QUATERNARY GEOLOGY OF THE CORN CREEK SPRINGS AREA, CLARK COUNTY, NEVADA

by

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ABSTRACT

Six stratigraphic units and six soils of the late Pleistocene and Holocene are recognized from dissected badlands fringing Corn Creek Flat, 30 km northwest of Las Vegas, Nevada. Units 0 and 1 probably fall beyond the range of carbon-14 dating. Unit 2 is correlative with Unit D at Tule Springs and dates from roughly 30,000 years P.B. to before 14,000 years B.P. Unit 1 is fluvial. Units 0 and 2 are fluvio-paludal, reflecting periods of moister conditions during the late Pleistocene. Ground-water carbonate cementation and extensive burrowing by Cicadidae accompany these units. In the latest Pleistocene, springs deposited spring mats (units 3 and 4) and fed a perennial stream connecting Corn Creek Flat and Gilcrease Flat to the southeast. During the mid to late Holocene, increased wind action, decreased biotic activity, and water-table lowering accompanied widespread erosion of earlier fine-grained deposits.

INTRODUCTION

A series of variegated, fine-grained sediments crops out as badlands on several broad, semi-enclosed flats within a northwest-trending basin that constitutes the Las Vegas Valley. The City of Las Vegas fills the lower, southeast end of the valley. The northwest end of the basin has no clear structural limit, but an interbasin sill some 45 km from Las Vegas hydrographically isolates Indian Springs and Three Lakes Valley to the north. Southeast of this divide, washes coalesce onto Corn Creek Flat. Corn Creek Station, herein used synonymously with the Desert Game Range Headquarters, is located on the east side of the flat adjacent to an active and several inactive springs. Gilcrease Flat, in which the Tule Springs archeological Site is located, and Steward Flat lie between Las Vegas and Corn Creek Flat. In this area the basin is bordered on the soutwest by the Spring Mountains, and on the opposite side by the Las Vegas and Sheep Ranges (fig. 1).

Corn Creek and Tule Springs lie on bypass flats (see Motts, 1970, p. 13) connected by Corn Creek Wash, which flows along a narrow neck between encroaching fans debouching from the adjacent high ranges. Corn Creek and Tule Springs Wash flow intermittently down valley and connect with Las Vegas Wash, which in turn feeds into the Virgin and Colorado Rivers. To the northwest, Pleistocene strata near Indian Springs and in Three Lakes Valley fringe fully enclosed playas. The presence of sediments straddling the drainage divide between Three Lakes Valley and Corn Creek Flat suggests a possible

