit A, and some sections exposed by trenching (pl. 6, trenches I and J) reveal that strong erosion followed development of S1, the strongest soil at the site. Gravel facies of unit B_1 occupy a channel cut into A, while the alluvial silt facies of B_1 cover a much greater area representing a broad flood plain. A strong paleosol (S2) is developed in the top of B_1 and, in places, forms a compound paleosol where superimposed upon S1. Erosion after S2 development has left only remnants of the resistant Cca horizon.

Unit B_2 ("green-pond unit") occupies a relatively narrow channel cut into unit B_1 and is best observed in the wash wall between localities 15 and 37 (Pl. 4). Here the upper part of the unit is spread out over unit B_1 and apparently represents deposition in a broad shallow pond or swamp. The occurrence of aquatic pollen types at the top of

Mehringer's (1964) pollen profile I, collected in trench D at 4+00N, tends to support this interpretation. The lower part of the green-pond unit contains numerous buried spring-feeder conduits that were exposed during the course of archaeological excavations at localities 2, 7, 8, 9, 10, and 11 (Pl. 5). The roughly conical conduits taper with depth, are filled with very well sorted quartz sand, and commonly underlie bowl-shaped depressions filled with mudstones (Appendix I, p. 142). These ancient springs all lie along the course of the B_2 channel indicating much of the stream discharge to have been from artesian flow.

Invariably associated with the ancient springs are numerous bones of extinct animals, fossil wood, and abundant mollusc valves. At locality 2 a jumbled mass of bones was found at the bottom of a buried depression containing several spring feeders (Pl. 3, fig. 3). Carbonized plant remains occur as disseminated fragments (Pl. 11, fig. 1) and as broken branches or small logs concentrated in mudstones around the walls of the depressions (Appendix I, p. 142). Some of these wood fragments have been identified by Robert Koeppen, U. S. Department of Agriculture (personal communication), as *Fraxinus* (ash) and *Vitis* (grape), and radiocarbon dating of this material as well as mollusc shell carbonate (Table 6) indicates an age in excess of 40,000 years for unit B_2 and the associated fauna which includes extinct forms of elephant, horse, camel, and bison (Table 2).

Unit B_3 is lithologically similar to the alluvial silt facies of B_1 and conformably overlies the green-pond unit (B_2). It represents a brief return to conditions of alluvial deposition similar to those existing prior to the intense spring activity indicated by unit B_2. The strong soil (S3) on unit B_3 indicates a period of erosional-depositional stability and is somewhat stronger than soil S2 developed on unit B_1. At the north end of trench K where it cuts the toe of the Gass Peak bajada, the alluvial facies of unit B_3 interfingers with the alluvial-fan facies which contain the strong Cca horizon of soil S3. The deeper parts of the horizon are cemented with calcium carbonate forming a well cemented fanglomerate. Soil S3 and parts of older units (Pl. 3, fig. 1) were severely eroded prior to the deposition of unit C which, like the earlier unit B_1, consists of gravel in channels and silt forming a broad flood plain. Alluvial-fan facies of unit C are not observed in the north end of trench K.

The lacustrine mudstone of unit D disconformably overlies the silt of unit C in some places and conformably overlies it elsewhere. Where it is in contact with the lacustrine mudstone, the top of unit C shows no evidence of subaerial weathering, although mammoth teeth and bones were found on the erosional contact (Appendix I, p.147). In trench D at 0 + 60 N (Pl. 6) there is evidence of compaction slippage or minor faulting during the very early stage of lacustrine deposition.

Within unit D there are several minor disconformities and gypsum-bearing mudstone beds. In a few places, small rills filled with sand and rolled caliche pebbles rest on these minor stratigraphic breaks. These relationships are interpreted as representing brief periods of desiccation or marked shrinkage of the lake. This interpretation is supported by increases in cattail (Typha) pollen as the stratigraphic breaks are approached. Because Typha pollen is not carried far from the source, Mehringer (1964, p. 15) interprets the rise as indicating movement of the near-shore cattail zone toward the sampling point. Molluscs from the Tule Springs beds are being studied by D. Taylor who suggests (personal communication) that the molluscan fauna from unit D also indicates fluctuating lacustrine conditions.

Radiocarbon dating suggests that deposition of most of unit D (Appendix I, p. 147) took place between 20,000 and 30,000 years ago (Table 6).

Toward the top of the lacustrine unit the minor disconformities are more frequent, the mudstones become sandier and more gypsiferous, and caliche nodules increase in frequency and in size (Pl. 11, fig. 2). These features are interpreted as indicating a trend toward final desiccation of the lake. Because prismatic structure in unit D (Table 1) occurs throughout the entire thickness and is strongest in the clayier layers, it is believed to be due to clay shrinkage upon desiccation and not to pedogenic processes. In addition, the absence of a reddish zone of oxidation particularly in association with the caliche nodules is taken to indicate a nonpedogenic origin for the caliche nodules. Instead, development of the indigenous caliche nodules, which in places have coalesced into nearly solid layers, may have been in response to evaporation of lake water permitting precipitation of calcium carbonate in bottom mud.

In the Tule Springs Site Area final desiccation of the lake was followed by, or possibly accompanied by entrenchment of a narrow channel that subsequently filled with alluvial gravels and silt of unit E_1 which contain abundant rolled caliche fragments, undoubtedly washed at least partly from unit D. The E_1 fill also contains concentrations of animal bones, fossil plant remains, and tufa commonly associated with spring-feeder conduits (localities 3, 5, 6, 27, 37, and 38; fig. 2). At locality 37, fault control of the ancient spring (and probably of the E_1 channel as well) is in evidence in the wash wall (Pl. 4) behind which a spring-laid sequence within the E_1 channel was revealed by a bulldozer trench (Appendix I, p. 148). The fault strikes approximately N. 74° W., dips 42° S., and has an undetermined displacement, probably less than 10 feet. The coincidence of ancient springs and the E_1 channel indicate that artesian flow made a substantial contribution to stream discharge. At locality 5, large animal bones are jacketed with a one-half inch layer of tufa. The abundance of carbonized wood, mollusc shell, and tufa has permitted repeated radiocarbon dating of unit E_1 at practically every exposure. The dates (Table 6) indicate an age between 11,500 and 14,000 years for unit E_1 and its abundant fauna including the same large animals as in unit B_2. Wood fragments in

PLATE 3. STRATIGRAPHIC FEATURES OF THE TULE SPRINGS SITE

Figure 1. Erosional contact between units B_1 below and C above exposed in the east wall of trench K (21 + 50 N.) at 2 + 00 N. Lighter color of B_1 is due to pedogenic calcium carbonate (Cca horizon) of soils S2 and S3.

Figure 2. Cross section of unit E_2 channel cut into unit D. Resistance of gravel to erosion has preserved ancient channel as a sinuous ridge in reversed topographic position (see Pl. 2, fig. 1).

Figure 3. Excavations of ancient springs in unit B_2 at locality 2 showing jumble of fossil bones, excavated feeder conduits left of bone pile, and remnant of unit E_1 rill fill (above dotted contact). Bone pile measures approximately 3 feet across and was dated as >40,000 (UCLA-517).

Figure 4. East wall of bulldozer trench at locality 4 (Fenley Hunter site) showing complex stratigraphy (see Appendix I, p. 143) within channel fill composed of unit E_1 below dotted contact and unit E_2 above. Carbonaceous lens at lower center dated 12,400 ± 350 B.P. (UCLA-512).

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

STRATIGRAPHIC FEATURES OF THE TULE SPRINGS SITE

E_1 have been identified by Robert Koeppen (personal communication) as Fraxinus sp. (ash), Populus sp., and Juniperus (juniper) or Cupressus (cypress).

Also associated with the unit E_1 sediments are the first possible artifacts encountered in the stratigraphic record at Tule Springs. However, none of these, three of bone and one of caliche, are indisputably artifacts.

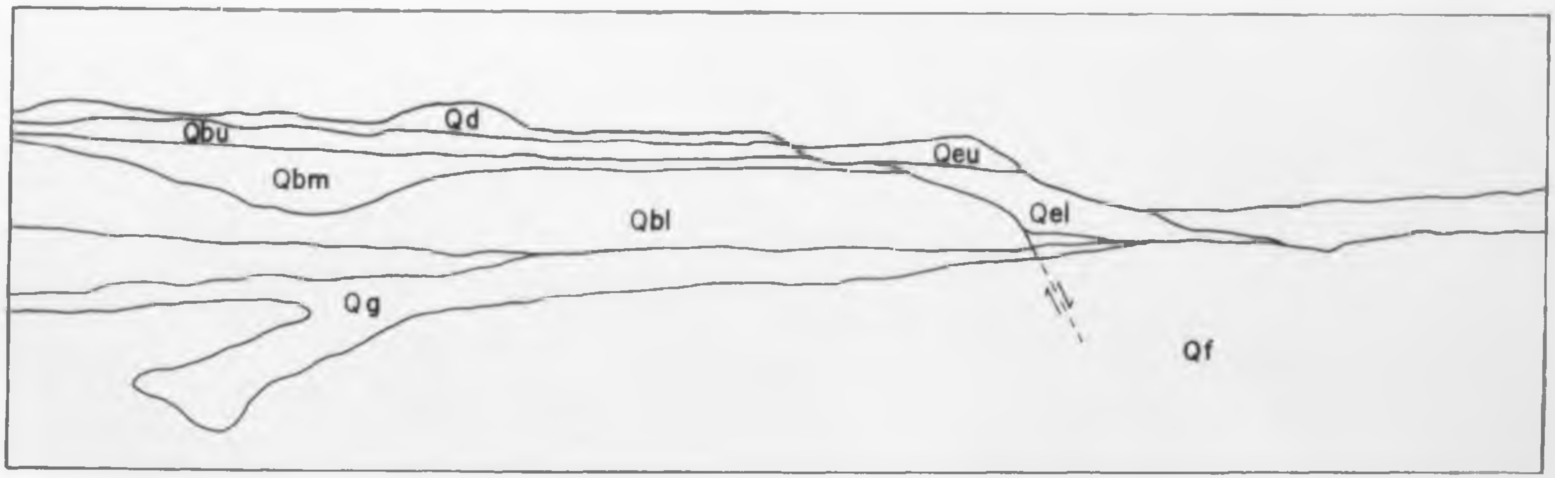
Where spared from erosion, upper parts of unit E_1 contain a moderately strong organic soil (S4) that appears to be relict of a wet-meadow soil restricted to the E_1 channel fill. Secondary calcification of the top foot of unit D is believed to be a pedocalic soil facies of S4 and is widespread in the area.

The period of weathering represented by the S4 soil was followed by a period of degradation during which a new and somewhat smaller channel was excavated along the same course as the E_1 channel, thus removing much of unit E_1. Silts of unit E_2 subsequently filled the new channel to overflowing.

Alluvial channel gravels are common in the upper part of E_2 and are widely distributed over the site area (Fig. 2). Today the reversed topographic

PLATE 4. LEFT BANK OF TULE SPRINGS WASH

View to the east showing stratigraphy between sites 15 (out of the picture to the left) and 37 (above fault). Tule Springs Site is visible in right background. (Qg = unit G, Qf = unit F, Qeu = unit E_2, Qel = unit E_1, Qd = unit D, Qbu = unit B_3, Qbm = unit B_2, and Qbl = unit B_1).



LEFT BANK OF TULE SPRINGS WASH

position of these gravels (Pl. 3, fig. 2) indicates that stream flow moved off the gravel channels and swept away the less competent silt facies during a period of intense degradation that eventually gave rise to the present channel of Tule Springs Wash. From exposures at the extreme north end of trench K (Pl. 7) and from photo mapping (Pl. 1), it is apparent that most of the Gass Peak bajada is covered with the alluvial-fan facies of unit E_2.

At localities 1 and 4A (Fig. 2) definite lithic artifacts were recovered from the early buried channel facies of unit E_2 (Appendix I, p.141 and 144), which by radiocarbon dating (Table 6) is from 8,500 to 11,000 years old. The artifacts are in the lowest part of the unit and probably date between 10,000 and 11,000 years old. The original Fenley Hunter discovery (Simpson, 1933) of an obsidian flake and associated camel remains was in either unit E_1 or the base of E_2 (Pl. 2, fig. 4). The presence of camel suggests unit E_1, but without more detailed stratigraphy concerning the find, there is nothing to preclude a possible mixture of the two facies, especially considering the close intermingling of the two channels. The upper part of E_2 produced only one carbon sample suitable for dating (Table 6), and this indicates an age of 7,500 years for the middle of the upper part of unit E_2 silt (Appendix I, p. 143). The E_2 gravel ridges contain a weak relict soil (S5) that represents the cumulative effects of weathering since abandonment of the channels.

The change from E_2 aggradation to degradation probably occurred sometime between 6,000 and 7,000 years ago. During this time the area probably attained its present topography and began to be occupied by Desert Culture peoples whose weathered artifacts are found on both the caliche- and gravel-capped surfaces (Susia, 1963). Within the modern wash, terrace remnants of unit F_1 gravels, with weak soil development (S5), may represent the stream grade established at the end of the period of degradation. The finer-grained facies of unit F_1 clearly indicate a period of considerable slope-wash deposition during which sand, caliche rubble, and lag gravel accumulated along the sides of the wash and in tributaries. It is from this facies of unit F_1 in one such tributary that a stone scraper found by the Southwest Museum in 1956 is believed to have come (see Appendix II). These sediments now stand as isolated remnants topographically higher than unit F_2 which shows a repetition of the same cycle as shown by F_1. It is likely that during degradation of unit F_1 its gravels were reworked to form F_2. No radiocarbon samples were recovered from units F_1 and F_2 at the site, but from correlations presented later, they are believed to be between 1,000 and 6,000 years old.

In aerial photographs, tongues of unit G_1 gravel can be seen to have extended from the toe of the Gass Peak bajada and to have spilled upon the floor of Tule Springs Wash where they have been little eroded since deposition (Pl. 2, figs. 1 and 2). In most examples, the lobate form of the terminus is well preserved (Fig. 2). This unit represents the last significant deposition in the Tule Springs Site Area. Today, most of the discharge through the wash is confined to the small channel (thalweg) cut into the F_2 gravel of the wash floor. Apparently this gravel is only slightly disturbed even during flash floods which have formed the fluvial silt dunes of unit G_2 that overlie the gravel bed of F_2. On the caliche surface of Gilcrease flat, unit G_2 is represented by slope wash silt and sand in shallow rills, one of which becomes a significant arroyo paralleling the main wash, about a mile southeast of the site (Pl. 1).

Paleosols

The site stratigraphy reveals five paleosols, four of which were truncated by erosion immediately following the period of weathering represented by the soil. Soil 5, on the other hand, shows slightly stronger development on the higher E_2 gravel ridges (e.g., trench A at 9 + 00 S) than on lower E_2 gravels (e.g., trench K at 3 + 00 N). Because the higher gravels were exhumed earlier, the differences in S5 soils suggest that soil development occurred throughout the period of E_2 degradation. The effects of this period of weathering were undoubtedly added to exposures of the S4 soil.

By far the strongest soil is S1 developed on unit A. Soils S2 and S3 show similar development with S3 being the stronger. All younger soils are distinctly and successively weaker; i.e., they have weaker structure, weaker Cca horizons, and thinner profiles even though they are generally less eroded. Also, the earlier soils S1, S2, and S3 appear to have somewhat darker and redder loams than do later ones.

TABLE 1. SEDIMENTARY FACIES AND SOILS OF THE TULE SPRINGS SITE AREA

Unit	Description	Maximum Thickness
G_2	Slope-wash sand facies. Very pale brown (10YR 8/3), loose, calcareous, medium to fine, silty sand with numerous caliche fragments, and weakly laminated in places. Occurs as fluvial dunes in places on the gravel floor of Tule Springs Wash, and occupies broad shallow rills on the exposed caliche surface of Gilcrease flat. No soil development is recognizable.	1 ft.
	Disconformity	
G_1	Gravel facies. Brownish-gray, loose, medium to coarse, subrounded, limestone, pebble gravel. Displays foreset bedding in places. Occurs as tongues extending from the toe of Gass Peak bajada and overlying the gravel bed of Tule Springs Wash. Type exposure is in trench K at 25 + 00 N.	5 ft.
	Disconformity	
S6	Very weak gray desert soil best developed on F_1 exposures.	0.5 ft.
F_2	Alluvial sand and gravel facies. Grey, weakly consolidated, subrounded, coarse-pebble to small-cobble, silty, limestone gravel with interbedded lenses of pale brown (10 YR 7/3), fine, current-bedded silty sand with dispersed coarse sand to fine-pebble-size caliche	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	fragments. Along the edges of the channel (trench F at 8 + 50 N.) this unit contains a weak, coarse, blocky to fine platy structure.	8 ft.
	Disconformity	
F_{1b}	Slope-wash sand facies. Very pale brown (10 YR 7/3), soft calcareous, silty, gritty, poorly sorted, in places current-bedded, medium sand with numerous, fine to medium pebble-sized caliche fragments. Laminae dip away from source area slopes. Erosional upper contact. Occurs as protected remnants along Tule Springs Wash and as rill deposits in adjacent badlands. Type exposure is in trench K at 19 + 50 N.	4 ft.
F_{1a}	Alluvial gravel facies. Gray, weakly consolidated, subrounded, coarse-pebble to small-cobble, silty, limestone gravel. Occurs as rare terrace and island remnants along Tule Springs Wash. The upper 4 inches of some exposures contain minute crystal aggregates of calcium carbonate adhering to pebbles and is overlain by a thin ($<$ 1-in. thick) vessicular horizon.	8 ft.
	Disconformity	
S5	Weak soil best developed in exhumed remnants of unit E_2 alluvial gravel facies. Type exposure is in trench K at 4 + 00 N.	
	A horizon. Very pale brown (10 YR 8/3), soft, calcareous, laminated,	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	vessicular, clayey silt loam with moderate, coarse prismatic structure breaking to moderate, medium platy. Silt is commonly overlain by a single layer pebble pavement.	0.2 ft.
	B horizon. Very pale brown (10 YR 7/3), soft to slightly hard, calcareous, laminated, clayey silt loam with moderate, coarse prismatic structure	0.1 ft.
	Cca horizon. Gray to brown, sandy, subrounded, medium to coarse pebble, limestone gravel with irregular crystal aggregates of calcium carbonate forming incomplete coating on bottoms of pebbles which show earlier 1-mm. thick, partially dissolved caliche jackets.	0.7 ft.
E_2	Alluvial silt facies. Very pale brown (10 YR 7/3), soft to slightly hard, very calcareous, very fine, clayey silt with thin ($<$ 1 in.) silty, clay lenses. Contains carbonized plant remains in places and an erosional break near the middle. Occurs mainly where protected from erosion by overlying gravel facies. Type exposure is locality 4, Fenley Hunter trench.	13 ft.
E_2	Alluvial gravel facies. Gray to brown, moderately well consolidated, subrounded, medium-pebble to small-cobble, silty, limestone gravel with interbedded lenses of silt and sand. Occupies channels cut into older units and occurs as channel remnants overlying and protecting silt facies. Gravel ridges stand in reversed topographic positions. These gravels also comprise most of the surficial deposit on Gass Peak bajada.	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	Desert pavement on this unit shows moderate solution features, desert varnish on siliceous pebbles, and a few weather-fractured siliceous rocks. Type exposure is in trench K between 1 + 00 N. and 4 + 00 N.	5 ft.
	Disconformity	
S4	Local paleosol developed on the alluvial channel facies of unit E_1. Type exposure is in Fenley Hunter trench at locality 4.	
	B horizon. Gray (10 YR 5/1), hard, calcareous, sandy, clayey silt loam with rootlet molds and strong, fine to medium irregular prismatic structure breaking to angular. Erosional upper contact.	4 ft.
S4	Relict Cca horizon developed on unit D. Very pale brown (10 YR 8/3), soft to hard, silty caliche with moderate to strong, medium, irregular blocky structure breaking to moderate, medium platy. Occurs as secondary carbonate development in mudstone of unit D. Type exposure is in trench K at 1 + 00 S.	1 ft.
E_1	Alluvial sand and gravel facies. Light gray (7.5 YR 7/1), slightly hard to hard, friable, calcareous, fine clayey, silty sand interbedded with silty, sandy, fine to medium, rolled caliche, pebble gravel and sandy, rounded medium-pebble, limestone gravel with 10% or more caliche pebbles. Contains abundant bones of large mammals, mollusc valves, carbonized wood fragments, and tufa masses, especially near spring-feeder conduits which are filled with well sorted, fine, quartz sand. Type exposure is in trench K at 4 + 50 N.	10 ft.

TABLE I (Continued)

Unit	Description	Maximum Thickness
	Disconformity	
D	Lacustrine mudstone facies. Light gray (2.5 Y 7/2), hard, very calcareous, clayey siltstone to silty claystone with very strong, medium-prismatic structure and numerous indigenous, irregular, subrounded caliche nodules ranging from medium-pebble to small-cobble size. Some layers contain crystal rosetts of gypsum in voids. Unit contains mollusc valves, silicified monocotyledon fragments, and rootlet molds. Interbedded with light gray (10 YR 7/1.5), slightly hard, laminated, fine, silty-sand layers up to 6 inches thick. Basal 6 inches to 1 foot is light gray (10 YR 7/1), hard, massive, fine to medium, silty sand with widely scattered lumps of carbonized wood and scattered mammoth bone fragments along basal contact. Erosional upper contact. Weathered surface is commonly littered with very angular caliche fragments displaying strong solution features. Type exposure is in trench K at 1 + 00 S.	15 ft.
	Disconformity	
C	Alluvial silt and gravel facies. Very pale brown (10 YR 8/3), soft to hard, calcareous, clayey silt to silty sand with interbedded lenses of gray, consolidated, coarse-pebble to large-cobble gravel with sooty coatings of manganese oxide in some places. Charco clays and current bedded sands occur locally. Erosional upper contact. Type exposure is in trench K at 3 + 00 N.	20 ft.
	Disconformity	

TABLE I (Continued)

Unit	Description	Maximum Thickness
S3	Buried Bca horizon of strong paleosol developed in unit B_3. Pale brown (10 YR 6/3), slightly hard to hard, calcareous, silty-clay loam with strong, fine to medium prismatic structure breaking to angular. Contains numerous, dispersed, irregular medium-pebble size, slightly hard, indigenous caliche nodules. Peds contain rootlet molds and show surficial manganese oxide stains. Sharp erosional upper contact; smooth abrupt lower boundary with unweathered unit B_3 (C horizon). Type exposure is in trench I at 4 + 50 N.	3 ft.
B_3	Alluvial silt facies. Very pale brown (10 YR 8/3), hard, calcareous, clayey to sandy silt. Erosional upper contact. Type exposure is in trench J at 4 + 00 N.	5 ft.
B_3	Alluvial fan facies. Brown to gray, hard, compact, carbonate cemented, silty, subangular, coarse-pebble to large-cobble, limestone gravel and fanglomerate. Erosional upper contact. Type exposure is in trench K at 30 + 50 N.	6 ft.
B_2	Fluvio-lacustrine mudstone facies. Pale olive gray (5 Y 7/2), hard to very hard, very calcareous, clayey to silty mudstone with conchoidal fracture and strong medium prismatic structure. Contains mollusc valves, carbonized plant remains; and large mammal bones especially in and near spring feeder conduits commonly filled with fine, well sorted, quartz sand. Occupies broad shallow channel. Basal one foot is	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	commonly medium-pebble to small-cobble, subrounded, limestone gravel and occupies narrow part of the channel. Erosional upper contact. Type exposure is in trench D at 4 + 00 N.	15 ft.
	Disconformity	
S2	Buried strong paleosol developed in unit B_1. Type exposure is in south wall of Tule Springs Wash at 18 + 00 W.	
	B horizon. Pale brown (10 YR 6/3), hard to very hard, calcareous, silty-clay loam with strong, medium, prismatic structure breaking to angular. Contains numerous rootlet molds and surficial manganese oxide stains. Erosional upper contact. Smooth, gradual lower soil boundary.	2 ft.
	Cca horizon. White (10 YR 8/2), very hard, very calcareous silty mudstone with numerous indigenous irregular subrounded, coarse-pebble size caliche nodules and strong, medium prismatic structure. Long dimension, of caliche nodules are horizontal. Smooth, gradual lower boundary with unweathered unit B_1 (C horizon).	0.7 ft.
B_1	Alluvial silt and gravel facies. Very pale brown (10 YR 8/3), hard to soft, calcareous, clayey silt to silty sand interbedded, in lower parts, with lenses of the sand and gray, consolidated, coarse-pebble to large-cobble, subrounded, sandy, limestone gravel with sooty coatings of manganese oxide in some places. Two darker	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	zones with weak to moderate medium prismatic structure observed in trenches A and D may be remnants of B horizons of weak paleosols. Erosional upper contact. Type exposure is in trench K at 2 + 00 N.	16 ft.
	Disconformity	
S1	Buried, very strong compound paleosol developed in unit A. Type exposure is in south wall of Tule Springs Wash at 14 + 50 W.	
	B horizon of S2 developed in B horizon of S1. Very pale brown (10 YR 7/3), hard, moderately calcareous, clayey, silt loam with very strong, medium prismatic structure breaking to angular. Contains rootlet molds and manganese oxide stains on ped surfaces. Erosional upper contact.	1.5 ft.
	Cca horizon of S2 developed in B horizon of S1. White (10 YR 8/1), hard to very hard, very calcareous, clayey silt loam with very strong, medium prismatic structure and numerous, indigenous, closely dispersed, medium-pebble size, caliche nodules. In lower half caliche nodules have coalesced into white, hard, friable, silty caliche zone within which are circular (6-in. diam.) to horizontally elongated exposures of light brown (7.5 YR 6/4), hard to soft non-calcareous, silty clay loam. Smooth, gradual lower boundary.	1 ft.
	Cca horizon of S1 developed in unit A. White (10 YR 8/1), very	

TABLE I (Continued)

Unit	Description	Maximum Thickness
	hard, very calcareous, silty caliche with strong, fine angular structure. Contains small (~ 3/16 in. diam.), very irregular pores and manganese oxide stains. Smooth, gradual lower boundary.	4 ft.
A	Alluvial silt. Light brown (7.5 YR 6/4), very hard, moderately calcareous, silty mudstone with strong, irregular, medium to coarse prismatic structure breaking to angular. Contains light gray (2.5 Y 7/2) zones in some places. Erosional upper contact.	$>$5 ft.