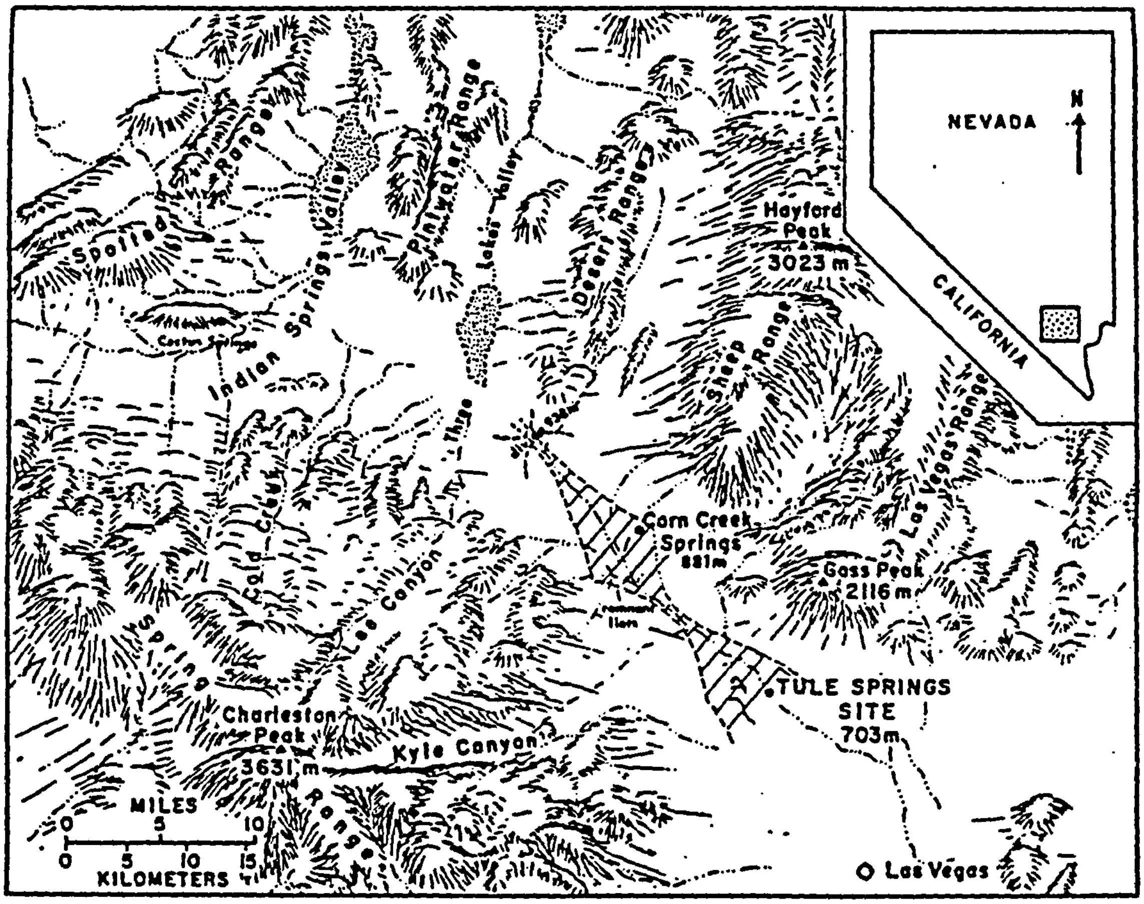

Figure 1. Physiographic setting of the Las Vegas Valley and surrounding basins and ranges. -- Modified from Mehringer (1967, fig. 4, p. 147).

hydrologic connection with Corn Creek Flat before the end of the Pleistocene.

Four to 5 kilometers of pediment and piedmont gravels generally divide the sinuous and embayed range front from the fine-grained badlands in the center of the basin. The range-front sinuosity is indicative of extended tectonic quiescence along most of the range-bounding fault(s).

The ranges adjacent to the Corn Creek area are composed entirely of Paleozoic carbonates, with only minor quartzite, siltstone, and claystone (Bowyer, Pampeyan, and Longwell, 1958). No igneous rocks crop out in the Corn Creek hydrographic basin; the nearest volcanic rocks are roughly 55 km to the northwest beyond Three Lakes Valley or the same distance southeast beyond Las Vegas. Introduction of grains of biotite, hornblende, and feldspar from these sources into the Corn Creek area could only have been through wind action.

Purpose

The purpose of this geological investigation was twofold: (1) to date and characterize late Pleistocene depositional events in the Corn Creek Springs area and (2) to compare and where possible correlate this stratigraphy with that established by Haynes (1967) at the Tule Springs archeological site to the southeast.

Previous Work

The earliest mention of the Corn Creek sediments was by Rhowe (cited by Spurr, 1903, p. 157), who collected mastodon teeth and bones from a "clay bank" between Tule Springs and Corn Springs. This locality may well have been within upper Pleistocene channel deposits (unit E_1 or unit E_2) where megafaunal remains are common. Rhowe described the fine-grained deposits as remnants of a former lake or playa, a view that has persisted to today.

Longwell and others (1966) formalized the name of these deposits as the Las Vegas Formation. They speculated that the deposits were deposited by shallow lakes within partially enclosed basins centered around Corn Creek Springs, Tule Springs, and Indian Springs. They also envisaged a large lake filling the lower valley now occupied by the City of Las Vegas, with former Lake Chemehuevi along the Colorado River acting as a drainage control.

The association of stone tools with Pleistocene megafaunal remains at what was to become the Tule Springs archeological site stimulated multidisciplinary research of the deposits in the early 1960s. Careful studies were devoted to the pollen record (Mehringer, 1967), molluscs (Taylor, 1967), other fauna and megafauna (Mawby, 1967), and Quaternary geology (Haynes, 1967) to create a complete paleoenvironmental reconstruction. It was one of the main purposes of the present study to establish a correlation between the Corn Creek stratigraphy and that established by Haynes.

Even to the present, the variegated badlands within Las Vegas Valley are routinely referred to as lake beds. Haynes showed that most Pleistocene and all Holocene deposits were fluvial or spring laid, whereas only the calcareous mudstones of Unit D were lacustrine. Since then, this last assertion has been a subject of controversy.

Mifflin and Wheat (1979), for example, contended that their climatological estimate for the Pleistocene based on the distribution of confirmed late Pleistocene lakes leaves the southerly Tule Springs area too hot or too dry or both to support a major pluvial lake. Others have contested the existence of such a lake on the basis of lack of closure of the basin. This problem for the Corn Creek Flat area is addressed in this study.

Four pluvial lakes, Lahontan, Searles, Mohave, and Bonneville, have been studied in detail. The studies provide a basis for comparison of lake-level fluctuations with time over a considerable area (Mehringer, 1977). Unfortunately, the age of depositional events at Corn Creek are only generally known as a result of his study. Correlation with outside areas other than that of Tule Springs would be unreasonable without drawing heavily from the findings of that already published work. A comparison can be attempted only when the ages of the Corn Creek deposits are better known. Until then, this work must be confined to proposing a number of refinements in the stratigraphy originally put forth by Haynes (1967).

Procedure

The area that is the subject of this study includes all of Corn Creek Flat, from the drainage divide isolating Three Lakes Valley to the north, south to Tule Springs Ranch on the north end of Gilcrease Flat. Mapping was done simultaneously on aerial photographs (1:48,000) and three U.S. Geological Survey 7½-minute quadrangles (1:24,000), Corn Creek Springs NW, Corn Creek Springs, and Tule Springs Park. The latter two were reduced to the 1:48,000-scale map included with this thesis (fig. 2, in pocket). The Three Lakes Valley and Indian Springs–Cactus Springs areas were both reconnoitered, and their stratigraphy is briefly discussed.

The system of unit designation used for the Corn Creek stratigraphy differs from that employed by Haynes at Tule Springs. Funding being limited, the absolute chronology for Corn Springs is not nearly as refined, and due to rapid lateral facies changes, particularly in Units 0 and 2, and to lack of physical connection, outcrops could not be readily traced between areas. When and if the Corn Creek stratigraphy can be carefully dated, some positive correlations can be made. Until that time, the stratigraphic nomenclatures will be kept separate, although some reasonably certain correlations can be posited between the two study areas. The numerical unit designations for the Corn Creek area were also applied in the Indian Springs–Cactus Springs area because of the striking similarity between their respective strata. For these areas, I kept soil and unit designations uncapitalized (e.g., unit 3 and soil 3) to emphasize the informality of the nomenclature. Designations for units in the Tule Springs area are lettered and capitalized (e.g., Unit D and Soil 3) as originally put forth by Haynes (1967).

For ease of presentation, the study area was divided into seven areas: A1 through A7 (fig. 2). The complex stratigraphy of the region cannot be easily encapsulated in a single stratigraphic column and description, and thus each area was dealt with separately. In addition, four cross-valley sections were profiled and representative stratigraphic sections measured. These are presented in the appendix and are keyed to the geologic map (fig. 2).

Field studies extended over 3 months, intermittently during the summer of 1980 and winter of 1982. Laboratory work consisted mainly of carbon-14 pretreatments and petrographic study of sands and carbonate nodules, all carried out at The University of Arizona. W. Pratt of the Museum of Natural History at the University of Nevada at Las Vegas examined and interpreted the molluscs collected during this study.

GENERAL GEOMORPHOLOGY AND STRATIGRAPHY

Geomorphology

The dissected badlands within and fringing on Corn Creek Flat are made up of a series of upper Pleistocene and Holocene soils and sediments. The most prominent and deeply dissected exposures, in places as much as 10 m, are located on the northwest fringe of the flat adjacent to Highway 95. Degree of dissection decreases both up and down valley, as well as toward the basin center. South of Corn Creek Station, broad areas contain no exposure. The station itself lies at the south end of several spring-mound alignments. The mounds up to 6–7 m high consist of aeolian sands trapped by phreatophytes watered by spring seeps. Along with the badlands, these mounds are visually the most prominent features of the valley.

At first glance the fine-grained strata appear to fill the valley like a white bathtub ring upon gray fan gravel. In reality, the elevation of the highest occurrences of the fine-grained outcrops decreases slightly downvalley, suggesting that whatever was responsible for their deposition was not flat lying along the length of the valley.