TABLE 2. VERTEBRATE FOSSILS OF THE TULE SPRINGS SITE AREA
(Mawby, 1963, and personal communication)

Unit E_1

Edentata

Megalonyx sp. (ground sloth)

Lagomorpha

Lepus sp. (jack rabbit)

Sylvilagus sp. (cottontail)

Brachylagus idahoensis (pigmy rabbit)

Rodentia

Dipodomys sp. (kangaroo rat)

Microtus cf. *M. californicus* (meadow mouse or vole)

Ondatra cf. *O. zibethica* (muskrat)

Thomomys sp. (reported by Simpson, 1933) (pocket gopher)

Carnivora

Canis latrons (coyote)

Felis (*Puma*) sp. (puma)

Proboscidea

Mammuthus columbi (columbian mammoth)

Perissodactyla

Equus, large sp. near *E. caballus* (horse)

TABLE 2 (Continued)

Equus, small sp., cf. *Asinus* (donkey)

Artiodactyla

Camelops hesternus (camel)

Odoccileus sp. (deer)

Tetrameryx sp. (prong horn)

Unit D

Proboscidea

Mammuthus columbi (columbian mammoth)

Artiodactyla

Camelops sp. (camel)

Unit B_2

Edentata

Nothrotherium shastensis (ground sloth)

Megalonyx sp. (ground sloth)

Lagomorpha

Sylvilagus sp. (cottontail)

Lepus sp. (jack rabbit)

Rodentia

Microtus sp. (meadow mouse or vole)

Carnivora

Felid, small, cf. *Lynx*

Panthera atrox (panther)

TABLE 2 (Continued)

Proboscidea

Mammuthus columbi (columbian mammoth)

Perissodactyla

Equus, large sp., near *E. caballus* (horse)

Equus, small sp. (horse)

Artiodactyla

Camelops hesternus (camel)

Bison sp. (American "buffalo")

GEOLOGY OF THE TULE SPRINGS RANCH AND GILCREASE RANCH AREAS

Geomorphology

Gilcrease flat, between the Tule Springs Site and the Kyle Canyon alluvial fan, is flat, barren, and relatively featureless. However, near the Kyle Canyon fan elevated erosion remnants (Pl. 9, figs. 1 and 2) are distributed in the form of a crescent around the fan toe (Pls. 1 and 8). At locality 56 the fanward side of these remnants of fine-grained sediments (unit C) is marked by a vertical cliff rising 15 to 20 feet above a gravel wash passing between the remnants and the fan toe (Fig. 4A). In several places the washes, which drain the fan, form small canyons between erosion remnants and distribute their load to the shallow rill system crossing Gilcrease flat. The side of the erosion remnants away from the fan (downslope) is strongly dissected by a dendritic system of rills (Pl. 9, fig. 1), most of which start on the flat surface on top of the remnants but do not extend headward as far as the cliff on the fanward side. The facts that the toe of the fan ends against a cliff and that the numerous rills working headward toward the cliff have failed to reach it are unusual features and their interpretation is dependent upon investigation of the Kyle Canyon fan.

From the air three distinct types of surfaces can be observed on the fan (Pl. 8). For purposes of discussion these are numbered 1 through 3. The number 1 surface is farther up slope from the toe and makes up the highest interfluvial surface on the lower fan. It shows up as dissected light areas in aerial photographs and appears to be partially "drowned" by alluvial-fan gravels making up lower surfaces. The number 2 surface is the darkest, is strongly dissected on a finer scale than surface number 1, and appears to be partially buried by gravels of the number 3 surface deposit which is the lowest and is intermediate in color. Actually the number 3 surface is made up of several surfaces and terraces too indistinct to differentiate on aerial photographs.

Close inspection in the field reveals the causes of the differences observed in photographs and from the air. The number 1 surface is a fanglomerate cemented by dense hard calcium carbonate which is responsible for the light color. It may correlate with unit B or possibly older units. The number 2 surface is composed of gravel (unit D) showing strong solution effects, weather fracturing, wind faceting, and strong desert varnish (Pl. 11, fig. 4), while the number 3 surfaces show similar effects but less well developed. The surfaces are numbered in order from that exposed the longest to the youngest, and, as will be discussed, each surface displays the effects of weathering of successively younger alluvial-fan gravels constituting mapable units.

Near Tule Springs Ranch the number 2 surface appears to be graded to the surface of the erosion remnants, while the number 3 surface can be seen graded to some point below the cliff but above the present stream gravel (Fig. 4A). From these relationships the number 2 alluvial-fan gravels appear to be facies of the finer sediments making up the erosion remnants. During degradation, erosion of the fine sediments apparently followed rills already established by drainage from the fan, and dissection of the less resistant sediments at the toe of the gravels eventually isolated them from the erosion remnants. The small canyons separating remnants obviously resulted from channels of sufficient size to maintain their course from the fan

AERIAL PHOTOGRAPH OF THE TULE SPRINGS SITE (△) AND ADJACENT AREA (U.S. Geol. Survey photos LJ-1-55,56)

PLATE 9. GEOLOGIC FEATURES OF THE TULE SPRINGS AND GILCREASE RANCH AREAS

Figure 1. Aerial view to northeast showing badlands of units C and D in foreground, unit B(?) gravel between badlands and Tule Springs Ranch, Gilcrease flat in middle ground, and Las Vegas Range and Gass Peak bajada in background. Outlier on unit B gravels is capped by lacustrine mudstone of unit D. Toe of Kyle Canyon fan is seen in lower left corner and ends against cliff of alluvial silts (unit C).

Figure 2. Aerial view to north overlooking spring mounds and dissected scarp between Tule Springs Ranch and Gilcrease Ranch. Bulldozer trench through spring mound 4 and 4a is visible below center of photograph.

Figure 3. View to northeast showing spring 7, Gilcrease Ranch. Prior to 1948, caldera-shaped depression contained sediments held in suspension by spring flow and was a notorious animal trap. White layer to right of person is calcareous sinter. Organic mat below sinter dated 1,450 ± 100 B.P. (UCLA-527).

Figure 4. South wall of trench through spring mound 4 (Appendix, p.149), Gilcrease Ranch, showing buried organic mat (9,920 ± 150 B.P. (UCLA-537) covered by mound of eolian sand. Vertical light streak just to the right of center is a sand filled feeder conduit representing a late period of spring flow. Mound became dry in early 1930's. Horizontal distance between flags is 10 feet. Vertical rows of tags mark samples of pollen profile III. Extension of trench through spring 4a is visible at the far right. (Photo by William Belknap)

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

GEOLOGIC FEATURES OF THE TULE SPRINGS RANCH AND GILCREASE RANCH AREAS through the fine sediments. Evidence will be presented later that suggests tectonic activity as a possible cause of the peculiar course of erosion.

From Tule Springs Ranch to Gilcrease Ranch the erosion remnants (units C and D) became gradually less elevated until in the vicinity of Gilcrease Ranch they are apparently buried (Pl. 1). Between the two ranches there are a number of springs that went dry within the last 50 years (Pl. 9, figs. 2, 3, and 4). Seven of these between locality 43 and 53 lie on a nearly straight north-south line, and 5 others between Stillwell spring and Tule Springs Ranch define another, but not quite parallel, alignment farther west (Pl. 1). These will be referred to as the Gilcrease and Stillwell spring alignments respectively.

Stratigraphy

Sediments and soils of the area of Tule Springs and Gilcrease Ranches are described in Table 3. The oldest sediment exposed in the area is a clayey silt of unknown age and containing a very strong pedalferic paleosol. Where exposed in a pump house excavation at locality 54 (Pl. 1), the soil is truncated and overlain by gravels probably of unit B age (Pl. 9, fig.1). At locality 56 (Pl. 1) these contain a well developed paleosol (S3?) and are disconformably overlain by as much as 15 feet of interbedded clayey silts and sands (unit C) capped by a relict caliche horizon (S4). In an outlier by locality 54 the relict soil and the silts are separated by approximately 6 feet of gray silty mudstones (unit D) (Fig. 4) containing numerous mollusc valves. Both the lithologies and the depositional sequence duplicate those of units C, D, and soil S4 at the Tule Springs Site and are so correlated. If this correlation is correct, and it most likely is, then tectonic activity may be in evidence by the fact that unit D near locality 54 is at least 70 feet higher than on the flat immediately east of the Gilcrease spring alignment and approximately 200 feet higher than the sequence at the site. Downthrow east of Kyle Canyon fan may account for the unusual erosional pattern discussed earlier, and abandonment of the number 2 fan surface. Dissection of the alluvial-fan facies of unit D could coincide with this tectonic event.

The number 2 surface is on gravels that are considered to be the alluvial-fan facies of the unit D lacustrine sediments, and the Cca horizon of soil S4

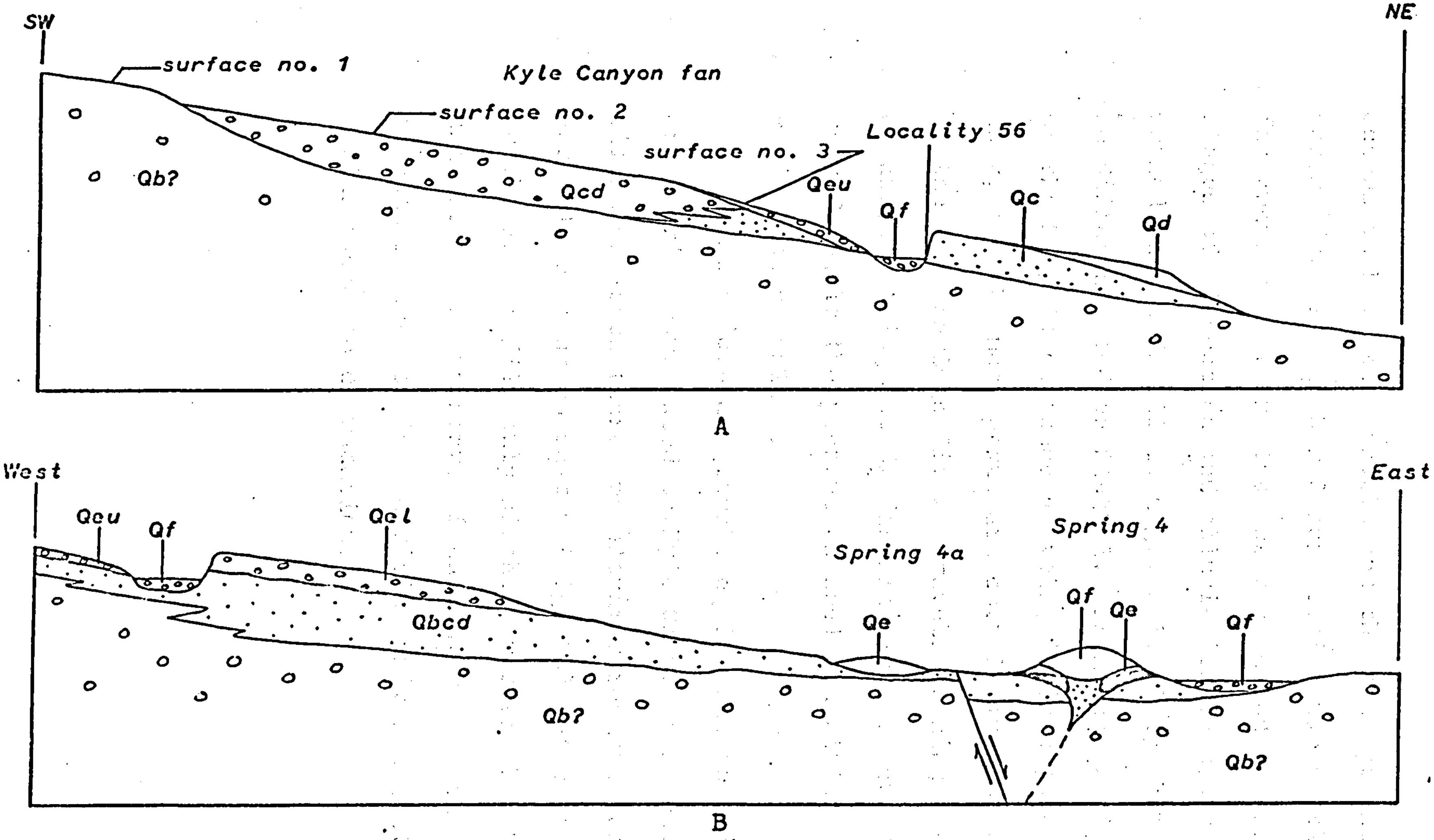


Figure 4. Generalized stratigraphic cross sections in the Tule Springs Ranch (A) and Gilcrease Ranch (B) areas. No scale.

occurs on both the gravels and the fine grained sediments. The number 3 surface is also on alluvial-fan gravels that are less weathered and reveal several stages of dissection and alluviation that can be worked out in detail at a given locality, but cannot be differentiated on Plate 1. From the areal extent of the S5 soil on these gravels, it is apparent that they, for the most part, are correlatives of unit E_2 at the Tule Springs Site. Gravels forming terraces in channels cutting the E_2 fan gravels are equated with unit F, while the present channel gravels are the equivalent of unit G.

Alluvial-fan gravels equivalent to unit E_1 are poorly represented on Kyle Canyon fan, but near Gilcrease Ranch there are elevated remnants of gravel and silt resting on unit C (Fig. 4B) yet containing a weathering profile only slightly weaker than S4 on unit D. These remnants of unit E_1 may be the result of unit D fan-gravels overriding unit D lacustrine facies prior to degradation.

Spring Mounds

The Tule Springs Site contained abundant evidence of ancient springs in the sedimentary record. Commonly associated with these were numerous concentrations of fossil animal bones, decayed plant remains, and possible artifacts. It became of prime interest to archaeologists to learn if concentrated masses of broken bones and carbonized wood in the ancient springs were reasonable a priori evidence of the activities of man. It was decided, therefore, to conduct a detailed investigation of the 11 modern springs occurring between the two ranches (Pl. 9, fig. 2).

Most of the 7 springs on the Gilcrease alignment have the form of dome-shaped mounds 100 to 500 feet in diameter and 10 to 20 feet high (Pl. 9, fig. 4), but one is an S-shaped ridge. The 5 springs on the western alignment are calderalike depressions (cauldron springs) on low mounds, and are 50 to 100 feet in diameter and over 10 feet deep (Pl. 9, fig. 3). According to Mr. T. A. Gilcrease (in conversation) most of the springs went dry within the last 20 years in response to pumping from deep wells on the ranches. The last to go dry was the S-shaped "snake" ridge in 1959. The cauldron springs were filled with "boiling quick sand" and constituted notorious animal traps during cattle ranching days prior to World War II, and several of the springs were used to irrigate alfalfa fields after the war. As these went dry, efforts were made to regain flow by excavation which revealed both flint artifacts and numerous animal bones within the spring sediments. Some of the artifacts in the Gilcrease collection display an ultra high polish apparently acquired while being suspended in a sand-filled spring conduit. These cauldron springs can be entered and examined today whereupon animal bones, flint debris, and pottery fragments (sherds) can be found protruding from the walls and in the floors. Hand excavation reveals some of the sand-filled feeders to be 6 feet or more in diameter. Radiocarbon dating the organic mat around the perifery of spring 7 (Pl. 9, fig. 3) showed it to be at least 1,400 years old (Table 6).

Regarding the occurrences of bones in ancient spring sediment, the observations of Carpenter (1915, p. 24) in Duck Valley, Nevada, are pertinent:

> Most of these springs are deep, jug-shaped reservoirs, which are always partly and sometimes completely covered by a shelf of soil and grass roots. Their depth is not known, but according to popular belief it is

very great. In attempting to drink from them many horses and cattle have lost their footing and have sunk beneath the shelf never to be recovered.

Two mounds, spring 4 dry since 1930 (locality 45), and spring 4a extinct in prehistoric time (locality 46), were dissected by a bulldozer trench in order to ascertain the internal stratigraphy (see Appendix I, p. 149). Both mounds contained buried black, peaty organic mats over feeder conduits filled with well-sorted fine sand (Pl. 9, fig. 4). Radiocarbon dating of the peat and related tufas indicate that the springs had started to flow sometime before 11,000 years ago (Table 6). The mat in spring 4a is overlain by weathered silt identical to, and probably correlative with, unit E_2, as is the mat itself. The spring apparently dried up before or during deposition of the E_2 silt. A similar unit buried in spring mound 4 was strongly weathered and possibly eroded before burial, thus indicating drying up of the spring after 9,000 years ago but before deposition of the mound which is made up of massive, coarse, well-sorted quartz silt in places cemented by calcium carbonate in the outer 2 to 4 feet covering the mound. On the eastern side, this layer is a dense, hard caliche. A small sand feeder conduit in the south wall of the trench extends from the sand below the mat to the middle of the unit F silt where it ends abruptly against a weak disconformity (Pl. 9, fig. 4).

Radiocarbon dating shows the top of the mound to be about 1,000 years old (Table 6), indicating that the silt is equivalent to unit F for which the pollen record here shows a marked increase in grass pollen and a loss of tree types starting at the erosional contact with unit E_2 (Mehringer, 1964, pollen profile III). Loose, only slightly weathered sand and silt occurring as partially deflated patches on the mound is correlated with unit G. The top of mound 4 was damp in 1930, and in 1962, no water was encountered by the bulldozer trench until damp sand below the organic mat was exposed 14 feet below the top of the mound.

The lower stratigraphy and the dating of mound 4 indicate that the spring began to flow through a 6-foot diameter feeder conduit some time before 11,000 years ago. A better estimate can be had on the basis of palynological investigations. Mehringer (1964, fig. 8, and personal communication) suggests that pollen sample 66 from a clay lens within the upper part of the large buried conduit at Gilcrease spring 4 correlates with sample 233 which is 6 inches below an organic mat that is 13,000 years old at locality 37 (Appendix I, p.148). If the correlation is valid, spring 4 discharge, as indicated by the size of the conduit, was at a peak about this time.

The organic mat grew between 9,000 to 10,000 years ago, and the spring was overridden by E_2 silt after 9,000 years ago when it may have stopped flowing temporarily. Mound 4a definitely became extinct at this time, and the absence of E_2 silt over the center or "eye" of spring 4 may indicate erosion or deflation. Between the end of E_2 deposition (about 7,000 years ago, if correlation with the radiocarbon dated sediments at the site is correct) and 1,000 years ago, coarse quartz silt was deposited to form the present mound. The massive structure and relatively well sorted silt suggest eolian deposition, and it is likely that the mound grew as wind driven silt accumulated on damp ground (Carpenter, 1915, p. 25). As stated by Meinzer and Kelton (1913, p. 42), a mound would grow in this way until the artesian pressure head was equalized. At this stage, evaporation of water from the soaked mound of spring 4 apparently led to precipitation of calcium carbonate to form the caliche observed around the outer parts of the mound.

The internal structure of mound 4a (Appendix I, p.150) reveals the organic mats (unit E) to overlie a mudstone containing bone fragments, a fossil horse tooth (Equus sp.), and several thin (< 1 in.), dark gray organic layers, the lowest of which dated 25,300 years (Table 6, no. 66). These facts support correlation of the mudstone with the lacustrine unit D at the site but it may be a springlaid facies. An underlying pale greenish-gray sandy mudstone contains tusks and teeth of mammoth, and truncated feeder conduits indicating an older period of spring activity, possibly equivalent to that represented by unit B_2 at the Tule Springs Site. The lowest unit uncovered by the trenching is a coarse cobble limestone gravel about 2 feet below the surface at the east side of spring 4a. A 30-inch diameter auger hole 40 feet to the east failed to reach the gravel at 12 feet, suggesting that a 10-foot or more vertical displacement of the gravel occurs between the two mounds (Fig. 5).

One-quarter mile east of mound 4, what may be the same gravel crops out over a wide area, and is overlain farther east by several feet of lacustrine mudstone (unit D) as revealed by additional auger holes. While direct evidence is lacking, the alignment of springs, the possible displacement, and the differences in elevation of units C and D on either side of the spring alignment are convincing indications that faulting has downthrown Gilcrease flat relative to Kyle Canyon fan since deposition of unit D.

The intermittent flow of springs may have been in response to activity along the fault zone at various times, but could also have been dependent upon climatically controlled fluctuations in the water table. During pumping from the 700-foot wells, the springs intermittently flowed or stopped in response to nearby pumps being off or on until the springs went dry altogether because of the artificial drawdown. Obviously the springs are connected with a deep aquifer which is probably not affected by short term climatic fluctuations. Another argument supporting fault control is that the mound stratigraphy indicates a sudden birth and slow death of the springs.

If the emergence of the springs was fault controlled, it appears that the Gilcrease fault (alignment of mound springs) last became active before 13,000 years ago, while the Stillwell fault (alignment of Cauldron springs) appeared or was reactivated sometime before 1,500 years ago. Spring flow for the past 7,000 years at mound 4 was slack compared to that before 10,000 years ago which coincides with a climatic shift from more moist to drier about the same time (Mehringer, 1964, fig. 8). One of the cauldron springs along the Stillwell alignment discharged 100 to 400 gallons per minute between 1922 and 1946 (Maxey and Jameson, 1948, p. 80) and probably discharged considerably more when the organic mat formed 1,500 years ago in spite of the desert climate of the past 7,000 years. Spring discharge appears to be controlled by both structural changes and climate.

The absence of mounds at cauldron springs is probably due to discharge being sufficient to flush away eolian material until their premature "death" was brought on by deep wells. The existence of a small, active, youthful mound at Corn Creek Springs (Pl. 12, fig. 3) suggests that there is eolian deposition today sufficient to build a mound if discharge is low enough.

TABLE 3. SEDIMENTS AND SOILS OF THE TULE SPRINGS RANCH AND GILCREASE RANCH AREA

Unit	Description	Maximum Thickness
F	Undifferentiated alluvial-fan facies. Gray, weakly consolidated, subrounded, coarse-pebble to small-cobble, silty, limestone gravel with well developed imbrication in places. Occurs as islands and low terraces in rills and channels of the Kyle Canyon fan. Desert pavement on this unit shows little or no desert varnish, solution features, or weather-fractured pebbles.	>10 ft.
F	Undifferentiated eolian silt facies. Light gray (10 YR 7/2), soft to slightly hard, friable polleniferous calcareous, well sorted, fine-sandy, silt with iron and manganese oxide stains, rootlet molds, and massive to weak, medium, blocky structure. Contains irregular zones of strong calichefication. Occurs locally as mounds covering the organic mats of ancient springs. Exposed by trench through spring 4 (locality 45).	15 ft.
	Disconformity	
S5	Soil developed on unit E_2 alluvial-fan facies of Kyle Canyon fan and exposed in gravel pit at locality 97.	
	A horizon. Very pale brown (10 YR 3/4), soft, moderately calcareous, weakly laminated, vesicular, clayey-silt loam with moderate, coarse, prismatic	

TABLE 3 (Continued)

Unit	Description	Maximum Thickness
	structure breaking to moderate, medium platy. Silt is overlain by a single-layer pebble pavement showing moderate solution features, desert varnish, and weather fractured siliceous rocks.	0.2 ft.
	B horizon. Very pale brown (10 YR 7/4), slightly hard, calcareous, clayey silt loam with moderate, coarse prismatic structure.	0.2 ft.
	Cca horizon. Gray to brown, subrounded, coarse-pebble to small-cobble, sandy, limestone gravel with thin ($<$ 1 mm.) caliche coatings on bottoms of pebbles.	0.8 ft.
E_2	Alluvial-fan facies. Gray to brown, weakly consolidated, subrounded, medium-pebble to small-cobble, silty, limestone gravel with interbedded silt and sand lenses. Imbrication well developed in some exposures. Makes up a major portion of Kyle Canyon fan and Gass Peak bajada. Exposed in gravel pit at locality 97.	14 ft.
	Disconformity	
S4	Compound soil (S4 + S5) developed in alluvial-fan facies of unit D on Kyle Canyon fan.	
	A horizon of S5 and later soil development. Very pale brown (10 YR 8/3), soft, calcareous, laminated, vesicular, clayey-silt loam with moderate, coarse	

TABLE 3 (Continued)

Unit	Description	Maximum Thickness
	prismatic structure breaking to moderate, medium platy. Silt is overlain by a single layer pebble pavement with strong solution features displayed by limestone pebbles, strong to moderate desert varnish on siliceous pebbles, and wind faceting on some cobbles.	0.2 ft.
	B horizon of S5 and later soil development. Very pale brown (10 YR 7/4), slightly hard, calcareous, clayey-silt loam with moderate coarse prismatic structure.	0.1 ft.
	Cca horizon of S5 and S4. White, soft, sandy caliche interstitial to medium-pebble to small-cobble, limestone gravel with thin ($<$ 1/16-inch thick) caliche jackets on bottoms of pebbles.	1.5 ft.
D	Lacustrine mudstone facies. Light gray (2.5 Y 7/1), hard to soft very calcareous, clayey siltstone with numerous indigenous caliche nodules grading to a solid caliche cap. Contains mollusc valves. Weathered surface is littered with sharply angular solution pitted caliche rubble. Occurs on erosion remnants near Tule Springs Ranch.	8 ft.
D	Alluvial-fan facies. Gray to brown, moderately well consolidated, subangular to subrounded, coarse-pebble to large-cobble, silty, limestone gravel with interbedded silt and sand. Makes up a major portion of the Kyle Canyon fan (No. 2 surface), but not observed on the Gass Peak bajada.	$>$5 ft.

TABLE 3 (Continued)

Unit	Description	Maximum Thickness
C	Alluvial silt and sand facies. Very pale brown (10 YR 8/3), slightly hard to hard, calcareous, interbedded, clayey silt and silty sand with a 6-inch thick relict Cca horizon of soil S4 at the top. Surface is littered with a caliche rubble of irregular pebble-sized fragments showing strong solution features. Occurs as erosion remnants and inliers along the toe of Kyle Canyon fan. Best exposed at locality 56.	12 ft.
	Disconformity	
S3	Buried strong paleosol developed in alluvial-fan gravels of the Kyle Canyon fan.	
	B horizon. Light brown (7.5 YR 6/4), hard, intermixed clayey-silt loam with moderate, medium, prismatic structure and subangular, medium-pebble to large-cobble, limestone gravel. Some cobbles show thin ($< 1/16$ inch) alteration rinds. Erosional upper contact. Best exposed at locality 56.	4 ft.
	Cca horizon. Light brown (7.5 YR 6/4), slightly hard to hard, well consolidated, calcareous, small to large-cobble, subrounded, limestone gravel with thin (1/8 inch) caliche jackets on bottom halves of cobbles. Exposed in floor of gravel pit at locality 97.	>1 ft.

TABLE 3 (Continued)

Unit	Description	Maximum Thickness
B?	Fanglomerate facies. Brown, very hard, small to large-cobble, subangular, limestone gravel cemented by dense calcium carbonate. Makes up major part of higher portion of Kyle Canyon fan (No. 1 surface).	>10 ft.
B?	Alluvial silt facies. Pale olive gray (5 Y 6/2), slightly hard to hard, clayey silt with strong, medium, prismatic structure. Contains bones of mammoth and horse. Exposed in the immediate area of springs, 3, 4, and 4a (localities 45 and 46) where this unit overlies a coarse-cobble, limestone gravel of unknown age and with numerous rotten cobbles. This unit, as well as the rotten gravel, may be peculiar to this area of concentrated springs.	12 ft.

GEOLOGY OF THE EGLINGTON SCARP AREA

Geomorphology

Approximately 3 miles southeast of the Tule Springs Site Gilcrease flat ends at a low-angle escarpment that will be referred to as the Eglington scarp (Pl. 10, fig. 1) after a ranch shown by Carpenter (1915, Pl. 2). At the foot of the scarp, which is dissected by several arroyos and numerous tributary rills (Pl. 10, fig. 2), and approximately 80 feet below Gilcrease flat lies Stewart flat (Pl. 1), also named after an early ranch shown by Carpenter. To the southwest, the scarp becomes shallower, curves to the south, and loses its identity south of Craig road (Pl. 1). To the northeast, it curves northward and is separated from an alluvial fan by Tule Springs Wash which, from that point, takes a more southerly course. Roughly parallel to the wash are several elongated remnants of channel gravels that stand above the general level of Stewart flat but below the scarp.

Throughout the general area of the scarp but especially in the northeast are linear or curvilinear

PLATE 10. GEOLOGIC FEATURES OF THE EGLINGTON SCARP AREA

Figure 1. Aerial view showing Eglington scarp separating Gilcrease flat (background) from Stewart flat (foreground) with weak scarp (center foreground), and Wann Wash (left foreground). Tule Springs Site is located at toe of the Gass Peak bajada (center background).

Figure 2. View to south showing dissection of the Eglington scarp and 8-foot alluvial terrace (unit G) within the arroyo. Top of terrace dates 200 ± 80 B. P. (UCLA-640).

Figure 3. Ridge of cauliflowerlike tufa at locality 64 dated 10,160 ± 160 B. P. (A-471) and may represent spring deposition along a fault trace.

Figure 4. Right bank of Tule Springs Wash at locality 71 showing compression slippage in unit B. Over-all length of trench shovel (folded) is 21 inches. (Photo by P. J. Mehringer, Jr.).

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

GEOLOGIC FEATURES OF THE EGLINGTON SCARP AREA outcrops of tufa and tufa rubble (Pl. 1). These have the form of cauliflowerlike masses (Pl. 10, fig. 3) and cylindrical or brachiate tubes of various sizes (Pl. 11, fig. 3). Rubber casts of the interiors of these tubes confirmed the opinion that the tufa had formed around sticks, reeds, and other plant matter.

The tufa alignments are commonly straight, transect topographic contours, and in places lie on top of the lacustrine caliche of unit D, all of which argue against a lacustrine littoral origin. At the Tule Springs Site and in the area of Gilcrease Ranch tufa is a common product of springs believed to be fault controlled, and such an origin seems likely for the scarp occurrences.

Two extinct mound springs occur near the head of Wann Wash (locality 66, Pl. 1), and are covered with evidence of aboriginal use including artifacts, charcoal, and burned caliche fragments. Numerous buried spring mats occur within the scarp arroyos and will be described in the next section on stratigraphy. Dune hummocks held by mesquite are scattered throughout the scarp area. Below the scarp, Stewart flat is entrenched by the canyon of Wann Wash which exceeds a depth of 40 feet along one stretch. In aerial photographs, other, more subtle, very low angle scarps can be seen crossing the flat (Pl. 10, fig. 1) approximately in parallel with the main scarp.

Stratigraphy

Most of the strata exposed by arroyos in the Eglington scarp are extensions of those described for the Tule Springs Site, but some facies are different and others are better represented (Table 4). The scarp itself is made up of reddish-brown, hard, calichefied mudstones capped by gray mudstone and dense caliche that form falls at the arroyo heads. This upper caliche and mudstone is an extension of unit D, while the underlying brown mudstones and caliches may correlate with unit A on the basis of (1) color which is darker and redder than unit B, and (2) location which is away from Tule Springs Wash where unit B sediments are apparently confined to a broad channel. This correlation with unit A is admittedly tenuous and nothing precludes correlation with even older units not exposed in the areas previously mentioned.

Below the scarp caliche and gray, mollusc-bearing, mudstones typical of unit D crop out on

Stewart flat along Wann Wash (Pl. 1) which exposes several units that are undoubtedly earlier than unit A.

The gravel-capped hills and ridges in the eastern part of the area resemble those on Gilcrease flat closer to the site except that (1) their relief is greater, (2) they represent larger channels, and (3) they contain a desert pavement and underlying soil comparable to those on the alluvial-fan facies of units D and E_1 in the Gilcrease Ranch area. They are, therefore, older than the E_2 gravel ridges and are probably equivalent to unit E_1 with the S4 soil development. Tufa alignments occur on either side of the main ridge and radiocarbon dating of one of these at locality 64 gave an age of about 10,000 years ago (Table 6). The unstable topographic position of this tufa ridge (Pl. 10, fig. 3) makes it unlikely that it was exhumed. It appears, therefore, that the one-mile-long tufa alignment and extension of inliers to the southeast mark the trace of a fault that postdates exhumation of the gravel ridge (Pl. 1). Two tufa outcrops at localities 63 and 68 have been dated at approximately 13,500 years ago and may date a period of faulting in the scarp area associated with the E_1 channel at the site.

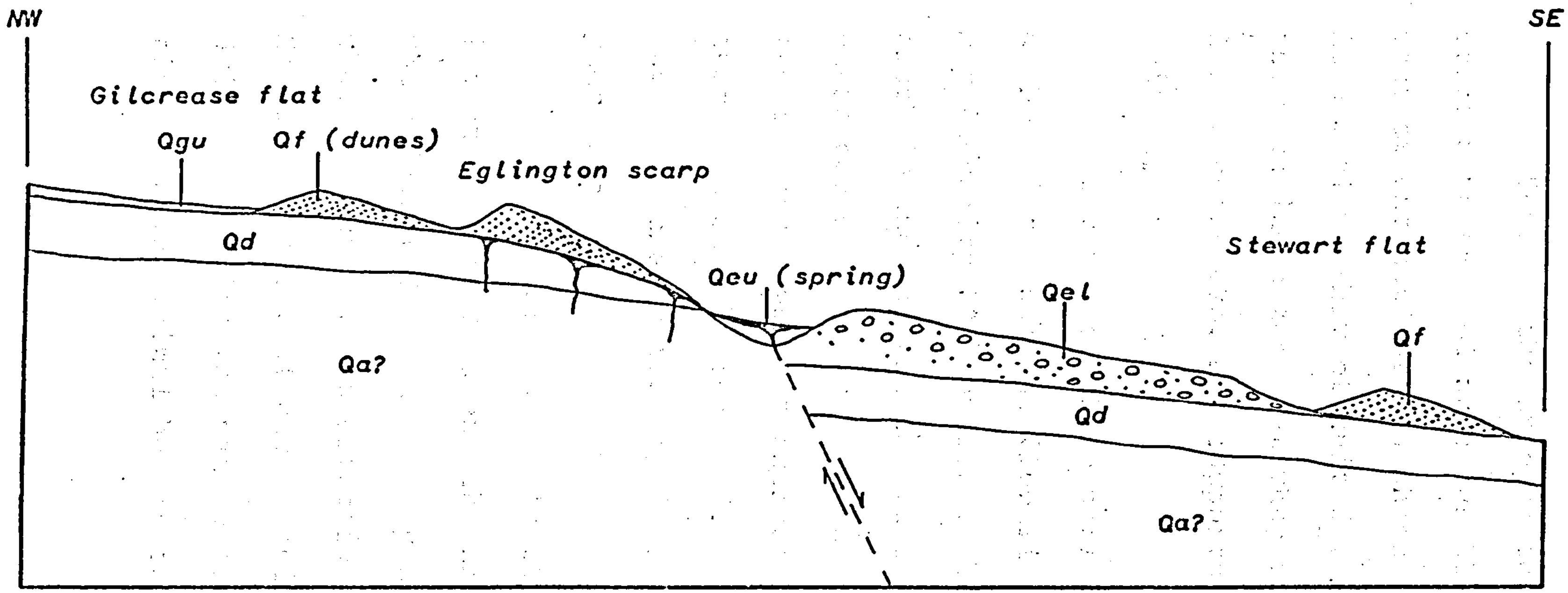


Figure 5. Generalized stratigraphic cross section across the Eglington scarp. No scale.

Some of the arroyos cutting the Eglington scarp have exposed numerous black, peaty, organic mats of extinct springs which are overlain by silt identical to that of unit E_2. Radiocarbon dating of the mats indicates that they formed between 8,000 and 11,000 years ago, and supports correlation with unit E_2.

Several of these spring mats overlie a layer of brecciated caliche (locality 61), and one spring mat (locality 59) appears to be related to a large crack in the caliche cap (unit D). From the abrupt emergence of Wann Wash in the scarp arroyo containing the largest number of extinct springs, it is clear that deep entrenchment of the wash is almost solely due to discharge from springs beginning about 11,000 years ago.

Dune hummocks up to 20 feet high occur as isolated remnants along the Eglington scarp and on the adjacent flats above and below the scarp indicating that the scarp is an effective aerodynamic trap. Mesquite trees that once stabilized the dunes are dying and making the sand again vulnerable to deflation. An aboriginal hearth exposed by this process at locality 65 dated early dune formation at approximately 4,000 years ago. It probably correlates with the unit F eolian silt in spring mound 4.

Dune sands also occur in some of the scarp arroyos as falling dunes, and are overlain in places by as much as 10 feet of silts forming a distinct terrace (Pl. 10, fig. 2). On the basis of stratigraphic position these silts are correlated with unit G_1 gravels at the site, and, according to radiocarbon dating (Table 6), are between 200 and 900 years old. Cottonwood trees growing in the floor of the present arroyo are as much as a foot in diameter, and assuming their age to be in excess of 50 years, it appears that the present dissection of the arroyos began between 50 and 200 years ago. Material washed from the scarp arroyos and over the scarp now covers most of Stewart flat as a thin sheet of slope wash alluvium equivalent to unit G_2.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

SPECIAL GEOLOGIC FEATURES

PLATE 11. SPECIAL FEATURES

Figure 1. Carbonized plant fragments (> 32,000 B. P., UCLA-502), and gastropod valves in spring-laid facies of unit B_2 at locality 2. Hole at upper left is feeder conduit from which loose, well-sorted sand was removed during excavations (see Pl. 3, fig. 3).

Figure 2. Irregular caliche nodules in upper part of unit D are probably of lacustrine origin and not pedogenic.

Figure 3. Typical assemblage of tufa "tubes" formed around plants that have been lost by decay. Locality 75. Tube just below center measures approximately 6 inches in length. (Photo by P. J. Mehringer, Jr.)

Figure 4. Surface of alluvial fan facies of unit D, Kyle Canyon fan showing typical desert varnish on noncarbonate pebbles, solution faceting of carbonate rocks, and possible wind faceting of cobble prior to partial solution. Removal of cobble revealed vesicular horizon and coarse prismatic structure in underlying silt. (Photo by P. J. Mehringer, Jr.)

Origin of Eglington Scarp

The localization of springs along Eglington scarp, the apparent association of some of these with brecciated caliche and fissures, the alignments of springlaid tufas, and spring emergence during specific intervals of time suggest that these features are the direct result of faulting along the scarp. This supports the fault origin of the scarps offered by Maxey and Jameson (1948, p. 69-71) as opposed to a lacustrine terrace origin (Carpenter, 1915, p. 31-32). Subsurface displacements of as much as 150 feet were noted by Maxey and Jameson in drillers' logs. The 80-foot difference in elevation between unit D above and below the scarp indicates such as the probable displacement in that area.

If tufa alignments do, in fact, mark fault traces, then some faults are transverse to the scarp. Surface indications of significant displacement, if present, are obscured by slope wash. The right wall of Tule Springs Wash in the vicinity of locality 71 shows several small reverse faults indicating compressional forces (Pl. 10, fig. 4). These may have resulted from drag forces (shear) flexing the downthrown beds. Dips of beds in the scarp are not easily determined because of poor exposures, but several Brunton readings consistently indicate a slight southward dip suggesting a complementary flexure, but these could be due to slight local tilting of blocks between transverse faults or to flexures caused by differential compaction.

Maxey and Jameson (1948, p. 70) suggested that the many scarps that show a semiconcentric pattern about the town of Las Vegas are due to faulting as a result of differential compaction of sediments under the valley floor. This would require the loss of substantial amounts of water from the artesian aquifers, and the evidence for large spring discharges in the past may account for this loss. Malmberg (1961, p. 17) has estimated that the average annual rate of recharge to the Las Vegas basin artesian system (25,000 acre-feet) was balanced by the natural discharge from springs and transpiration before the advent of artesian wells in 1906. During the time of intense spring activity around 11,000 years ago precipitation may have been somewhat higher than it is today, but more abundant phreatophytes plus much higher spring discharge may have caused a net loss, thus leading to compaction which would be aided if not triggered by earthquaking during the tectonic adjustments that were apparently taking place. At birth some of the springs may have erupted as fountains (Richter, 1958, p. 106-109). The sinuous and rough concentricity of the scarps in relation to the basin is duplicated in miniature today in areas of heavy drawdown where considerable land subsidence has occurred around well heads (Longwell in Smith and others, 1960, p. 35; and Thomas Humphrey, personal communication).

While compaction seems likely near Las Vegas, Eglington scarp is not apt to be due solely to this cause if tilting of Gilcrease flat to the southwest has occurred as suggested previously. Gilcrease fault is not concentrically arranged, is nearly straight, and transects alluvial-fan gravels as well as finer grained valley fill. It is probably of tectonic origin.

Pre-unit A Alluvium

To the south at Craig road, Stewart flat is broken by low, dissected hills, called here Craig Hills, made up of sandstones, mudstones, and caliche beds (Qx, Pl. 1). They show some definite dips, contain stronger paleosols, and are of redder hues (5 YR) than any of the sediments at the Tule Springs Site. Their weathering, lithology, and dissection suggest that they are different sediments than the Tule Springs beds and probably are older sediments forming an inlier. These have been mapped by Longwell and are a part of his Las Vegas formation (Longwell and others, in press, and personal communication).

TABLE 4. SEDIMENTARY FACIES AND SOILS OF THE EGLINGTON SCARP AREA

Unit	Description	Maximum Thickness
G_1	Alluvial sand facies. Pale brown (10 YR 7/3), soft, fine to medium, silty sand with 1-inch thick laminations of sandy, silty clay. Contains tree roots and coarse grass remains in places. Type exposure is at locality 41.	9 ft.
	Disconformity	
F	Undifferentiated eolian sand facies. Pale brown (10 YR 7/3), soft, well sorted, medium sand occurring as dune hummocks in the process of being deflated upon the death of stabilizing vegetation.	10 ft.
	Disconformity	
E_2	Alluvial silt facies. Very pale brown (10 YR 7/3), soft to slightly hard, very calcareous, fine, clayey silt carbonized plant remains and small mammal bones in places. Occurs locally as remnants in protected recesses and is best exposed at locality 62.	6 ft.
	Disconformity	
S4	Relict Cca horizon developed on alluvial gravel of unit E_1 capping the ridges below Eglington scarp. White, soft to slightly hard, silty caliche interstitial to and coating medium-pebble to small-cobble, limestone gravel and grading downward to only thin	

Unit	Description	Maximum Thickness
	(< 1/32-inch) coatings on bottoms of pebbles. Type exposure is locality 71.	1.5 ft.
E_1	Alluvial silt and gravel facies. Very pale brown (10 YR 7/3), soft to slightly hard, calcareous and gypsiferous, laminated, very fine, clayey silt with thin (3/8-inch), hard carbonate laminae, and interbedded with fine-pebble to small-cobble, subrounded, limestone gravel with approximately 10% caliche pebbles. Desert pavement on this unit shows strong solution features on limestone pebbles, desert varnish on siliceous rocks, and weather-fractured siliceous rocks.	30 ft.
	Disconformity	
D	Lacustrine mudstone facies. Light gray (2.5 Y 7/2), hard, very calcareous, mudstone with mollusc valves; rootlet molds; strong, medium-prismatic structure; and numerous indigenous caliche nodules that in places coalesce into a nearly solid layer. Weathered surface is commonly littered with caliche rubble displaying strong solution features.	> 10 ft.

GEOLOGY OF THE CORN CREEK SPRINGS AREA

Geomorphology

The Corn Creek Springs area lies approximately 10 miles northwest of Tule Springs Ranch (Pl. 1). Numerous mounds extending northwest-southeast on either side of the Desert Game Range Headquarters mark the locations of springs, most of which recently became extinct. Three of the mounds southeast of the headquarters have small pools of water on top and exemplify in miniature what the mound springs of the Tule Springs area were like when active. The conduit of one of these is clearly visible beneath a pool of clear water, and contains silt suspended by rising water (Pl. 12, figs. 3 and 4).

To the northwest of the headquarters a large area of active eolian sand and deflating dune hummocks 30 feet or more high is terminated on the southwest by a nearly straight-line border that extends to the spring-mound alignment (Pl. 13). To the northwest a caliche bed ends abruptly at this border (Pl. 12, fig. 1), and tufa fragments occur along the border on the southwest side which is everywhere lower than the

PLATE 12. GEOLOGIC FEATURES OF THE CORN CREEK SPRINGS AREA

Figure 1. Aerial view to southeast showing stabilized dune hummocks on raised fault block at Corn Creek Springs. Road on the right parallels the Corn Creek fault. White outcrops at upper left mark the Headquarters fault. Corn Creek flat is at the right. Termination of caliche cap at fault is visible at lower right.

Figure 2. View eastward toward Corn Creek Springs showing ancient spring mat (10,800 $\pm$ 300 B. P., UCLA-530) buried by unit E_2 silt at locality 83 and on the northwestward projection of the Corn Creek fault.

Figure 3. Grass covered spring mound at Corn Creek Springs, locality 88.

Figure 4. "Eye" of spring in Figure 2. Pool is supplied with water through the feeder conduit which contains well sorted sand held in suspension by ascending water. Conduit is 7 inches in diameter.