Gravels from the adjacent piedmont pass through erosional breaches in the fine-grained outcrops, setting them off in stark contrast to the channel-bottom gravels. The highest outcrops are generally covered by eroding gravel caps. Broad areas are littered with sharp, solution-pitted carbonate rubble, which lends a yellowish-brown tint to the otherwise lighter sediments (fig. 3). Scant protection

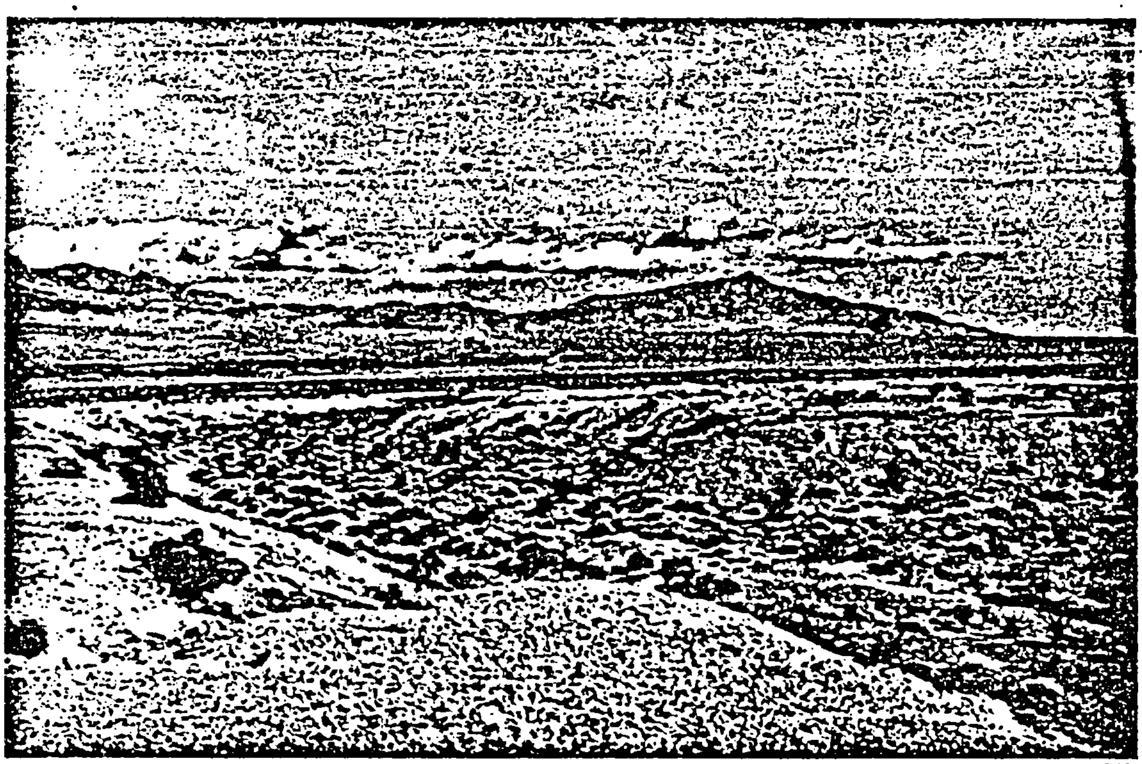

Figure 3. General view of the Corn Creek badlands

Nodular calcium carbonate mantles whiter fine-grained host sediments as an erosional lag. Vegetated coppice dunes around Corn Creek Station are visible in the background.

against erosion is afforded by an occasional creosote bush or joshua tree.

Corn Creek Wash displays several stream modes. In its headwaters below the drainage divide with Three Lakes Valley, the wash is entrenched into Pleistocene strata. This entrenchment persists downvalley several kilometers, although at present the wash is aggrading in places, downcutting with prominent head cuts in others. Toward the basin bottom, adjacent to Corn Creek Station and below it, the wash splays out into an unconfined, anastomosed network of channels. Here older strata are buried rather than dissected. Only just above the neck separating Gilcrease Flat from Corn Creek Flat and to the south are badlands again visible and the wash deeply entrenched. This situation persists to Tule Springs Ranch and beyond.

Stratigraphy

Figure 4 contains brief descriptions, depositional settings, and proposed ages of the various Tule Springs deposits (Haynes, 1967) and those of the Corn Creek area. Proposed correlations of units between areas is also shown. A detailed discussion of the material presented in figure 4 is in the final chapter of this thesis.