FIGURE 1

FIGURE 2

FIGURE 3

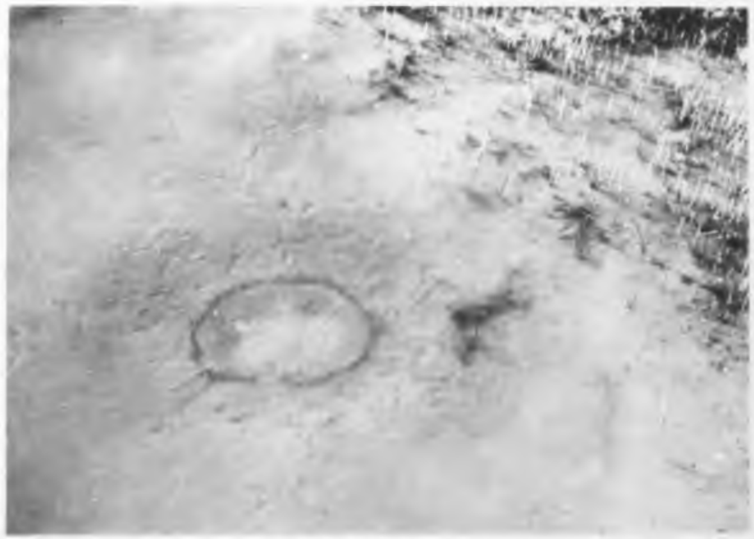
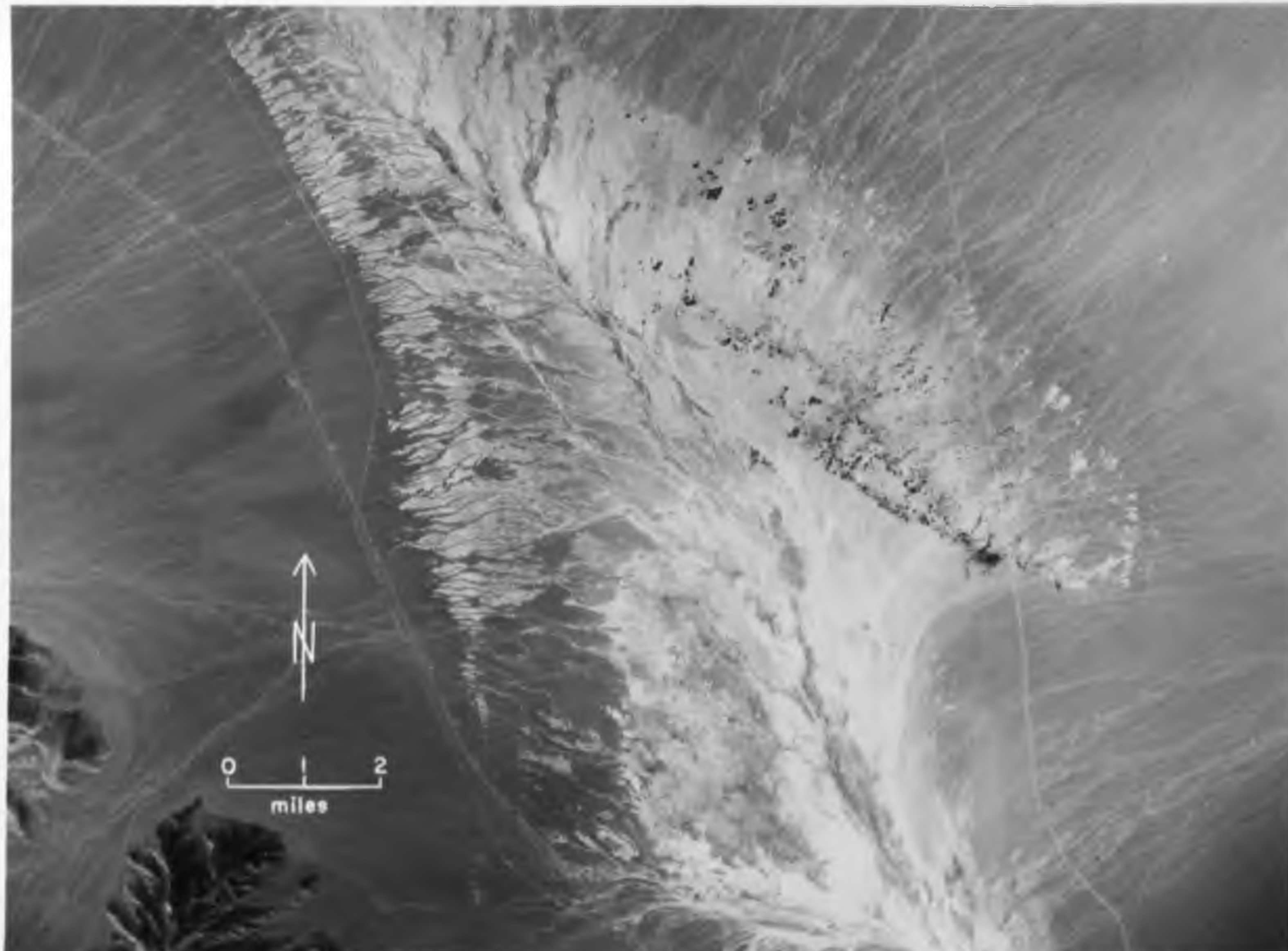


FIGURE 4

GEOLOGIC FEATURES OF THE CORN CREEK SPRINGS AREA



AERIAL PHOTOGRAPH OF THE CORN CREEK SPRINGS AREA northeast side. These linear relationships obviously indicate a fault that strikes N. 55° W., and will be referred to as the Corn Creek fault. The dune field is apparently the result of the settling of wind-borne sand in response to velocity loss across a former scarp now partially obscured by erosion and deposition.

To the northeast the dune field adjoins alluvial-fan gravels that have partially buried older sediment except for a number of inliers that are aligned along a southeasterly line that curves to the south and ends at the Corn Creek fault. Several of the inliers contain buried spring mats, and again a fault, the Headquarters fault, is in evidence, with the longest portion striking N. 40° W. The area between the two faults is a wedge-shaped horst with the maximum displacement at the southeast end (Pl. 13).

Stratigraphy

Except for dune facies, the sediments of the Corn Creek area duplicate those of the other areas described. Alluvial silts and lacustrine mudstones and caliches, probably correlative with units C and D, are exposed in the inliers along the Headquarters fault, near highway 95, and at locality 89 where mammoth and camel bones occur (Pl. 1). Characteristics of underlying sediments are not sufficiently diagnostic to suggest correlation with units B and A at the Tule Springs Site.

Buried spring mats along the faults are overlain by light brown silts and alluvial gravels similar to unit E_2. Dates indicate that the mats came into existence by 12,000 years ago (Table 6) and were overridden by unit E_2 alluvial fan sediments soon after 10,000 years ago, but the E_2 gravel unit with soil S5 on it occurs on top of some of the inliers as well as around them (Fig. 6) indicating that at least one period of uplift occurred during deposition of the fan gravels.

In the dune field there is abundant evidence of aboriginal occupation in the form of lithic debris and fire hearths marking ancient camps (Williams and Orlins, 1963). This material is being uncovered today by deflation of ancient dunes along the Corn Creek fault. A bulldozer trench at the Corn Creek dunes archaeological site (locality 82) revealed a buried dune sequence (Table 5) shown in Appendix I, p. 151.

The floor of the trench exposed a hard caliche that ended abruptly at the southwest end of the trench

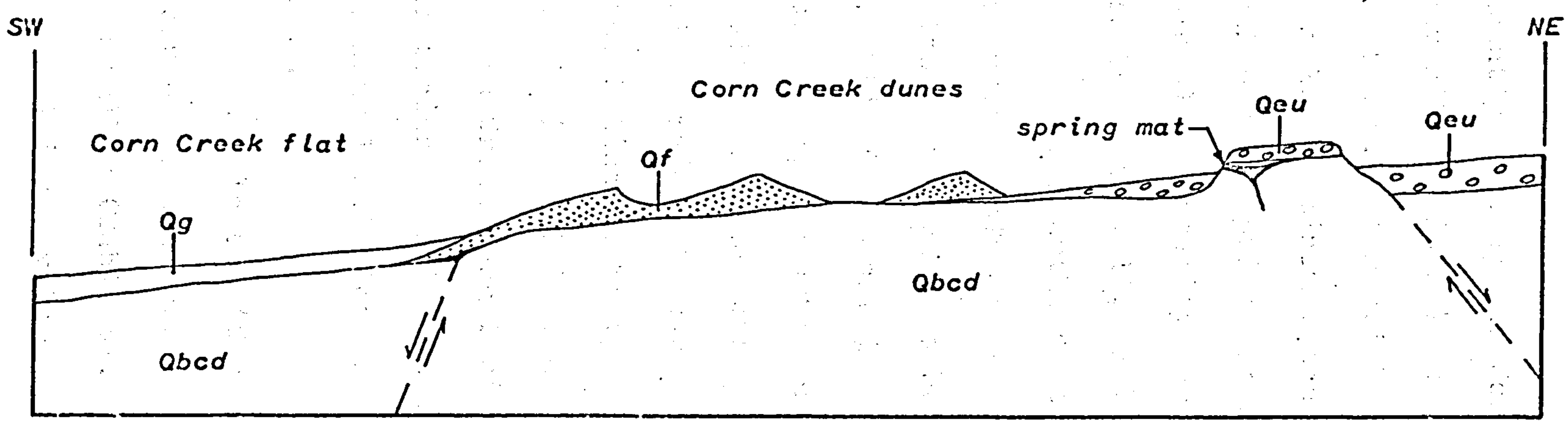


Figure 6. Generalized stratigraphic cross section in the Corn Creek Springs area. No scale.

apparently marking the Corn Creek fault. Overlying clayey silt (unit E?) at this point was damp indicating that, today, water still approaches the surface via the fault. A minimum age for the Corn Creek fault is revealed by a spring mat date of 10,800 years ago (Table 6) at locality 83 on the projection of the fault trace (Pl. 12, fig. 2).

Four hearths discovered in the Corn Creek dunes trench, plus three exposed on the surface, dated the lower dune unit as between 4,000 and 5,000 years old. This unit contains a weak disconformity that occurs above the buried hearths and divides the unit in half. The radiocarbon dating as well as the archaeological material suggest correlation with unit F dunes in the Eglington scarp area and in spring mound 4, but there is insufficient evidence to further subdivide the Corn Creek dune facies into F_1 and F_2. Within the dune facies of unit F thin laminae of silty clay may represent local slope washing of dunes during rain storms.

A paleosol (S6) at the top of the Corn Creek exposure has not been observed elsewhere in the Las Vegas valley (Table 5). Two possible reasons for this are: (1) its development in dunes where the possibility of preservation by dune burial are better, and

(2) its development on older weathered surfaces where its identity is lost in the stronger pedogenic features of the earlier soils. In the bulldozer trench cross section (Appendix I, p.151) soil S6 is truncated by an erosional, probably deflational, contact and is buried by laminated dune sand that probably is an eolian facies of unit G. This facies contains very weak soil structure (S7) at the top in association with living vegetation and is likely the product of modern weathering.

The alluvial facies of unit G is represented by fine silt that covers what is here called Corn Creek flat (Pl. 1). From its distribution it is obviously material washed from the alluvial fans and the dune field. On Corn Creek flat early 20th century bottles and cans occur in the upper 6 inches of unit G.

TABLE 5. SOME SEDIMENTS AND SOILS OF THE CORN CREEK DUNE FIELD

Unit	Description	Maximum Thickness
S7	Incipient soil in unit G dune facies at the Corn Creek dunes site. Pale brown (10 YR 6/3) very soft, silty-sand loam with weak, coarse, prismatic structure.	1 ft.
G	Undifferentiated eolian sand facies. Pale brown (10 YR 6/3), loose, well sorted, silty sand with current bedding and thin (< 1/2-inch) carbonaceous layers.	7 ft.
	Disconformity	
S6	B horizon in unit F, eolian sand facies. Pale brown (10 YR 6/3), soft, moderately calcareous, silty, sand-loam with weak, very coarse, prismatic structure breaking to moderate, fine platy. Upper contact is erosional. Exposed at Corn Creek dunes site, locality 84.	1 ft.
F	Undifferentiated eolian sand facies. Very pale brown (10 YR 7/3), soft, current-bedded, fine, well sorted, quartz sand with thin (< 1/2-inch) clayey silt laminations. Erosional upper contact and weak erosional break in middle of unit. Lower half contains aboriginal hearths at locality 84.	10 ft.

ANALYSIS OF RADIOCARBON DATING

Procedure

Dr. Libby's procedure was to have a courier visit the site once each week to help collect samples for analysis in his laboratory at the University of California at Los Angeles, and to bring back results of the previous week's radiocarbon dating. Most of the University of California (Los Angeles) dates have been reported by Ferguson and Libby (1964). In order to avoid possible confusion in sample provenience and interpretation from a potential proliferation of radiocarbon measurements, it was decided early that (1) no sample would be submitted for analysis until its position within the stratigraphic framework had been evaluated, (2) all samples would be examined in place by the expedition geologist before collecting, and (3) an on-the-spot evaluation would be made of each sample's suitability for dating, and its prospects of geochemical contamination noted. The use of carbonates for radiocarbon dating was purposefully delayed until a chronology based upon material less subject to initial $C14$ deficiency could be established. As a result of these precautions, only three samples (Table 6, nos. 20, 22, and 32) out of 77 yielded anomalous ages that could not be explained by subsequent events but had to be rationalized via logic.

Sample Materials and Pretreatment

Materials dated by the radiocarbon method included carbonized woods (27 samples), charcoals (14), organic mats (11), tufa organics (7), tufa carbonates (6), mollusc shell carbonates (5), woods (2), secondary bone carbonates (2), burned bone (1), humates (1), and water bicarbonate (3).

The carbonized woods presented a special problem in that they had previously been interpreted as charcoal and hence evidence of aboriginal fires (Harrington and Simpson, 1961, Chap. 3), but preliminary testing by the author and independently by Professor Fergusson at Dr. Libby's laboratory indicated that most of the "charcoal" from locality 2 was 80 to 90 percent soluble in dilute sodium hydroxide solution, and left some inorganic residue to account for much of the remaining weight. From both Fergusson's and my own experience in pretreating hundreds of charcoal samples we have found this material to be relatively insoluble even after prolonged treatment in boiling 5 percent sodium hydroxide solution; and indeed it should be if it has been thoroughly pyrolyzed because elemental carbon is indestructible in even strong basic solutions.

While we are tempted to conclude that the carbonized wood from both units B_2 and E_1 is not charcoal, we are not certain of this because some lumps of material were found to be relatively insoluble in strong base. As mentioned previously, these woods were identified by the Forest Products Laboratory of the U. S. Department of Agriculture as including ash, cottonwood, and juniper. Upon microscopic examination of insoluble residues of samples from both units at four localities, Dr. Elso S. Barghoorn at Harvard University concluded that none of the specimens could be distinguished in this way from carmelized (partially burned) wood and, hence, all are partially pyrolized (personal communication). On the other hand, S. F. Cook, using chemical procedures similar to, but stronger than those used in the pretreatment of radiocarbon samples, concluded that all of the Tule Springs samples tested were decayed wood and not charcoal (Cook, 1964). Until this problem is resolved, the material associated with buried springs and not in definite hearths will be referred to as carbonized wood.

Evidence for or against pyrolysis will have little effect on the conclusions regarding the earliest time of human occupation of the area because burned wood, especially in the absence of artifacts, is not prima facie evidence of man's presence. Furthermore, the identification as wood or charcoal does not affect the material's suitability for radiocarbon dating, and the dates in excess of the method show that contamination by later organic matter (humic and fulvic acids) is completely negligible.

The 14 charcoal samples listed in Table 6 presented no problems as all were in distinct fire hearths and yielded no soluble organic matter during standard laboratory pretreatment to remove carbonates and humic acids. Provided contemporary wood was used by the aborigines, the dates should be accurate. Organic mats of ancient springs, on the other hand, could not be treated in the standard way. These consist of fine-grained decayed plant remains and intrusive roots in a silt matrix. Humic acid extraction would concentrate soluble lignins and humic acids, possibly of several ages, and leave a residue of cellulosic material including mostly young roots. Upon standard treatment with hydrochloric acid to remove carbonates, it was learned that what appeared to be intrusive vegetable matter tended to float or stay in suspension while finer-grained black material tended to settle. By repeated decantations, the heavier black residue was concentrated and subsequently dried and converted to purified carbon dioxide for counting. An organic mat which dated 580 $\pm$ 100 B. P. (Table 6, no. 67) at the top of an active mound spring at Corn Creek suggests that dates from organic mats are reasonably accurate. If the organic mat dates are in error, they are probably too young because of younger plant matter remaining after pretreatment.

Of several materials tried from the lacustrine unit D, the only one found in sufficient quantity to yield finite ages was mollusc shell (Table 6, A.). While it is known that the carbonate of modern snail shell can be as much as 32 percent deficient in C^{14} or 3,000 years too old (Keith and Anderson, 1963; Rubin and Taylor, 1963) dating shell from unit D confirmed the interpretation that the lacustrine unit correlates with the last pluvial maximum or to late Wisconsin time. Subsequent cross checking of a mollusc shell carbonate date against carbonized wood from locality 5 indicates an initial C^{14} deficiency of 12 percent or about 1,000 years (Table 6, A, nos. 17, 19, and 24). This can be applied reasonably to the other shell dates.

In addition to carbonized wood and shell locality 5 also produced lithoid tufa composed of porous calcium carbonate in the form of botryoidal masses and jackets surrounding bones and carbonized wood. Theoretically, the maximum C^{14} deficiency to be expected in carbonates deposited in surface water systems is 50 percent, but Broecker and Walton (1959, p. 32) found 25 percent (2,400 years too old) to be empirically a more typical limit of maximum deficiency. The tufa carbonate at locality 5 could have been deposited by spring waters containing juvenile carbon dioxide or ancient water either of which would make the initial C^{14} deficiency even greater, and the carbonate date of 16,900 $\pm$ 300 B. P. compared to the carbonized wood date of 13,100 $\pm$ 200 B. P. (Table 6, nos. 19 and 21) suggests that such may be the explanation for the 3,800-year (38 percent deficient) discrepancy. This age difference might be applicable as a correction to another tufa from the E_1 channel at locality 2 (Table 6, no. 23) as discussed later.

Because of isotopic fractionation during precipitation there is a tendency for calcium carbonate to be enriched somewhat in the heavier isotopes (C^{13} and C^{14}) with respect to contemporary plants. This decreases the age, and while a correction based upon C^{13}/C^{12} ratios would reduce the -3,800-year discrepancy, the error due to fractionation would be insignificant compared to the uncertainties regarding the C^{14} content of the bicarbonate solution from which the tufa was deposited.

Upon pyrolysis it was found that all of the tufas turned black and left a black carbon residue when dissolved in acid solution. Microscopic fibrous material observed in the residue of tufa digested in dilute acid was identified by Dr. Hoshaw, University of Arizona, as possibly being remains of filamentous algae. Filamentous blue-green algae is believed to be the source of lithoid tufa at Mono Lake, California (Scholl and Taft, 1964) and Lake Lahontan, Nevada (Broecker and Orr, 1958, p. 1011). It is reasonable to assume, therefore, that the organic matter in tufas of the Tule Springs area is the remains of algae and C^{14} analyses of this material should provide an additional means of evaluating the carbonate dates.

If the tufa organic matter is algal, its carbon-isotopic composition could have been similar to that of contemporary terrestrial plants if atmospheric carbon dioxide was used in photosynthesis. However, if instead carbon dioxide in the spring water as bicarbonate ions was metabolized, the isotopic constitution of the algae could be similar (except for fractionation effects) to that of the tufa carbonate. The photosynthetic consumption of carbon dioxide from the water would promote precipitation of calcium carbonate (Craig, 1954, p. 129) to form tufa.

Samples of tufa organic matter were prepared by dissolving the outer surfaces of tufa fragments in dilute nitric acid and scrubbing with a wire brush until all lichens were completely removed. The dry samples were charred in an inert atmosphere before final leaching.

The organic fraction of the tufa at locality 5 dated 17,600 ± 1,500 B. P. as compared to 16,900 ± 300 B. P. for the carbonate and 13,100 ± 200 B. P. for carbonized wood (Table 6, nos. 19, 20, and 21), thus indicating that both the organic and carbonate fractions of the tufa reflect the C^{14} content of the water assuming that the carbonized wood is closer to the atmospheric C^{14} content.

Numerous tufa fragments are scattered about on the eroded surface around spring mound 4 (locality 45), Gilcrease Ranch. These cannot be directly correlated to the buried organic mat underlying the mound, but as they are definitely not related to the unit F silts, they are thought to represent algal tufa deposited in shallow parts of the spring pool during or before growth of the organic mat. That the tufa was deposited in shallow water is indicated by the triangular cross sections of sedge-leaf molds observed in several tufa fragments. As mentioned previously, the mat of spring 4 dated 9,920 $\pm$ 150 B. P. (Table 6, no. 63). The tufa carbonate which should be C^{14} deficient (older) relative to the organic fraction dated 10,260 $\pm$ 100 B. P. while the tufa organic fraction dated 10,810 $\pm$ 460 B. P. but within statistical agreement (Table 6, nos. 64 and 65). The dates support the assumptions regarding the relative ages of organic mat development and tufa growth and suggest that the tufa was deposited in spring water with a C^{14}

content of at least 90 percent that of the atmosphere, or essentially contemporary water. Therefore, the -3,800-year correction mentioned in connection with locality 5 does not appear to be applicable here. Two organic fraction dates at the top of the mound indicate that growth of the mound ended about 800 years ago (Table 6, nos. 59 and 60).

All of the tufa pairs (organic and carbonate fractions) analyzed from the Eglington scarp area showed that the organic fractions were consistently younger than the carbonates (Table 6, nos. 50, 51, 53-56). Because this is the reverse sign for differences due to fractionation, it is likely that the tufa organic matter acquired some of its carbon dioxide from the atmosphere and, therefore, should provide a better indication of the maximum possible age for the tufa if less than the carbonate age. However, if the discrepancy is too great (>2,000 years), the results may be suspect (e.g. Olsen and Broecker, 1961, p. 157) as discussed below.

A major discrepancy in dates from tufa fractions is in analysis of surface material from locality 2 (Table 6, nos. 22 and 23). Carbonate dated 15,920 ± 220 B. P. whereas an organic fraction was older than 28,000 years. The samples were believed to be associated with a spring feeding the E_1 channel. Applying the 3,800-year correction from data gathered at locality 5 to the carbonate date at locality 2 yields a date of 12,120 B. P. and supports the interpretation, but the very old date on the organic fraction of tufa collected separately is quite anomalous. The most reasonable conclusion is that there are two generations of tufa at the locality, each representing a separate period of spring activity. This interpretation is supported by the fact that one sample of carbonized wood from sediments beneath the E_1 channel at locality 2 provided a date of 26,000 $\pm$ 1,000, whereas most of the carbonized wood from these lower sediments are older than 40,000 years (Table 6, nos. 32, 34, 35, and 38). In other words, it appears that springs were active at locality 2 over 40,000 years ago and quasi-continuously from 26,000 years ago to nearly 12,000 years ago.

Only one sample of soil humates was analyzed and demonstrates that the modern soil on top of spring mound 4 is enriched in nuclear-age C^{14} (Table 6, no. 57). These humates were extracted with 2 percent sodium hydroxide solution without first decalcifying the sample, hence they are adsorbed humates and not absorbed humates fixed by calcium. The latter are represented in part by sample 60 (Table 6) which was pyrolized and decalcified in acid to produce a carbon residue derived from fixed humates and particulate organic matter. Because of contamination by the modern humates, the true age is somewhat older than the indicated 1,085 years.

One sample of burned bone was analyzed. This consisted of three charred camel wrist bones and a dark gray carbonate matrix (pyrolized?) from unit D. This material was decalcified in acid and the carbon residue was dated as older than 23,000 years (Table 6, no. 28). As there was no evidence of human activity, the bones are believed to have been burned by a natural fire.

The carbonate fractions of two bone samples were analyzed and produced unexpected but very useful results. One sample was from unit B_2 ($>$40,000 B. P.), and the other was from the E_1 channel (12,400 B. P.), yet the calcium carbonate fractions representing approximately 35 percent of both samples yielded ages of 5,160 B. P. and 4,510 B. P. respectively (Table 6, nos. 1 and 2). As these dates are close together and are during the time of E_2 degradation leading eventually to the present dry-wash topography, they apparently represent a time of carbonate percipitation in the buried bone as the water table dropped. As long as the bones remained within the zone of saturation carbonate was not precipitated and may have actually been removed, but lowering of the water table, leaving the bones above the saturated zone, permitted the deposition of secondary carbonate. By using the sample-contamination graph of Olson (1963, fig. 3) it is observed that both samples will have secondary carbonate of the same age if 20 percent of the total carbonate is original, i. e., 7 percent of the original weight of each bone remained as unreplaced carbonate. As modern bone is about 10 percent calcium carbonate, the assumptions seem reasonable and the secondary carbonate appears to have been deposited 3,500 years ago, thus dating the last time the water table stood between 2,292 and 2,295 feet, the elevations of the two samples. If there is no original carbonate remaining in the two samples, the relative elevations of the samples are in the right order to suggest that the 650-year age difference is due to the time it took the water table to permanently drop the 3 feet in elevation separating them.

The dissolved bicarbonate and carbon dioxide from two samples of water were analyzed in order to aid in the interpretation of tufa dates and to shed light on the age and source of ground water. After bulldozing the trench through Gilcrease spring 4 mound, water appeared in the floor of the cut where it uncovered an ancient feeder conduit. This water dated 12,100 ± 200 B. P. (Table 6, no. 78) which could be the true age or it could be due to either a mixture of modern water with water older than 12,200 years or to "dead" carbon dissolved from limestone during passage of the water from the surface to the underground system. Admixed juvenile water is unlikely (Craig, in press).

As mentioned earlier, the 10,000 year old tufa at spring 4 probably was deposited in water that was less than 10 percent deficient in C^{14} with respect to the atmosphere at the time of deposition. As the water was apparently unmixed, then, there is little reason to expect mixing today, although this possibility cannot be precluded. It is also unlikely that there would be much more than a 10 percent C^{14} deficiency due to "dead" carbon today as compared to when the tufas were deposited because a slightly cooler and more humid climate, as may have prevailed then (Mehringer, 1964, fig. 8), would allow for more dissolved carbonates and more soil carbon dioxide than would be expected today (Vogel and Ehhalt, 1963, p. 386). A 10 percent deficiency would contribute about 835 years to the age. It is suggested, therefore, that the water issuing from Gilcrease spring 4 today is essentially "fossil" water that fell as rain between 11,000 and 12,000 years ago.

Water from 105 feet below the surface (near-surface zone of Maxey and Jameson, 1948, p. 82) at a well 1 mile north of spring 4 dated 16,540 ± 1,200 B. P. (Table 6, no. 79). These data suggest that mixing between aquifers has been incomplete and that the ground water is stratified according to age. If the carbon-14 dates are accurate, then the ground water of the Las Vegas Valley has not been significantly replenished in the last 11,000 years and the cessation of spring discharge in the Tule Springs area may be partly due to a loss of the head that had built up in Kyle Canyon fan during late Wisconsin time. The stratigraphic evidence at Gilcrease spring 4 indicates: (1) a high discharge about 13,000 to 15,000 years ago, (2) reduction of discharge 10,000 years ago as indicated by encroachment of the organic mat upon the "eye"; (3) near desiccation between deposition of units E_2 and F ; and (4) possibly pulsational discharge over a period (the past 7,000 years) of general decline of flow during deposition of eolian sand (unit F) on the dampened ground. The data from locality 2 at the Tule Springs Site and from Gilcrease spring 4 suggest that while emergence of springs may have been fault controlled, the discharge was at least partly controlled by climate.

Tufa carbon-14 dates are useful in providing maximum possible ages. If contemporary wood or charcoal is associated with tufa, then radiocarbon analysis can shed light on the isotopic constitution and history of water at the time of tufa deposition at springs. Such data from Gilcrease spring 4 suggest that its water is at least 10,000 years old.

Three dates require additional explanation. Two of these were determined before the present expedition and one was analyzed after this. Sample 25 consisted of carbonized wood gathered by collecting widely dispersed fragments in the fill of the unit E_1 rill at locality 2; the same deposit that contained two possible bone tools. It was realized before submitting the sample for analysis that it could be either indigenous to the deposit or foreign matter redeposited from the underlying organic layer through which the spring water had to pass (Haynes and others, in press). The age in excess of 40,000 years supports the latter interpretation.

The first radiocarbon date from the Tule Springs Site (Libby, 1955, C-914) suggested an age for human occupation in excess of 23,800 years. In relating the provenience of this sample (Harrington and Simpson, 1961, p. 59, 73, and 74) to the geology of the site, it is apparent that the sample was a mixture of carbonized wood from locality 10 ("Ash Bed 2, Area 1") now known to be more than 40,000 years old (Table 6, no. 25) and 12 grams from unit E_1 at locality 4 (the Fenley Hunter site) now known to be 12,400 years old (Table 6, no. 13). It is known in addition that the carbonized wood at Ash Bed 2, Area 1 (locality 10) is part of the organic mat of an ancient spring and not a hearth.

The other sample was found to be more than 28,000 years old (Olson and Broecker, 1961, L-533B) and was reported in association with a scraper at "Site D, Area 2" (Harrington and Simpson, 1961, p. 75-76). From the special report presented in Appendix II, it appears that the radiocarbon sample was carbonized wood from unit B_2 which is older than 40,000 years, while the scraper was probably from unit F_1.

Summary of Results

From Table 6, and in consideration of the foregoing discussion, it can be seen that a consistent geochronological sequence has been established for the late Quaternary in the Las Vegas Valley. All sediments below unit C are more than 40,000 years old. Unit D is between 16,000 and 35,000 years old. On the basis of 11 dates, which are internally consistent where this can be judged, deposition of unit E_1 began shortly before 13,000 years ago and ended shortly after 11,500 years ago. Six dates relating to unit E_2 show deposition between 11,000 and 7,000 years ago.

Two detailed stratigraphic sections that serve as excellent tests of internal consistency of radiocarbon samples are shown in Appendix I (p. 141 and 143). These also demonstrate the need for knowledge of the detailed stratigraphic relationships in interpreting radiocarbon dates. Without this knowledge, rectification of the apparent age inversions would have necessitated challenging the accuracy of at least two valid dates.

No materials suitable for radiocarbon dating were found in unit F at the Tule Springs Site. Unit F is obviously younger than E_2 and is, therefore, less than about 7,000 years old. Its correlative at spring mound 4, the eolian silt, was deposited before 800 B. P. Taking into account an erosional hiatus between units E and F, it appears that unit F is between 6,000 and 1,000 years old. Dune facies in both the Eglington scarp and Corn Creek Springs areas date 4,000 to 5,000 B. P., and support previous correlation with unit F_1, based on archaeological materials.

In the Eglington scarp area, unit G_1 has 6 internally consistent dates from 200 to 900 B. P. that are in accord with the age indicated by aboriginal pottery (Shutler, personal communication), and by the fact that living cottonwood trees in excess of 50 years old are growing on the floor of modern arroyos entrenched in unit G.

The internal consistency of the radiocarbon measurements, the stratigraphic consistency over the area of the Las Vegas Valley, and the predictability on geochemical grounds of the discordances between paired samples, all attest to the usefulness and validity of the radiocarbon method in geological and geochemical studies. Most errors in accuracy are due to misinterpretation of either provenience or the geochemical history of the sample rather than to either the radiocarbon analysis or anomalous unpredictable contamination (Hunt, 1956).

TABLE 6. RADIOCARBON DATES FROM THE LAS VEGAS VALLEY, NEVADA

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
			A. Tule Springs Site Area		
			Unit G		
No radiocarbon dates.					
			Unit F_2		
No radiocarbon dates.					
			Unit F_1		
1	Secondary bone carbonate	4	4,510 ± 190	A508	Post E_2 drop of water table.
2	Secondary bone carbonate	2	5,160 ± 200	A509	Post E_2 drop of water table.
			Unit E_2		
3	Carbonized wood	4	7,480 ± 120	UCLA519	Middle of upper fill of unit E_2.
4	Carbonized wood	1	8,540 ± 340	A463a	Top of lower part of E_2.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
5	Fine Charcoal	4	9,000 ± 1,000	UCLA510	Top of lower part of E_2.
6	Carbonized wood	5	9,670 ± 200	I-991	Channel fill within fill.
7	Carbonized wood	1	10,000 ± 200	UCLA505	Channel fill within fill.
8	Carbonized wood	1	11,200 ± 200	UCLA508	Shown stratigraphically to be a mixture from upper E_1 and lower E_2 (see Appendix I, p.).
			Unit E_1		
9	Carbonized wood	1	11,500 ± 500	UCLA636	Top of E_1 fill.
10	Carbonized wood	1	11,900 ± 250	UCLA637	E_1 channel fill.
11	Carbonized wood	1	12,270 ± 200	UCLA507	E_1 channel fill.
12	Carbonized wood	3	12,300 ± 350	UCLA514	E_1 channel fill.
13	Carbonized wood	4	12,400 ± 350	UCLA512	E_1 channel fill.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
14	Carbonized wood	27	12,400 ± 200	UCLA604	E_1 channel fill.
15	Carbonized wood	3	12,450 ± 230	UCLA509	E_1 channel fill.
16	Carbonized wood	6	12,650 ± 200	UCLA518	E_1 channel fill.
17	Carbonized wood	5	12,920 ± 220	UCLA521	E_1 channel fill.
18	Carbonized wood	37	13,000 ± 200	UCLA552	Spring feeder.
19	Carbonized wood	5	13,100 ± 200	UCLA522	E_1 channel fill.
20	Tufa organic	5	17,600 ± 1,500	UCLA554	Too old due to initial C14 deficiency, organic fractionation, or both.
21	Tufa carbonate	5	16,900 ± 300	UCLA546	Same sample as above, but contemporaneous wood (UCLA522) dated 13,100 ± 200 indicating a -3,800-year correction is applicable due to initial C14 deficiency.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
22	Tufa organic	2	>28,000	A466	Too old due to initial C14 deficiency, organic fractionation, or both.
23	Tufa carbonate	2	15,920 ± 220	UCLA503	Applying -3,800-year correction due to initial disequilibrium as with UCLA-546 gives 12,100 for reactivation of the spring.
24	Mollusc shell	5	13,900 ± 300	UCLA543	Equivalent to UCLA521 and therefore ca. 1,000 years too old due to "dead" carbon.
25	Carbonized wood	2	>40,000	I-887	Redeposited from spring feeder.
			Unit D		
26	Mollusc shell	13	22,600 ± 550	UCLA536	Middle of lacustrine unit and probably 1,000 years too old (see UCLA543).
27	Mollusc shell	13	31,300 ± 2,500	A462	Base of lacustrine unit and probably 1,000 years too old (see UCLA543).
28	Burned bone	36	>23,000	UCLA420	Littoral facies of lacustrine unit.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
29	Mollusc shell	7	>31,000	UCLA524	Base of lacustrine unit spring facies.
30	Carbonized wood	13	>35,000	UCLA513	Lower contact of lacustrine unit and possibly redeposited.
			Unit C		
No radiocarbon dates.					
			Unit B_3		
31	Carbonized wood	10	>40,000	UCLA528	Spring feeder in B_3.
			Unit B_2		
32	Carbonized wood	2	26,000 $\pm$ 1,000	UCLA501	Either a mixture or spring was reactivated at this time. Does not date B_2.
33	Mollusc shell	8	>30,000	UCLA547	Middle of unit B_2 at break.
34	Carbonized wood	2	>32,000	UCLA502	Middle of unit B_2 at break.
35	Carbonized wood	2	>32,000	UCLA511	Lower part of unit B_2.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
36	Carbonized wood	7	>35,000	UCLA523	Position within B_2 uncertain.
37	Carbonized wood	9	>37,000	UCLA506	Middle of unit B_2 at break.
38	Carbonized wood	2	>40,000	UCLA517	From within the "bone pile."
			B. Eglington Scarp Area		
			Unit G		
39	Wood	42	200 ± 80	UCLA640	Stump at top of fill.
40	Carbonized wood	42	330 ± 80	UCLA639	Burned layer near top of fill.
41	Charcoal	39	360 ± 120	UCLA515	Burned layer near top of fill.
42	Charcoal	41	570 ± 80	UCLA635	Aboriginal hearth near base of fill.
43	Charcoal	40	725 ± 80	UCLA516	Aboriginal hearth near base of fill.
44	Charcoal	66	880 ± 80	UCLA638	Aboriginal hearths on spring mound.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
			Unit F_2		
No radiocarbon dates.					
			Unit F_1		
45	Charcoal	65	4,190 ± 170	A465	Hearth in Eglington scarp dune area.
			Unit E_2		
46	Carbonized wood	62	8,000 ± 400	UCLA548	Spring mat at base of upper part of unit E_2.
47	Organic mat	61	9,350 ± 200	UCLA551	Minimum date for emergence of spring.
48	Organic mat	59	9,520 ± 300	UCLA549	Minimum date for emergence of spring.
49	Organic mat	67	9,870 ± 400	A464	Minimum date for emergence of spring.
50	Tufa organics	64	10,160 ± 160	A471	Maximum date for emergence of spring
51	Tufa carbonate	64	11,800 ± 250	UCLA642	Same sample as above but too old because of initial C14 deficiency

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
52	Organic mat	60	11,100 ± 200	UCLA550	Minimum date for emergence of spring.
			Unit E_1		
53	Tufa organics	63	13,400 ± 230	A470	Maximum date for emergence of spring.
54	Tufa carbonate	63	15,000 ± 300	UCLA641	Same sample as above but too old because of initial C14 deficiency.
55	Tufa organics	68	13,680 ± 160	A459b	Maximum date for emergence of spring.
56	Tufa carbonate	68	14,100 ± 100	A459a	Same sample as above but too old because of initial C14 deficiency.
			C. Gilcrease Ranch Area		
			Unit G		
57	Humates	45	102.6% mod.		Soil on top of spring 4 mound.
58	Charcoal	49	315 ± 65	UCLA540	Aboriginal hearth.
59	Tufa organics	45	810 ± 70	A468	Top of spring 4 mound.
60	Caliche organics	45	1,085 ± 90	A467	Soil in top 1 foot of spring 4 mound.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
			Unit F_2		
61	Organic mat	49	1,450 ± 100	UCLA527	Stratigraphically isolated.
			Unit F_1		
No radiocarbon dates.					
			Unit E_2		
62	Organic mat	46	9,200 ± 250	UCLA529	Top of Gilcrease spring 4a.
63	Organic mat	45	9,920 ± 150	UCLA537	Base of Gilcrease spring 4 mound.
64	Tufa organic	45	10,810 ± 460	A442	Dates early activity of Gilcrease spring 4.
65	Tufa carbonate	45	10,260 ± 100	A441	Same sample as above and in statistical agreement.
			Unit E_1		
No radiocarbon dates.					
			Unit D		
66	Carbonized wood	46	25,300 ± 2,500	UCLA539	Base of Gilcrease spring 4a.

TABLE 6 (Continued)

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
			D. Corn Creek Springs Area		
			Unit G		
67	Organic mat	84	580 ± 100	UCLA538	Top of spring 4 mound.
			Unit F_2		
No radiocarbon dates.					
			Unit F_1		
68	Charcoal	82	4,030 ± 100	UCLA535	Hearth 10 in Corn Creek dunes.
69	Charcoal	82	4,380 ± 100	UCLA534	Hearth 9 in Corn Creek dunes.
70	Charcoal	82	4,440 ± 100	UCLA525	Hearth in Corn Creek dunes.
71	Charcoal	82	4,610 ± 100	UCLA532	Hearth 7 in Corn Creek dunes.
72	Charcoal	82	4,580 ± 100	UCLA531	Hearth in Corn Creek dunes.
73	Charcoal	82	4,900 ± 100	UCLA533	Hearth 8 in Corn Creek dunes.

TABLE 6 (Continued

No.	Material	Loc.	Date (BP)	Lab. No.	Remarks
74	Charcoal	82	5,200 ± 100	UCLA526	Hearth in Corn Creek dunes.
			Unit E_2		
75	Organic mat	86	10,200 ± 350	UCLA542	Base of Corn Creek spring 8.
76	Organic mat	83	10,800 ± 300	UCLA530	Base of Corn Creek spring 10.
			Unit E_1		
77	Organic mat	85	11,700 ± 250	UCLA541	Base of spring mat.
			E. Water Samples		
78	Bicarbonate ion	45	12,100 ± 200	A-557	Natural discharge.
79	Bicarbonate ion	-	16,540 ± 1,200	A-555	Fitzpatrick's 105-foot well.

LATE QUATERNARY HISTORY OF THE TULE SPRINGS AREA

What follows is intended to be a portrayal of geologic events in the Las Vegas Valley during the end of the Pleistocene.

The ancestral Las Vegas River occupied a channel nearly 700 feet wide that was incised in caliche and alluvium of an earlier, more extensive valley fill (unit A). From the limited exposures of unit B_1 it appears that all of the stream discharge from the valley was restricted to a channel flowing along the northeast side of the valley at the toe of Gass Peak bajada. Bed load changed from coarse pebble gravel in the lower part of the channel to flood plain sand and silt in a broad, probably braided, channel. Beyond the mapped area it is not known what course the river followed en route to the Colorado River.

Buried gravels in the area of Tule Springs Ranch and Gilcrease Ranch may be alluvial-fan facies representing this time as are B_1 gravels exposed in the north end of trench K indicating that the toe of Gass Peak bajada extended to about 24 + 00 N.

B_1 aggradation was followed by development of a strong weathering profile (S2) during a relatively stable period that was in turn followed by a period of erosion that removed much of soil S2. The appearance of numerous springs along the general course of the B_1 channel led to the relatively small stream represented by unit B_2. Fluvial conditions of deposition changed to lacustrine as shallow ponds fed by springs formed along the stream course. While no obvious fissures were found associated with the B_2 springs, vertical bleached zones were observed to extend from spring feeder conduits through underlying fine alluvium (Appendix I, p. 146).

Pollen investigations indicated that during the time represented by unit B_2 Las Vegas Valley contained Great Basin Desert vegetation dominated by sagebrush, while yellow pines and sagebrush occupied the bajadas (Mehringer, 1964, p. 12). Springs along the river were frequented by Pleistocene horses, camels, sloths, bison, and mammoths and their predators (Mawby, 1963).

Deposition of the "green-pond" unit was followed by renewed deposition of fine alluvium (B_3) without intervention of either pronounced erosion or soil development. After B_3 was laid down, a strong complex soil S3 was developed that reflects pedalferic conditions of development followed by pedocalic conditions suggesting a trend towards less humid environment of soil formation. Much of this weathering profile was removed by subsequent strong erosion and degradation, but some of the springs remained active in the area of the site.

Upon return to conditions of aggradation, the Las Vegas River deposited 20 feet or more of silt, sand, and gravel (unit C) in a channel at least 200 feet wide that roughly followed the previous channel. As before, upper facies of silt formed a broad, probably braided flood plain. The Gass Peak bajada did not extend to the river while gravels of Kyle Canyon fan extended northeastward to within a half mile of Tule Springs Ranch with fine alluvial-fan outwash graded to the river farther to the northeast. Similar conditions of deposition apparently prevailed in the Corn Creek Springs area.

Deposition of unit C at the site was interrupted by erosion without an intervening period of weathering. The erosional period was apparently brief and was followed by deposition of as much as

15 feet of lacustrine mudstones and carbonates in a shallow lake, Pluvial Lake Las Vegas, that extended at least from Corn Creek Springs in the northwest to Craig Hills and probably beyond in the southeast. The occurrence of Quaternary lacustrine sediments southeast of Las Vegas (Bowyer and others, 1958) suggests that Pluvial Lake Las Vegas occupied most of the Las Vegas Valley, and therefore constituted a major pluvial lake although the portion between Corn Creek Springs and Tule Springs was a rather narrow neck. Longwell (1961, p. 48) has mentioned the occurrence of similar lacustrine sediments in the Indian Springs Valley. It is not known if there was continuity between there and the Corn Creek Springs area (Hubbs and Miller, 1948, p. 101).

Why the Las Vegas River was blocked at this time is not known. It has been suggested that the late Pleistocene deposits of the Las Vegas Valley may correlate with the Chemehuevi formation along the Colorado River (Longwell, 1946, p. 827, and personal communication), thus indicating Lake Las Vegas to have been an arm of a much larger lake, the cause of which remains unknown.

Lake Las Vegas lasted from at least 35,000 to about 15,000 years ago, during which time vegetation in the valley consisted mainly of pine and sagebrush on bajadas and fans, and of cattail in shallow water around the margin of the lake. Both the pollen studies and mollusc analyses reveal fluctuations in lake level, and the few remains of mammoth and camel suggest the occasional presence of these animals at the lakeside. Minor faulting or slumping occurred and may be associated with two spring-organic-matter dates of around 26,000 years ago.

Longwell (personal communication) has observed a north-slope protected cirque at 9,300 feet in the Spring Mountains that may have been occupied by an alpine glacier during this time.

Before 14,000 years ago the lake apparently drained as suddenly as it appeared, and drainage of the valley thereafter was confined to a narrow, spring-fed channel along the present course of Tule Springs Wash. The formation of Eglington scarp at about this time is apparently related to tectonic adjustments farther to the southeast that led to the draining of the lake into the Colorado River. At least partial development of the scarp by 14,000 years ago would explain why above the scarp E_1 sediments are confined to a narrow channel while below the scarp E_1 silt and gravel occupied a much wider channel and lie as a thick wedge against the scarp.

During this general period moderately strong weathering led to the development of a pedocalic soil (S4) on the surface (No. 2) of Kyle Canyon fan, the newly exposed lacustrine sediments across Gilcrease flat, and on the E_1 wedge below the scarp. Between 13,000 and 14,000 years ago Kyle Canyon fan was dissected; numerous springs along Tule Springs Wash were active; and springlaid tufa formed along transverse fissures in the scarp area. From 13,000 to 11,500 years ago, the E_1 channel aggraded and discharge was confined to a small stream flowing through a wet meadow along the valley floor. E_1 gravels on the alluvial ridge below the scarp had been dissected and abandoned by this time leaving the gravel-capped ridges seen there today. Numerous springs supplying the stream were frequented by mammoths, camels, horses, bison, and smaller animals. Man may have appeared on the scene at this time. In the Corn Creek Springs area the Headquarters fault, and possibly the Corn Creek fault were active and produced springs along their traces. Pine, probably pinyon, and juniper apparently covered the lower slopes of Kyle Canyon fan and Gass Peak bajada, and water birch grew at some of the springs.

Soon after 11,500 years ago, a new channel was incised along the course of the E_1 channel and much of the earlier sediment was removed. Around 11,000 years ago, numerous springs emerged along Eglington scarp and along the Gilcrease fault. The beginning of E_2 aggradation was apparently coincident. This aggradation, with minor reversals, led to the overfilling of the channel and to flooding of Gilcrease flat by E_2 silts and gravels. This, plus the distributary pattern of the gravels towards the scarp, indicates disruption of local base level apparently by tilting Gilcrease flat to the southwest. On the Gass Peak bajada the number 2 fan surface is not visible and is apparently buried by E_2 fan gravels. In the ranch area, silts and gravels were washed from Kyle Canyon fan, through the area of springs, and on to Gilcrease flat. Between 8,000 and 9,000 years ago, many springs in both the Gilcrease Ranch area and along the scarp were buried by E_2 silts, but the depth of Wann Wash indicates that spring discharge at its head must have continued. At Corn Creek Springs alluvial-fan silts and gravels were washed over the uplifted fault block.

By 11,000 years ago, man was definitely in the area and mammoths, horses, camels, and sloths had become extinct. The area abounded in springs, although those along Tule Springs Wash became inactive before E_2 deposition. Pinyon pine, juniper, and sagebrush dominated the lower slopes, while Gilcrease flat was probably covered mostly by sagebrush and Atiriplex (Mehringer, 1964, p. 20.) Ash, willow, and sedge grew around some of the springs.

By 6,000 years ago major degradation had started, and in the ensuing 2,000 years, water tables dropped, spring activity lessened, arroyos were cut, and eolian action was intense. The present topographic expression of the area was developed during this period as was the modern vegetation, i. e., lower elevation Mohave Desert forms became dominant throughout the valley (Mehringer, 1964, p. 20). Conditions favored the development of Gray Desert soil (S5). Wandering aboriginal bands made frequent use of the spring-fed desert oases. Between 4,000 and 1,000 years ago, the Las Vegas River became a dry wash, although minor alluvial fluctuations occurred during this time, and eolian activity continued by reworking older dunes and by adding silt to spring mounds. Near the end of the period, large cauldron springs may have been reactivated along the earlier formed Stillwell alignment.

Close to 1,000 years ago alluvial gravels were washed from the toe of Gass Peak bajada onto the floor of Tule Springs Wash, yet there has been insufficient discharge through the wash to redistribute the tongues of gravel (G_1). The alluviation (G_1) of the arroyos in Eglington scarp that occurred from 1,000 to 200 years ago was probably correlative with the spilling of the gravels onto the wash floor. These events appear to correlate with the abandonment of Tule Springs Wash by discharge from Corn Creek Wash which now distributes its load across Gilcrease flat instead of through Tule Springs Wash. The only apparent explanation for this anomalous behavior is additional tilting of Gilcrease flat to the southwest. Had this not happened, it seems likely that the G_1 silts on Gilcrease flat and in the scarp arroyos would have been carried through Tule Springs Wash along with the gravel tongues from

Gass Peak bajada. The springs along the Stillwell alignment may have had renewed activity as a result of this adjustment.

During the past 200 years sediments in the scarp arroyos have been dissected and redistributed over Stewart flat and washed down the present washes such as Wann Wash. Similar sediments have been washed from the Corn Creek dune area and deposited over Corn Creek flat. Prehistoric man's inhabitation of the area was still largely dependent upon springs which in historic times attracted the white man, first as watering places for transients, then as nourishment for farms, ranches, and the railroads. The springs have been progressively diminishing in output, but today most of them are prematurely dry because of the heavy drawdown around modern wells.

The repeated history of tectonic adjustment in the Las Vegas Valley as late as 1,000 years ago suggest that further adjustments within the Las Vegas shear zone can be expected in the future.