The oldest surficial deposits in this portion of the valley are exhumed fan gravels found in interfluve areas adjacent to the mount front and in places several kilometers basinward from it. Haynes (1967, p. 41) originally identified three distinct geomorphic surfaces, distinguishing them on the basis of their surface and soil characteristics. Surface 1 was the oldest and is identical with above. It appears

Stratigraphy of the Tule Springs Area

Unit	Soil	
G_1		Extensive erosion and encroachment of gravels of the fine-grained Pleistocene deposits in valley center; slope wash and terrace deposits within the badlands; dry conditions with essentially modern vegetation
	S_6	Weakly developed, incipient Stage I calcic horizon
$F_{1,2}$		Inception of erosion of Pleistocene and lower Holocene sediments; eolian activity and gravel encroachment from valley margins; lessening spring activity and modern vegetation in dry conditions
	S_5	Weak cambic horizon and Stage I calcic horizon on gravelly silt alluvium; generally relict
E_2		Incision into older E_1 alluvial deposits and overfilling of Tule Springs Wash channel and flooding of lower Gilcrease Flat by alluvial silt, sand, and gravel; burial of spring depressions by alluvial silt toward the end of E_2 time, as well as of older geomorphic surfaces on the bajadas; no megafauna; probable first appearance of man; sagebrush and shadescale dominant in valley bottom, indicative of moist conditions
	S_4	Poorly preserved, remnant calcic horizon (?) on Unit D or weak organic soil on Unit E_2
E_1		Aggradation of alluvium along the main valley wash in which a small stream flowed, bordered by a wet meadow and fed by numerous springs in the valley bottom (?) and along fault traces; megafauna present; sage and juniper in the valley bottom, trending to more xerophytic sage and shadescale at the end of E_2 time
D		Wet conditions to formation of a shallow lake over lower Gilcrease Flat and Stewart Flat in which up to 5 m carbonate (primary and secondary?) and a green mudstone were deposited; fluctuating lake level as indicated by intercalated gypsum-rich beds and varry mollusc assemblages; megafauna present; *Typha* within the lake and sage and probable pine fringing the shoreline; stable bajada surface
C		Alluvial deposition along a broad channel paralleling the modern wash at Tule Springs site, under possibly dry conditions; possible intertonguing of portions of Units C and D
	S_3	Strong pedocalcic soil with Stage II calcic horizon in fine alluvium
B_3		Alluvial deposition following the drying of ponds and marshes associated with Unit B_2