CORRELATION OUTSIDE OF THE TULE SPRINGS AREA

In order to place the late Quaternary events of the Tule Springs area in proper perspective with respect to a few adjacent parts of the Southwest, an attempt is made here to correlate the deposits of Tule Springs with those of Lake Lahontan (Morrison, 1961a, 1961b, 1964), Searles Lake (Smith, 1962; Stuiver, 1964), La Sal Mountains (Richmond, 1962), and the Colorado Plateau (Hack, 1942). The correlations are supported by radiocarbon dating and are shown in Fig. 7 which is a self-explanatory interpretation, and will be discussed only briefly. Correlation of the Tule Springs sediments with those of other areas is based upon radiocarbon dating in relation to soils on the assumption that soils correspond in at least a general way to interstades (Richmond, 1950). Correlations between the other columns in Fig. 7 are justified, in part, by analogy with the mathematical premise that if A = B and B = C, then A = C.

In the Carson Desert area of Nevada Morrison (1964) has found an essentially complete sedimentary record of lacustrine and interfingering subaerial sediments and soils representing most of Wisconsin and Recent time. The deposits are correlated with the Sierra Nevadan glacial sequence on the basis of soils corresponding to interstades and lake maxima to stadial maxima (Morrison, 1961b), and with Antevs "ages" on the basis of correlation with archaeological sites having some radiocarbon control (Morrison, 1964, fig. 39). Morrison has recognized three late Wisconsin (Sehoo) lake stages with high stands at 4,370, 4,190, and 3,990 feet, and radiocarbon dating (Olson and Broecker, 1961, p. 155) suggests that these levels were reached between 34,000 and 13,000 years ago, 13,000 and 12,000 years ago, and near, or soon after, 8,850 years ago. Broecker and Orr (1958) have suggested three Lake Lahontan late-Wisconsin stands on the basis of corrected radiocarbon analyses (Broecker and Walton, 1958) of lacustrine tufas and marls: one at 4,190 feet between 24,000 and 17,000 years ago; one at 4,400 feet around 11,700 years ago; and possibly another stand at 4,400 feet around 9,700 years ago. The two sets of data, while in general agreement as to three late Wisconsin Lake stages, are discordant regarding the lake levels. As yet, there is no satisfactory solution to this problem.

In the La Sal Mountains of southeastern Utah, Richmond (1962) has investigated an unusually complete Pleistocene sedimentary record of fluvial, colluvial, and glacial deposits and soil facies. His Wisconsin and Recent sequence is here correlated with that at Tule Springs on the basis of soils. This is in agreement with the correlation to Lakes Lahontan and Bonneville based upon Richmond's (1961) correlation with his Rocky Mountain glacial sequence.

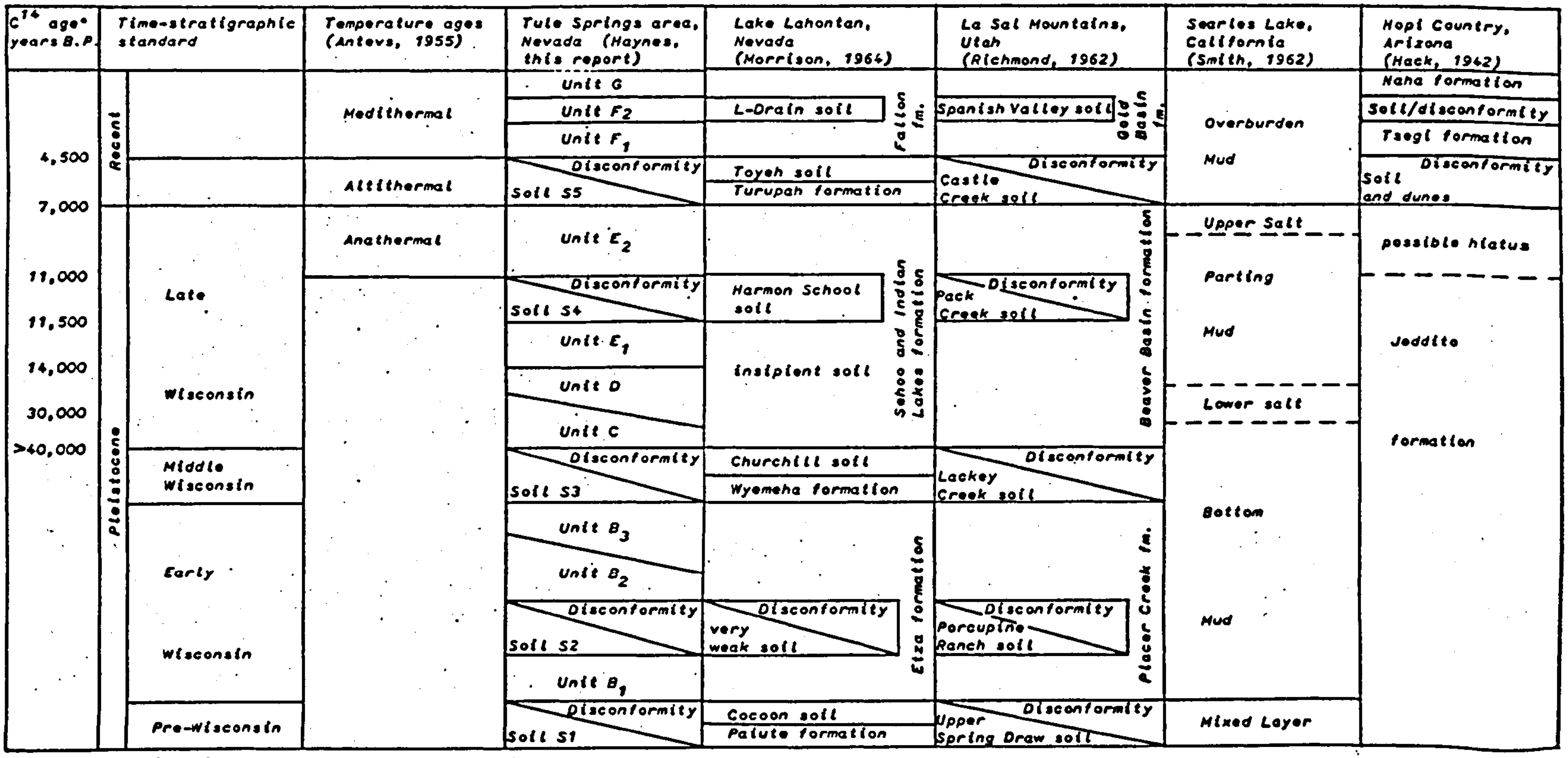
Wisconsin and Recent aged fluctuations of Searles Lake, California, have been determined through detailed analyses of subsurface stratigraphy, mineralogy, and radiocarbon analysis (Smith, 1962; Smith and Haines, 1964; and Stuiver, 1964). Correlation with Tule Springs is based upon radiocarbon dating.

Throughout much of the Southwest a consistent sequence of alluviation and degradation in minor stream valleys has been recorded by geologists working closely with archaeologists (Antevs, 1964; Bryan, 1941; Leopold and Miller, 1954). The sequence recorded by Hack (1942) for northeastern Arizona is commonly referred to as a "standard" for comparison. The Tule

Springs sediments are correlated with the "Alluvial Chronology" on the basis of radiocarbon dating, vertebrate fossils, and archaeology. The Jeddito formation contains an extinct fauna, and in the Hopi Country, is without evidence of human occupation. It is possible that the type Jeddito is pre-man and that units with artifacts in association with extinct mammals at other sites are absent by erosion in Hopi Country. This possible hiatus is shown in Fig. 7, and units D and E_1 at Tule Springs probably correspond to type Jeddito whereas unit E_2 may have no representative in Hopi Country.

The Tsegi formation and equivalents were deposited between 5,000 and 1,000 years ago (Malde and Schick, 1964, p. 70-71), and correlate with unit F in the Tule Springs area, while unit G correlates well with the Naha formation approximately between 1,000 and 200 years old. In some areas the equivalent of the Tsegi is underlain by a slightly older unit between 6,000 and 5,000 years old that is considered to be early Recent by some geologists (Scott, 1963, p. 40, 46). With the possible exception of spring mounds, deposits of this age are absent at Tule Springs, but are represented by the Turupah formation in the

Carson Sink area where Morrison (1961d) would place the Pleistocene-Recent boundary at the top of the Toyeh soil instead of at the base of his Turupah formation. This boundary problem needs review, but until such time the Pleistocene-Recent boundary is placed in Fig. 7 at the beginning of the Altithermal.



* Note nonlinearity of scale.

Figure 7. Correlation chart of late Quaternary sediments of the Tule Springs area.

CONCLUSIONS

A number of conclusions can be drawn from these investigations; some have local significance, while others have more broad application. They are as follows:

1. The Las Vegas Valley has been tectonically active at various times throughout the past 40,000 years and local tilting has occurred, possibly as late as 1,000 years ago.

2. The ancestral Las Vegas River was a major drainage that went through several fluvial cycles in late Quaternary times.

3. Aggradation corresponds in a general way to glacial stades and wetter climates, but correspondence of ponding (unit B_2) and Pluvial Lake Las Vegas to glacial stades (pluvials) may have been in part coincidental in that damming may have been tectonic.

4. Aggradation of alluvial fans coincides with stream alluviation, high lake stands (pluvials), and glacial stades.

5. Soil development is heightened during interstadial times. Erosional/depositional stability may be as much of a contributing factor as favorable climate.

6. The Tule Springs stratigraphy reveals repeated cycles of the sequence (1) alluviation, (2) stability and soil formation, and (3) erosion. A general decrease in amplitude and increase in frequency toward the present indicates a general trend toward lessening stream discharge and, therefore, lessening precipitation.

7. Pool or cauldron springs are natural animal traps and are commonly surrounded by dense coarse vegetation that becomes buried in spring sediments. Therefore, the simple association of animal bones and carbonized wood in springlaid sediments is not prima facie evidence of human activity.

8. The emergence of springs and deposition of algal-tufa alignments have been fault controlled and the time of faulting can be evaluated by stratigraphically controlled radiocarbon dating.

9. The organic fraction of algal tufa probably provides a more accurate C^{14} date than

the carbonate fraction. This should be tested by dating these fractions of modern tufas.

10. Early man may have been in the area as early as 13,000 years ago, but was probably not there until closer to 12,000. He was definitely in the area between 11,000 and 10,000 years ago, and his activities centered around springs.

11. The Pleistocene megafauna consisting of mammoths, horses, camels, bison, and sloths may have disappeared from the area by 11,500 years ago, and was definitely gone by 11,000 years ago.

12. The radiocarbon dating of ancient water from active springs indicates that natural discharge has exceeded recharge in post pluvial time.

13. The present topographic expression of the area was attained by 4,000 years ago when the water table had dropped to near early historic levels.

14. The use of artificial exposures across stream valleys is an invaluable aid to studying processes of alluviation, soil development, and erosion.

15. Radiocarbon dating, if used with discretion and understanding of the limitations, is the most important tool for better understanding geomorphic processes in relation to Pleistocene events that has appeared in the last century. It is a quantitative and unbiased way of timing and correlating geologic events of the last 40,000 years.

APPENDIX I. STRATIGRAPHIC CROSS SECTIONS AT PERTINENT LOCALITIES

TABLE 7. EXPLANATION OF SYMBOLS USED IN APPENDIX I

Qg	*Unit G, undifferentiated*
Qf	*Unit F, undifferentiated*
Qeu_2	*Unit E_2, upper part*
Qeu_1	*Unit E_2, lower part*
Qeu	*Unit E_2, undifferentiated*
Qe	*Unit E, undifferentiated*
Qel	*Unit E_1,*
Qd	*Unit D*
Qc	*Unit C*
Qbm	*Unit B_2*
Qbl	*Unit B_1*
Qb	*Unit B, undifferentiated*
Qa	*Unit A*
	Clay, silt, or mudstone
	Sand
	Gravel
■	*Carbon-14 sample. Date given in years B.P. followed by laboratory number.*
□	*Position of carbon-14 sample projected to the plane of section.*
○	*Pollen sample*
▲	*Artifact location*
◆	*Carbonized wood*
	Organic mat
	Snail shells
	Soil
	Contact, dashed where indistinct or inferred
....	*Minor stratigraphic break*

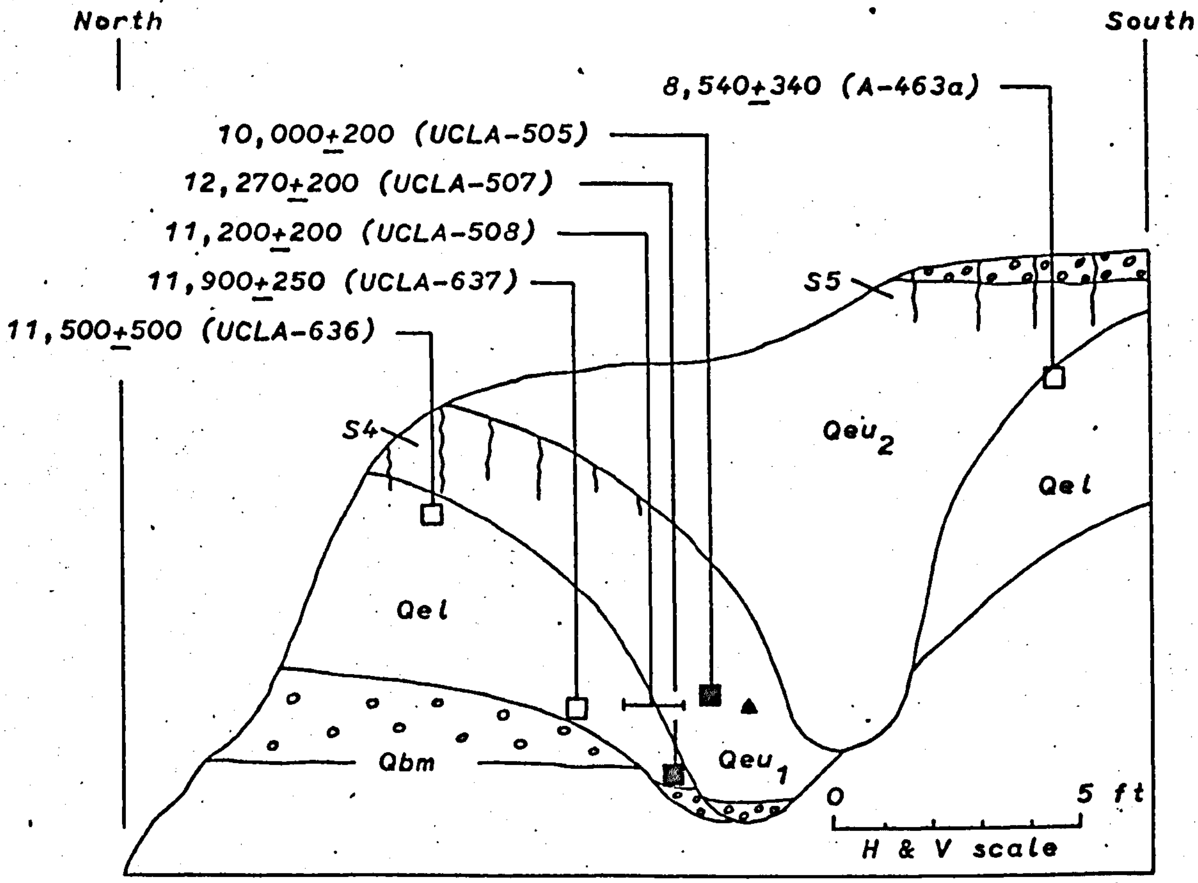


Figure 8. Stratigraphic profile at 5 + 70 N., 3 + 50 W., locality 1, showing position of carbon-14 dates and flint flake in relation to channel sediments and soils. UCLA-508 includes carbon from two units (E_1 and E_2) which explains its anomalous place in the sequence of dates.

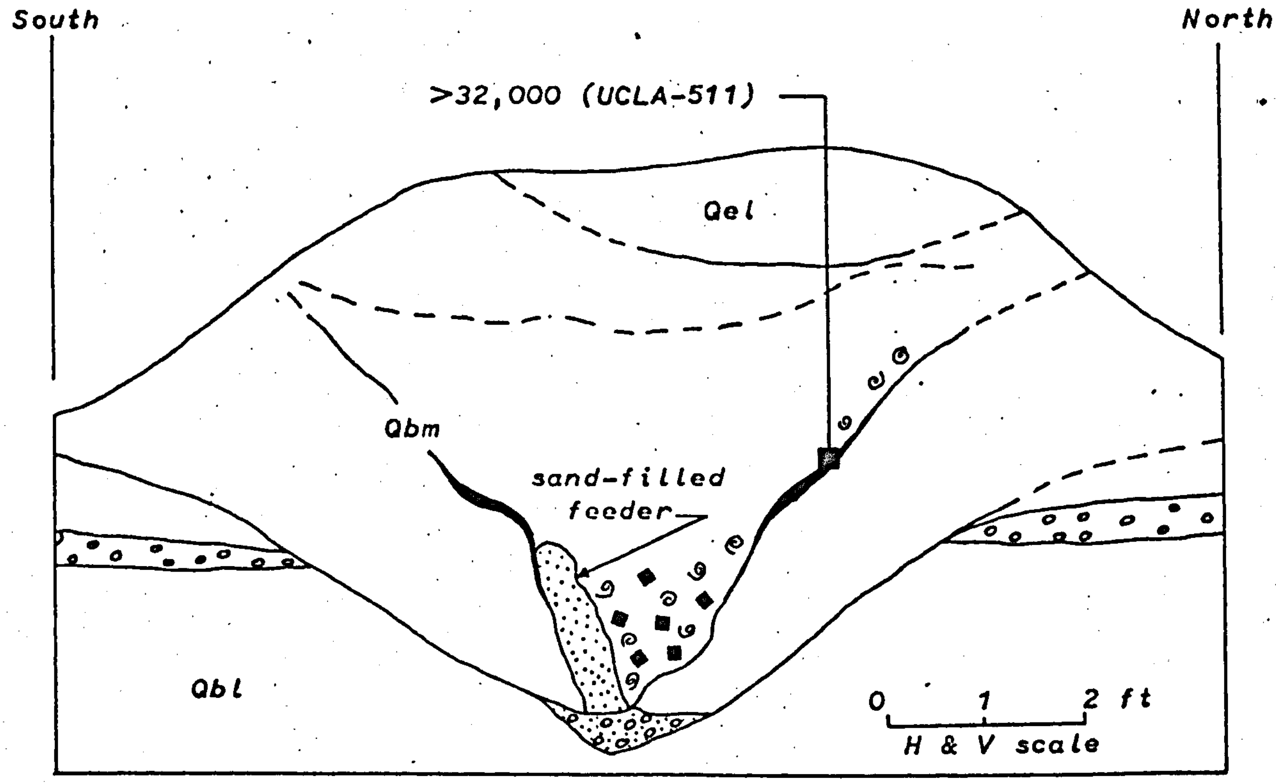


Figure 9. Stratigraphic sketch of the west wall of the excavations of an ancient spring at locality 2 showing position of feeder conduit, snail shells, disseminated carbonized wood, and concentration of carbonized wood which was dated by carbon-14.

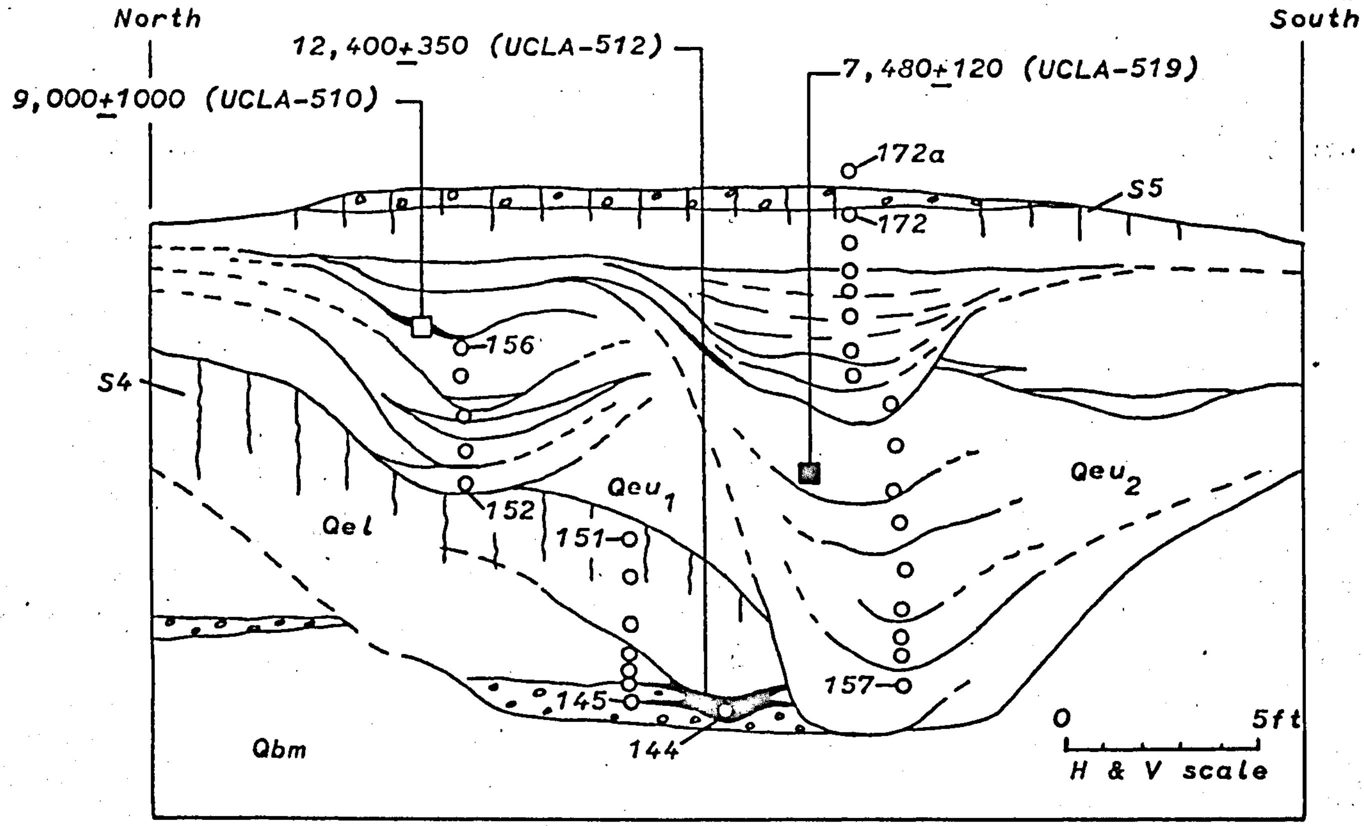


Figure 10. Stratigraphic profile of the east wall of the Fenley Hunter trench, locality 4, showing the position of carbon-14 samples and pollen samples of Mehringer's pollen profile IV in relation to the complex cut-and-fill sequence of beds within the unit E channels.

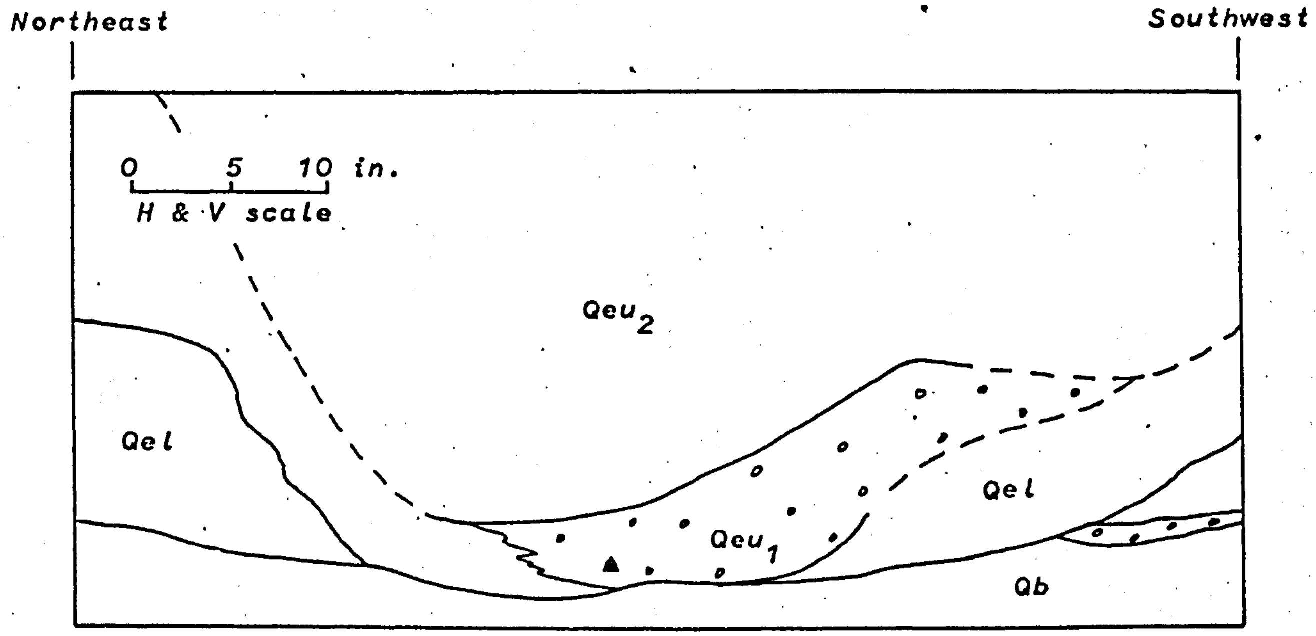


Figure 11. Stratigraphic profile of trench at locality 4A showing the position of a scraper in relation to sediments at the bottom of the unit E_2 channel.

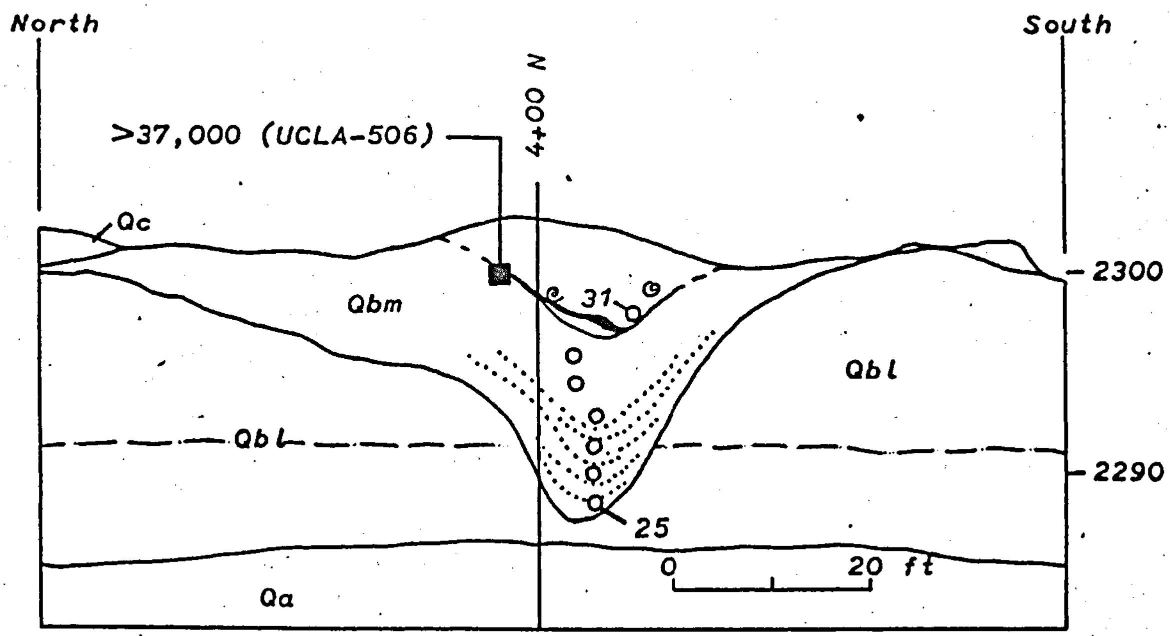


Figure 12. Stratigraphic profile of the east wall at locality 9 in trench D at 4 + 00 N. showing the position of a carbon-14 sample and pollen samples of Mehringer's pollen profile I.

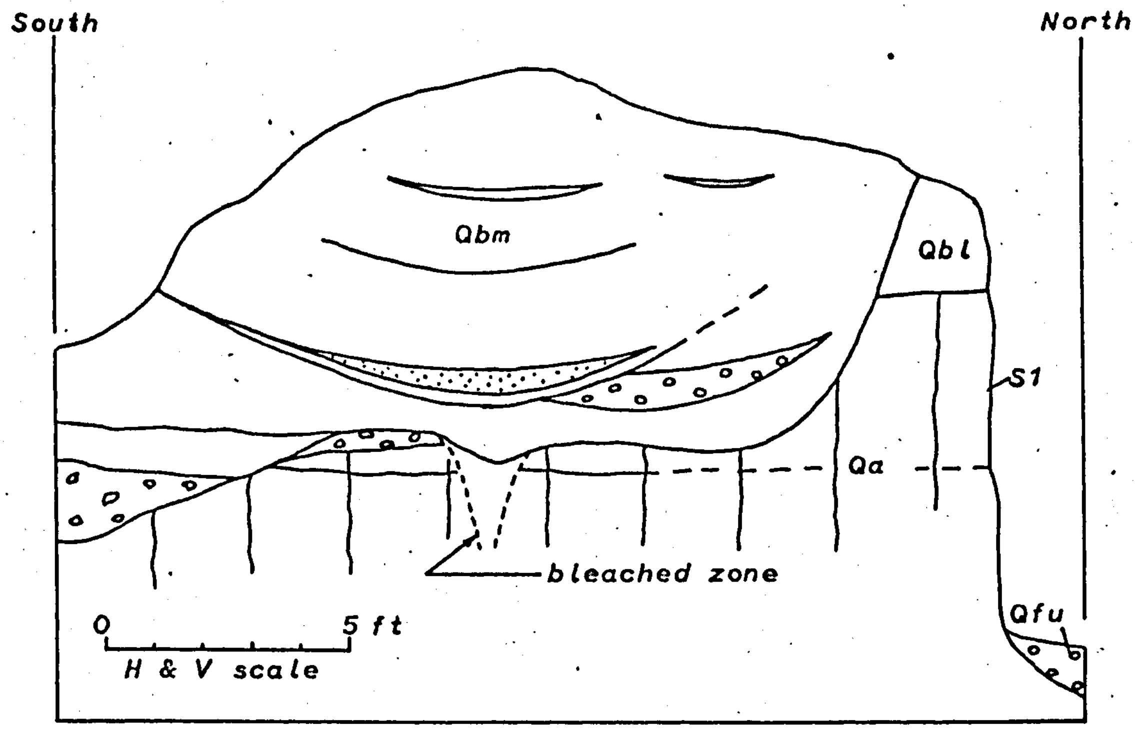


Figure 13. Stratigraphic sketch of the west wall of trench H at locality 11 showing relation of spring-laid sediments (unit B_2) to bleach zone probably representing location of ancient conduit.

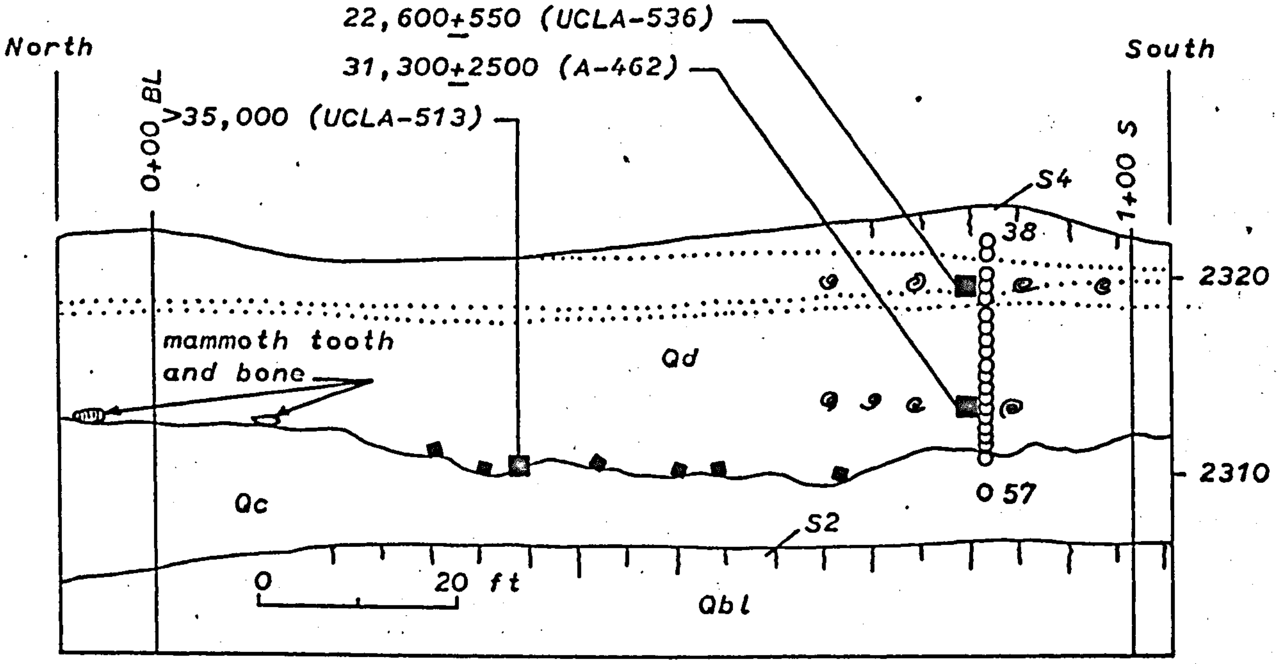


Figure 14. Stratigraphic profile of the east wall of trench K at locality 13 between base line (0 + 00 BL) and 1 + 00 S. showing the position of carbon-14 samples, snail shells, and pollen samples of Mehringer's pollen profile II.

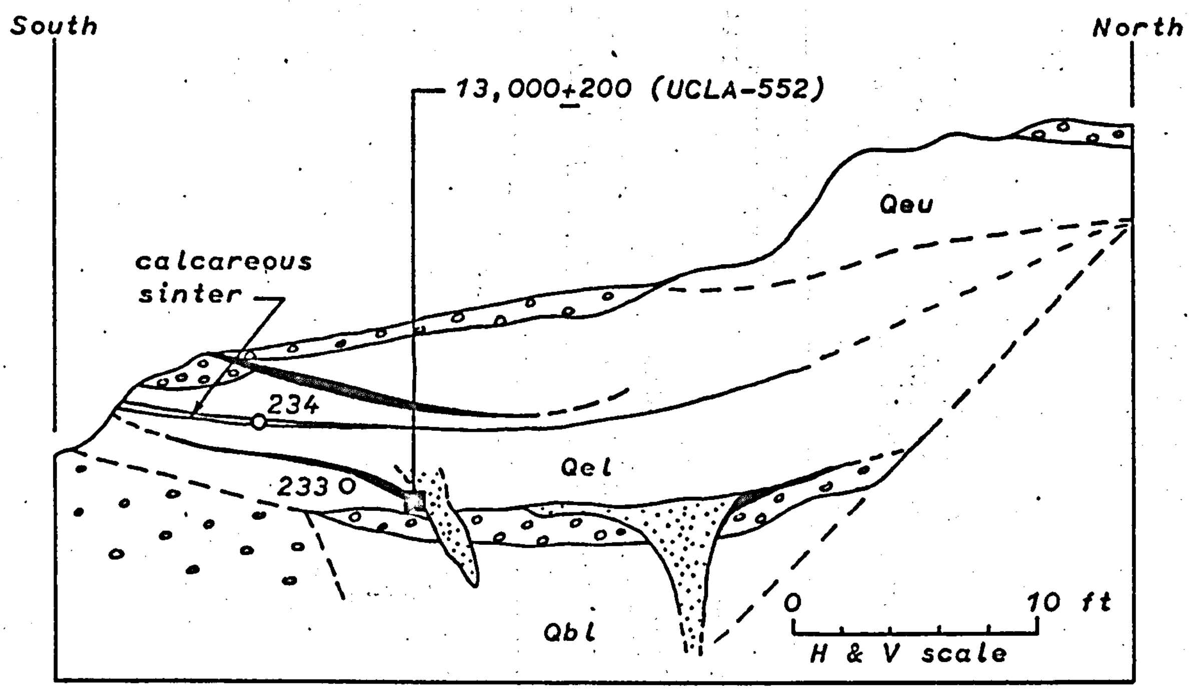


Figure 15. Stratigraphic sketch of trench through ancient spring at locality 37 showing carbon-14 sample and pollen samples (Mehringer's miscellaneous samples) in relation to spring-laid deposits of unit E.

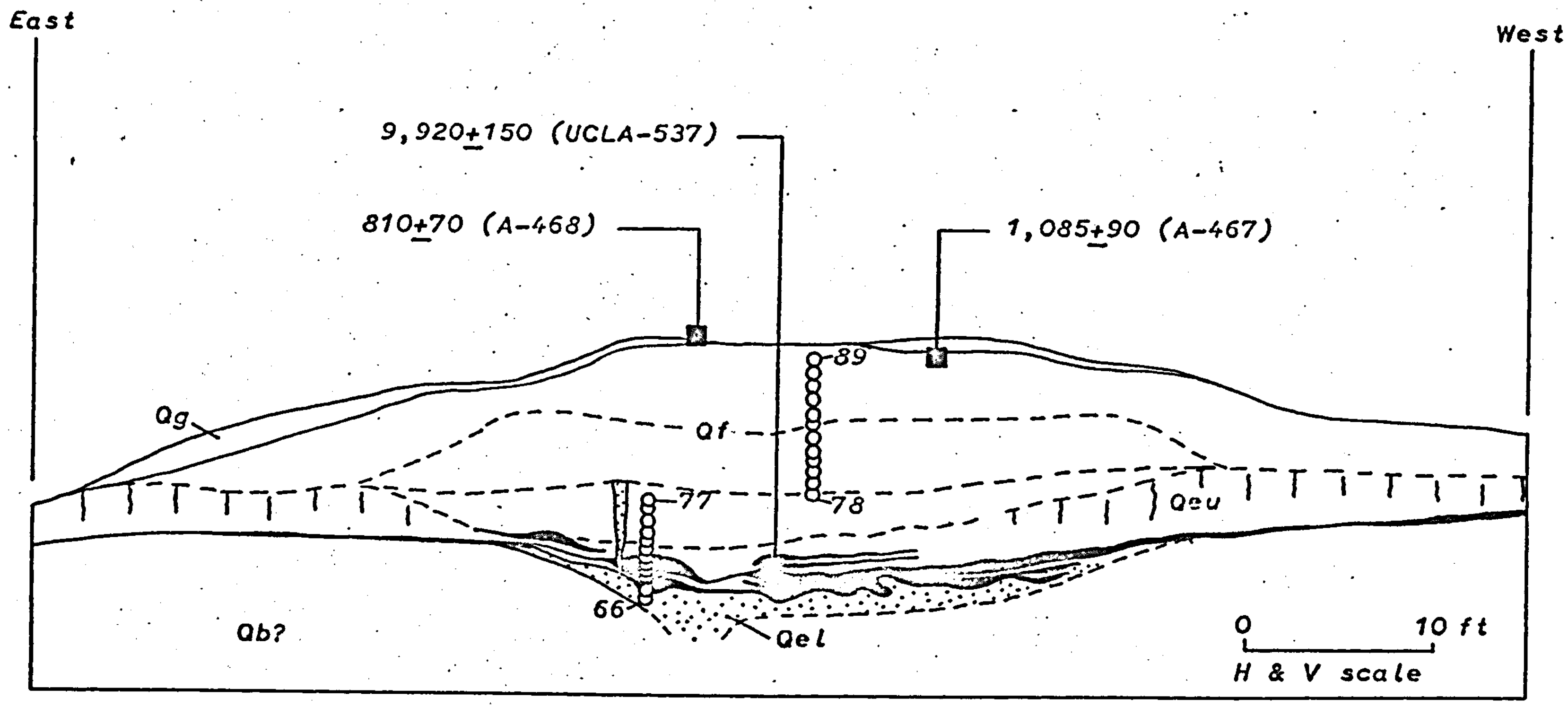


Figure 16. Stratigraphic profile of trench through mound spring 4 (locality 45), Gilcrease Ranch, showing position of carbon-14 samples and pollen samples of Mehringer's pollen profile III in relation to the buried organic mat of unit E and eolian silt of unit F.

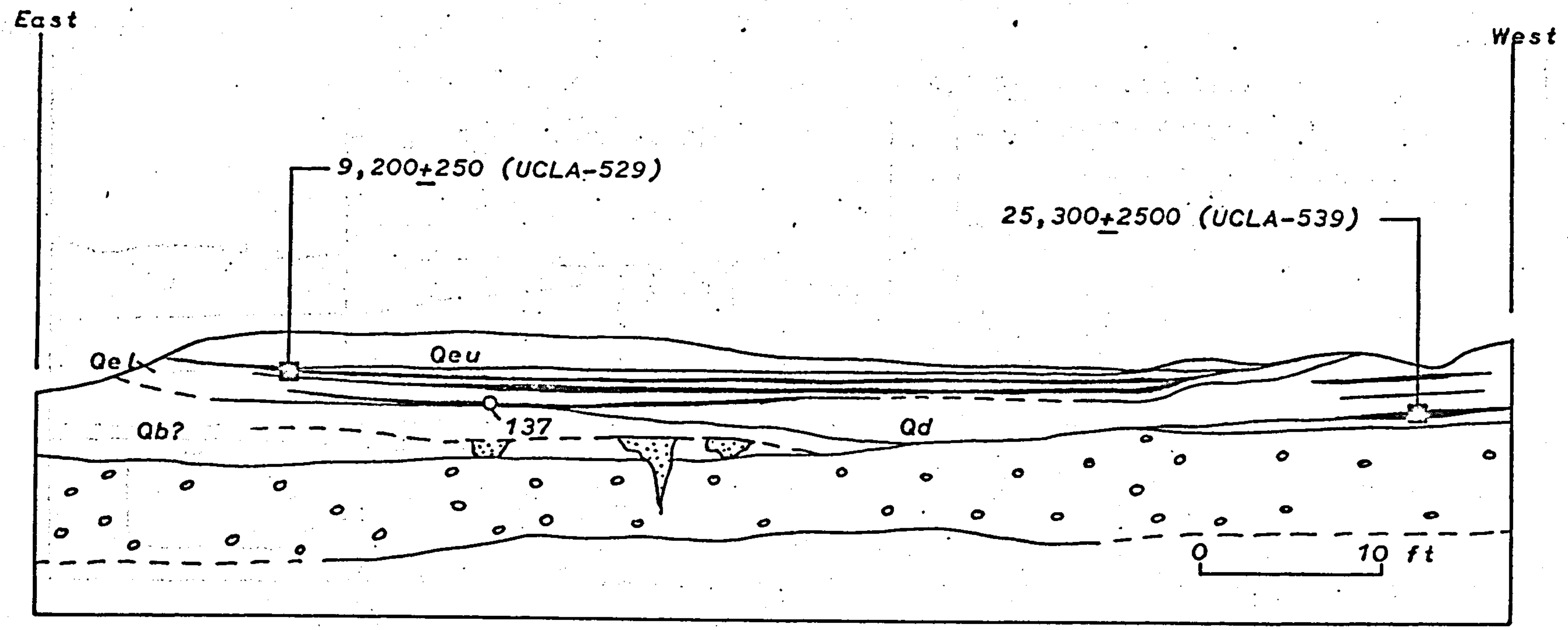


Figure 17. Stratigraphic profile of trench through spring 4 (locality 46), Gilcrease Ranch, showing the position of carbon-14 samples and pollen samples of Mehringer's pollen profile III in relation to the spring-laid sediments.

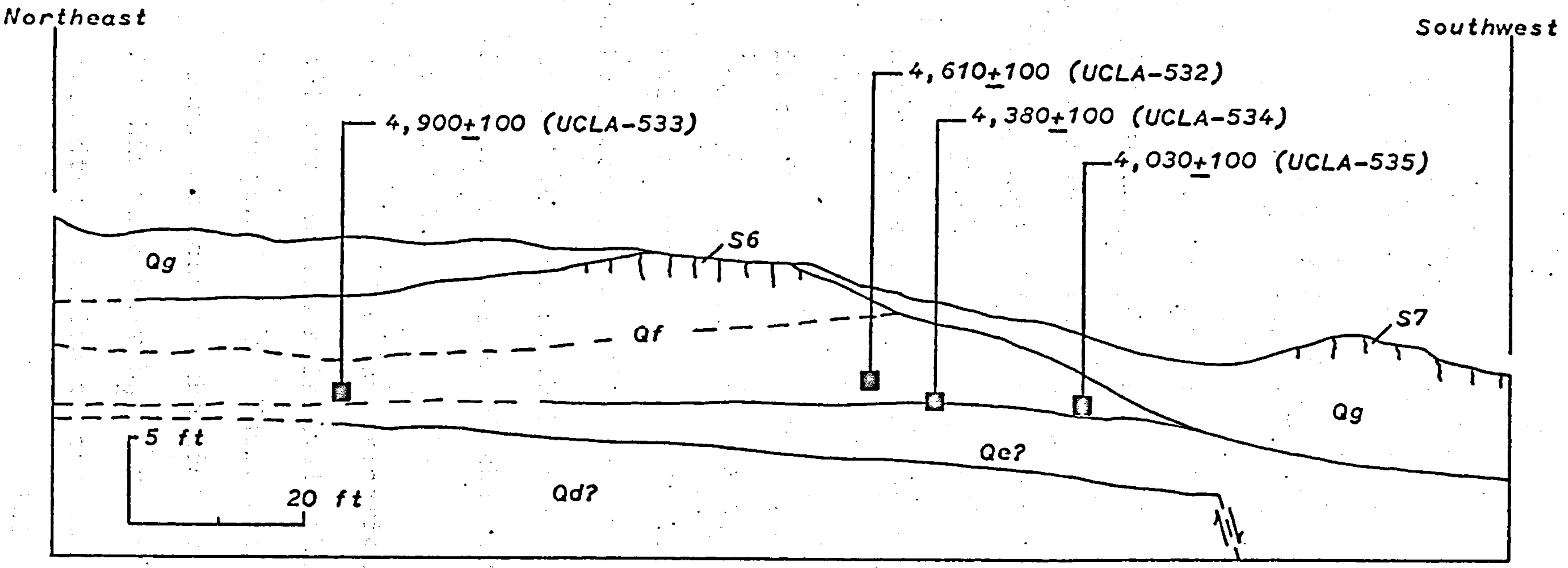


Figure 18. Stratigraphic profile of trench at the Corn Creek dunes site (locality 82) showing the position of aboriginal hearths (carbon-14 samples) in relation to soils and sand dunes along the Corn Creek fault.

APPENDIX II

GEOLOGY OF SOUTHWEST MUSEUM SITE D, AREA 2 TULE SPRINGS SITE, NEVADA

The location of a buried quartzite scraper at Site D (locality 8), Area 2 of the third Southwest Museum Tule Springs expedition is shown on the accompanying geologic map (Fig. 19). A 5- by 10-foot test pit was excavated at this site by the Nevada State Museum in order to ascertain the geologic stratigraphy in which the scraper was found. From the geologic map it can be seen that Site D, Area 2 is well within the area of outcrop of the "green pond" unit (unit B_2) which is dated at $>$37,000 B.P. (UCLA-506) in the nearby section exposed in trench D (Appendix I, p. 145) and at $>$30,000 B. P. (UCLA-547) in the adjacent archaeological excavations of the Nevada State Museum at locality 8.

Detailed investigation of the scraper locality pit reveals two relatively thin deposits overlying the "green pond" unit. These are shown on the accompanying cross sections of the test pit walls (Figs. 20 and 21). At this site unit B_2 is greenish white silty mudstone with strong medium to coarse prismatic structure and contains streaklike limonite stains, small snail shells, and disseminated lumps of black fossil wood.

Directly overlying unit B_2 is unit F_1, zero to 8 inches thick and composed of loose laminated silt, sand, and fine to medium caliche gravel. A fill in a small buried rill channel exposed in the north end of the west wall contains medium to coarse moderately rounded limestone pebbles. This unit is slope wash alluvium and colluvium, the caliche gravel being derived from numerous outcrops along the badland rill while the limestone pebbles came from upstream where the modern rill heads in an area capped by lag gravels of unit E_2 approximately 250 feet to the southwest.

Unit Z, one-half to 7 inches thick, is composed of medium to coarse angular fragments of greenish white mudstone; and silt, sand, and fine to medium caliche gravel. It is obviously a man-made mixture of units B_2 and F_1 and is apparently the backdirt of the Southwest Museum excavations.

The scraper in question came from either unit B_2 or F_1, or the contact between them. If the provenience of the scraper is the "green pond" unit, it is in excess of 37,000 years old, but the scraper contains a weak discontinuous coating of manganese oxide similar to desert varnish observed on some gravel exposures of considerably younger age. Unit B_2 at Site D, Area 2 does not contain black stains of manganese oxides, and the over-all greenish color, indicating ferrous iron, suggests that Eh-pH conditions were reducing and not favorable for manganese deposition. The yellow limonite stains in unit B_2 are believed to represent zones of secondary oxidation of iron. Absence of secondary black coatings indicates insignificant concentration of manganese in unit B_2 or in the water that once saturated unit B_2. These observations do not support a "green pond" provenience for the scraper.

Inspection of the artifact shows it to be weakly polished, presumably by wind action, and as mentioned previously, to have a weak discontinuous coating of desert varnish. Inspection of the gravel cap at the head of the rill reveals similar surfaces on quartzite pebbles. These facts suggest the gravel cap as a likely source of the scraper and the limestone pebbles in the buried rill. Geologic evidence indicates an age of 9,000 to 6,000 B.P.for the gravel cap and a maximum age of 6,000 B. P. for exposure of the gravel surface. Unit F_1 is believed to be between 6,000 and 2,000 years old. Limestone pebbles are confined to the buried rill or to the contact between units B_2 and F_1. They do not occur in the overlying laminated portion of unit F_1. If the scraper was deposited with these pebbles, an age of no more than 9,000 B.P. and probably less than 6,000 B.P. is suggested.

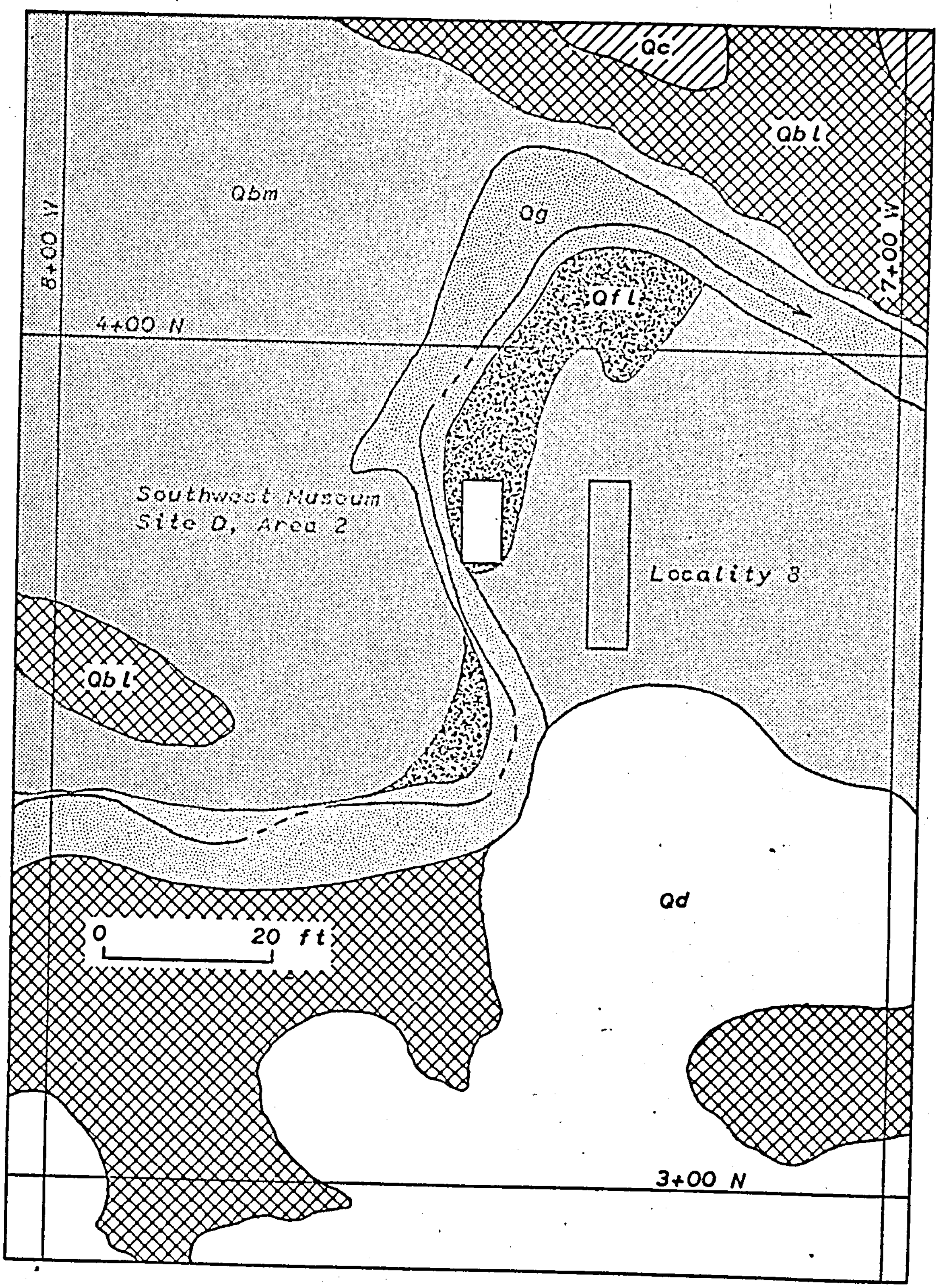


Figure 19. Geologic map of Southwest Museum Site D, Area 2.

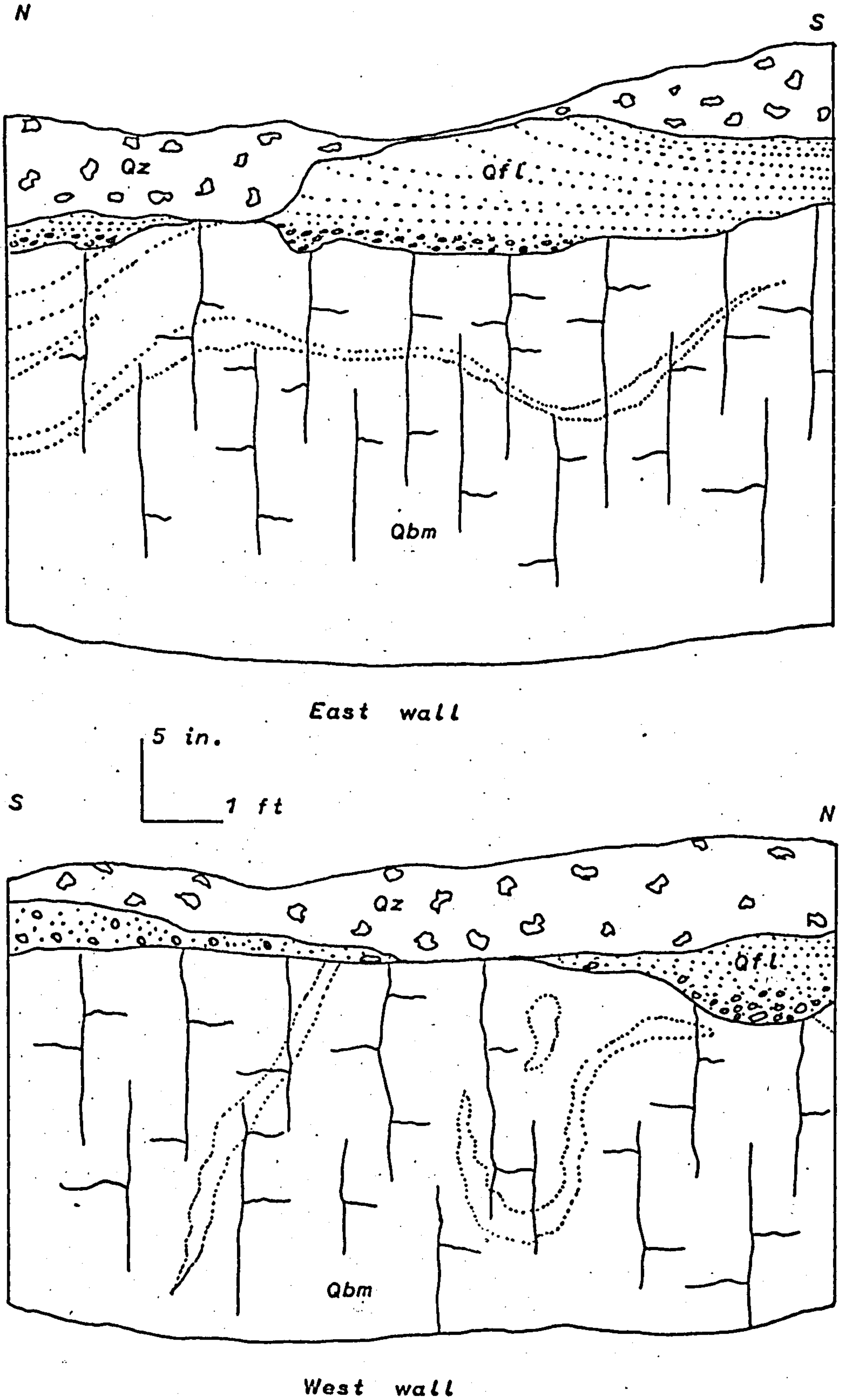


Figure 20. Stratigraphy of east and west walls, Site D, Area 2.

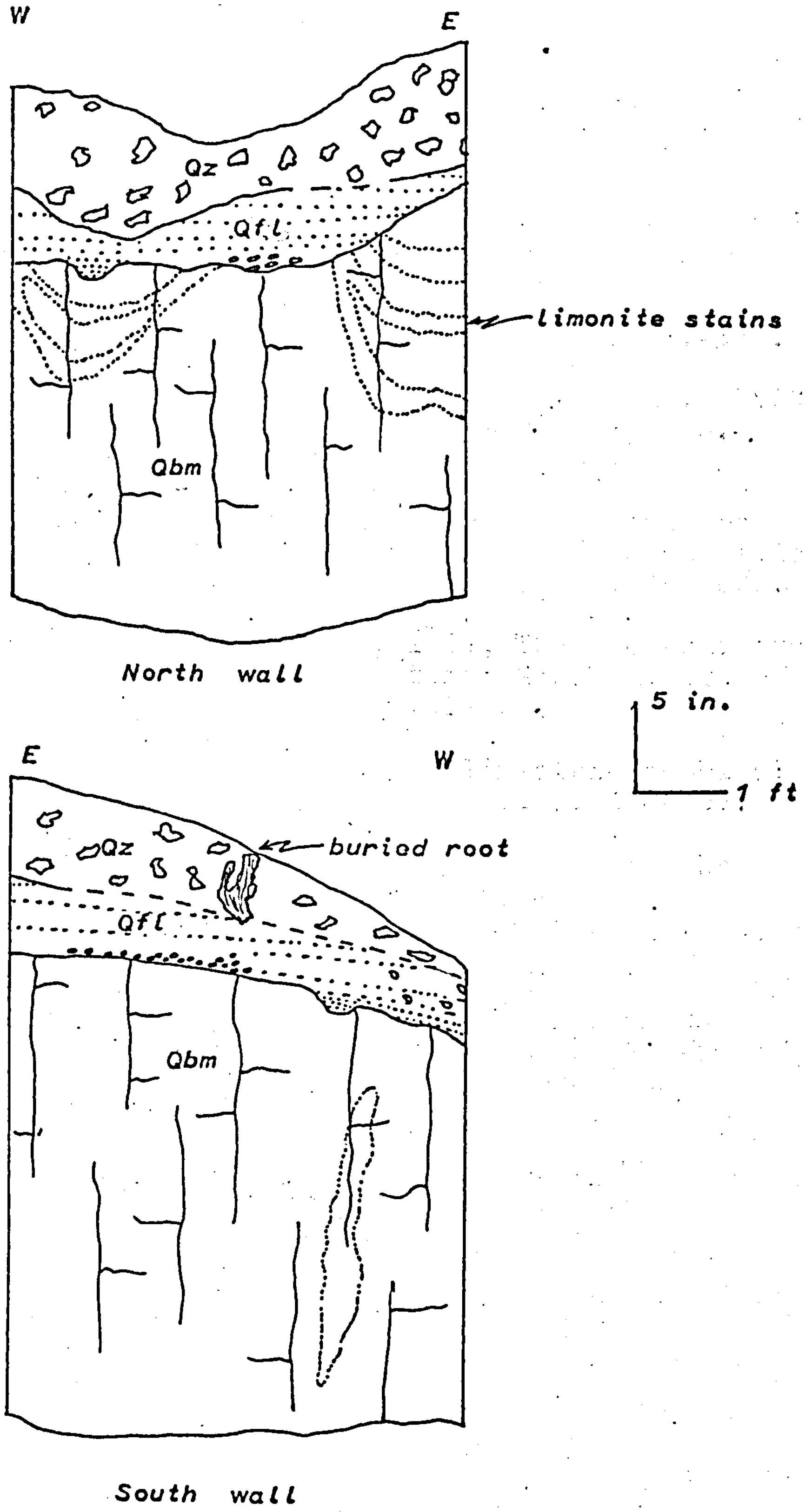


Figure 21. Stratigraphy of north and south walls, Site D, Area 2.

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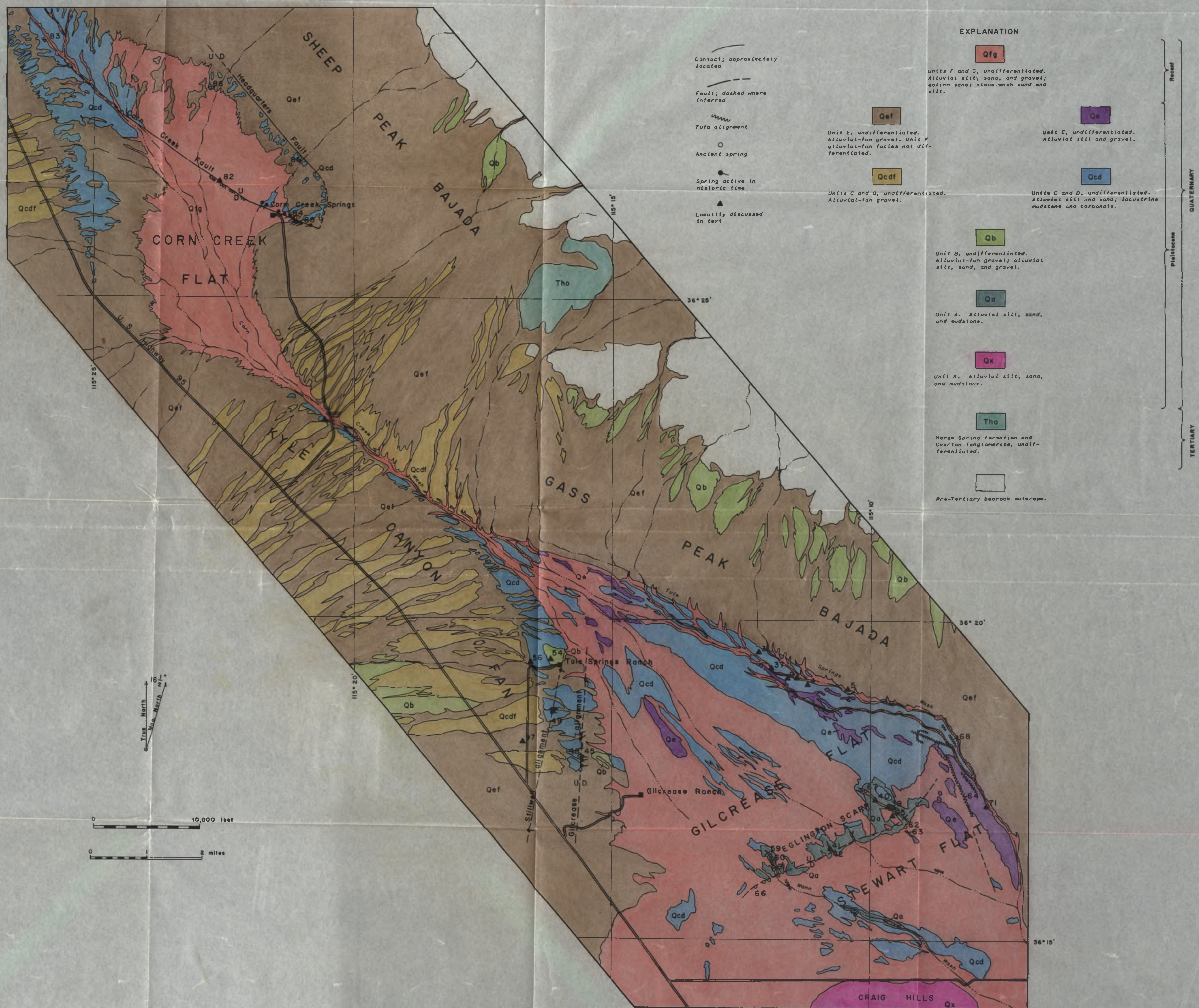
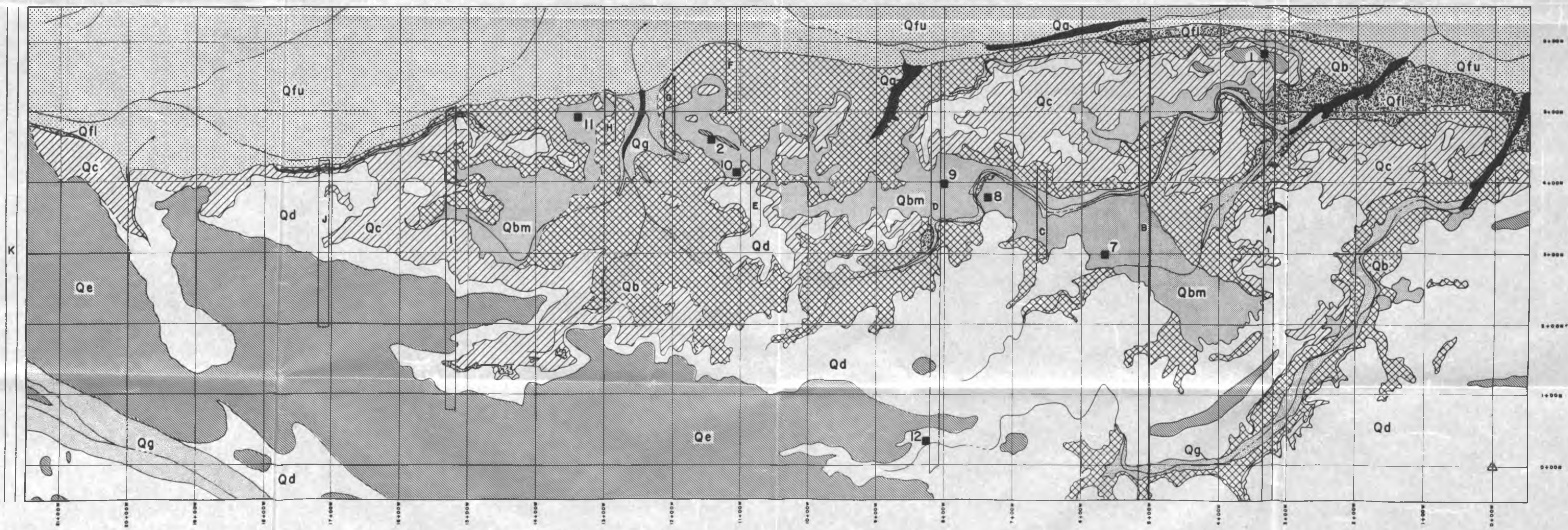
4 Plates



RECONNAISSANCE GEOLOGIC MAP OF THE NORTHERN LAS VEGAS VALLEY SURFICIAL DEPOSITS

E779? 1965 245

HAYNES, PLATE 1



Recent	
Qg	Unit G, undifferentiated. Alluvial sand and silt; slope wash
Qfu	Unit F_2. Alluvial gravel, sand, and silt
Qfl	Unit F_1. Alluvial gravel, sand, and silt; slope wash; eolian sand and silt
Pleistocene	
Qe	Unit E, undifferentiated. Alluvial silt and gravel
Qd	Unit D. Lacustrine siltstone and mudstone
Qc	Unit C. Alluvial silt, sand, and gravel
Pleistocene	
Qbm	Unit B_2. Lacustrine mudstone and siltstone interbedded with units B_1 and B_3
Qb	Units B_1 and B_3, undifferentiated. Alluvial silt, sand, and gravel
Qa	Unit A, undifferentiated. Alluvial silt and sand

Contact, dashed where inferred

△ Site datum; elevation 2307 feet

■ 7 Site locality

Marginal numbers are site grid coordinates in hundreds of feet from site datum.

Bulldozer trenches are designated by letters.

TRUE NORTH — MAGNETIC NORTH 16½°

0 100 200 feet

GEOLOGIC MAP OF THE TULE SPRINGS SITE, CLARK COUNTY, NEVADA

HAYNES, PLATE 5.

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HAYNES, PLATE 6.

STRATIGRAPHIC PROFILES OF TRENCHES A, D, F, I, & J, TULE SPRINGS SITE, NEVADA

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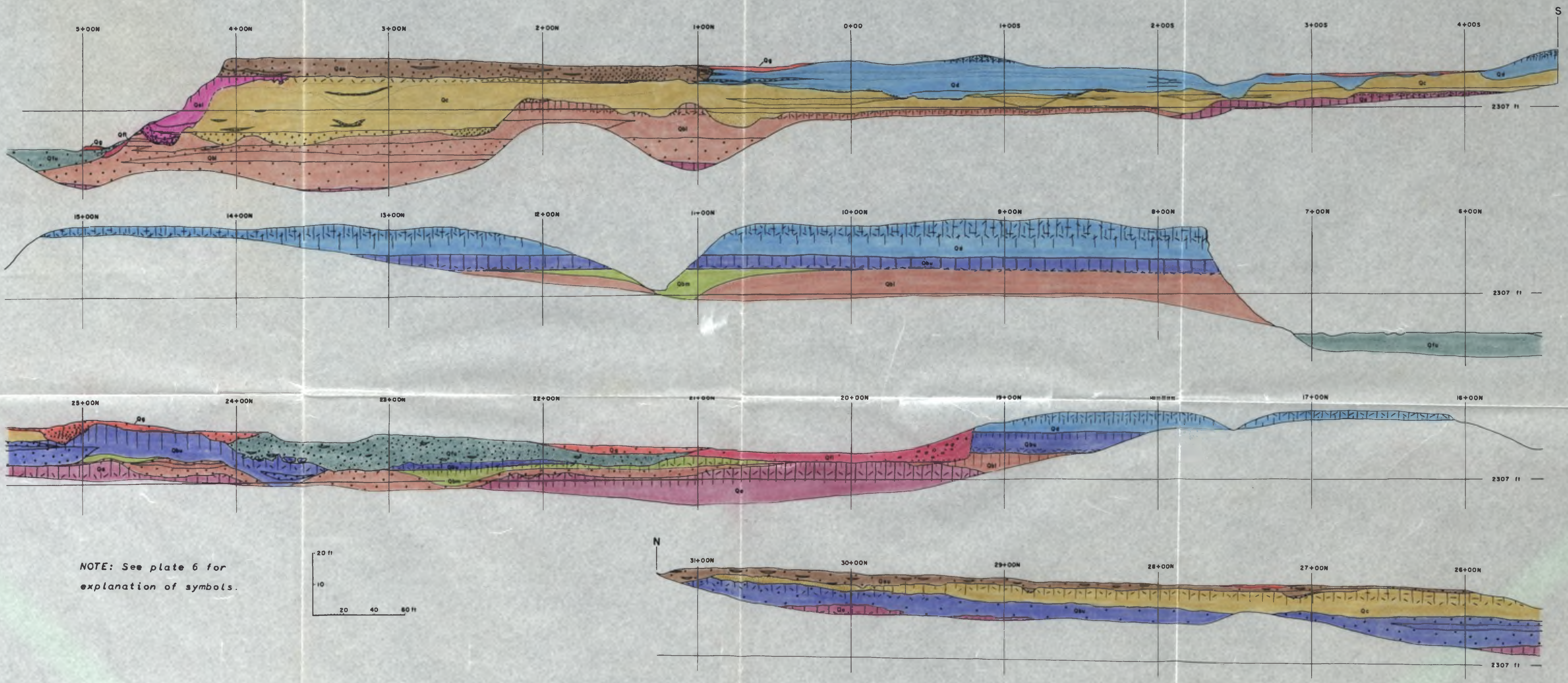

STRATIGRAPHIC PROFILE OF TRENCH K (21+50 W), TULE SPRINGS SITE, NEVADA

HAYNES, PLATE 7.

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