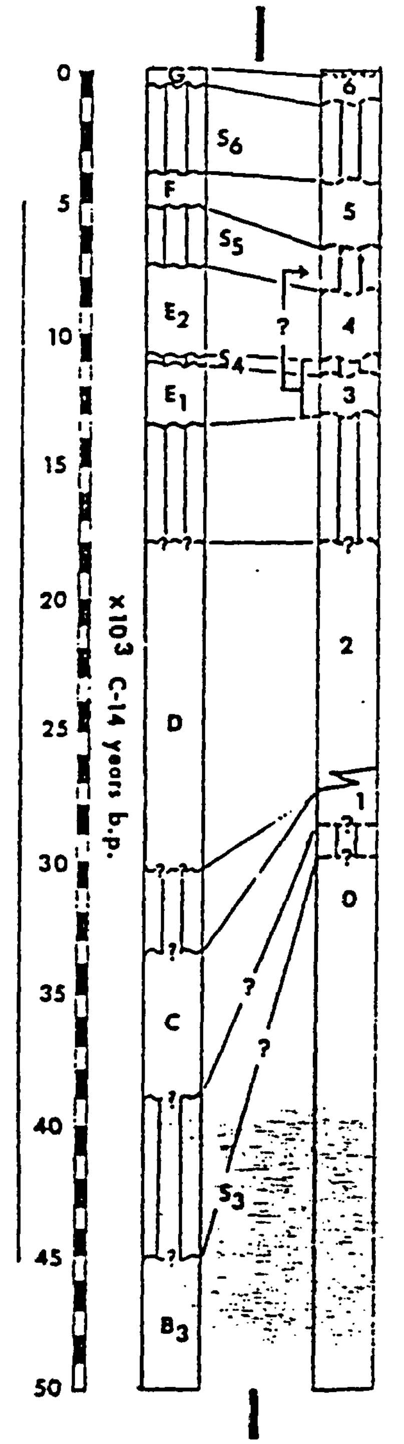

Figure 4. Time stratigraphic columns and proposed depositional settin
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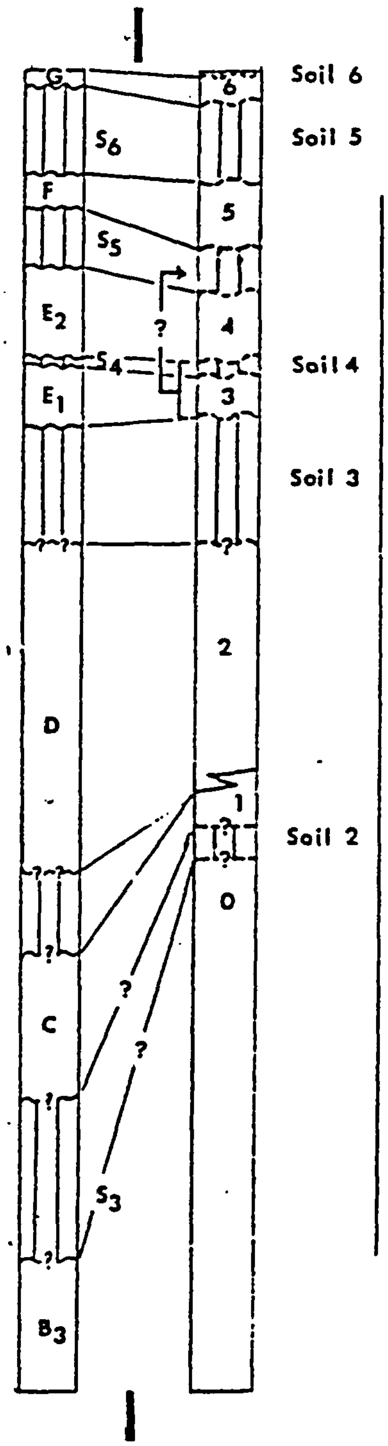

Stratigraphy of the Corn Creek Springs Area

Unit	Soil	
6		Similar to unit 5, with continued dry conditions and deep erosion of all older deposits, including thick blanket of unit 5 alluvium in valley center
	5	Weak development of an incipient Stage I calcic horizon; no associated bioturbation
5		Widespread erosion of earlier fine-grained deposits on valley margins by braided ephemeral streams under dry conditions; some filling of valley center and eolian accumulation around shrinking spring mounds; no secondary carbonate, bioturbation, molluscs, or megafauna
	4	Relict paleosol containing a weak Stage II calcic horizon in gravelly alluvium; extensive cicada bioturbation associated
4		Deposition of sand and silt on broad alluvial flats covering valley bottom and of gravels in narrow channels traversing flat; spring and marsh deposits (as organic mats and green mudstones) along fault traces and in lower portion of Corn Creek Flat; perennial stream connection with Gilcrease Flat; carbonate precipitation of older units off the capillary fringe of elevated water table; molluscs, bioturbation, and possible megafauna indicative of moister conditions than today
3		Similar to unit 4; generally moist conditions
	3	Poorly preserved soil containing a Stage II calcic horizon, bioturbation by cicadas, and possible well-developed argillic horizon
2		Marsh at center of Corn Creek Flat in which carbonate and green mudstones were deposited, indicative of wet conditions; marsh fringed by broad alluvial flat of silt, fine sand, and occasional gravel-bottomed channels; syn- and postdepositional precipitation of carbonate off capillary fringe in marsh and megafauna and extensive bioturbation by cicadas
1		Distinctively interbedded sand and silt deposited over broad alluvial flats extending over most of Corn Creek Flat; reworked secondary carbonate suggestive of fluctuating water table; lack of bodies of standing water or cicada bioturbation indicative of dry conditions
	2	Strong cambic horizon and bioturbation by cicadas; no discernible calci horizon
0		Similar setting to unit 2, but marsh and pond deposits poorly exposed and of unknown extent; molluscs and bioturbation of cicadas suggest moister conditions than today

›ositional settings of deposits in the Corn Creek and Tule Springs areas. --
: Tule Springs data were drawn from Haynes (1967) and Mehringer (1967).

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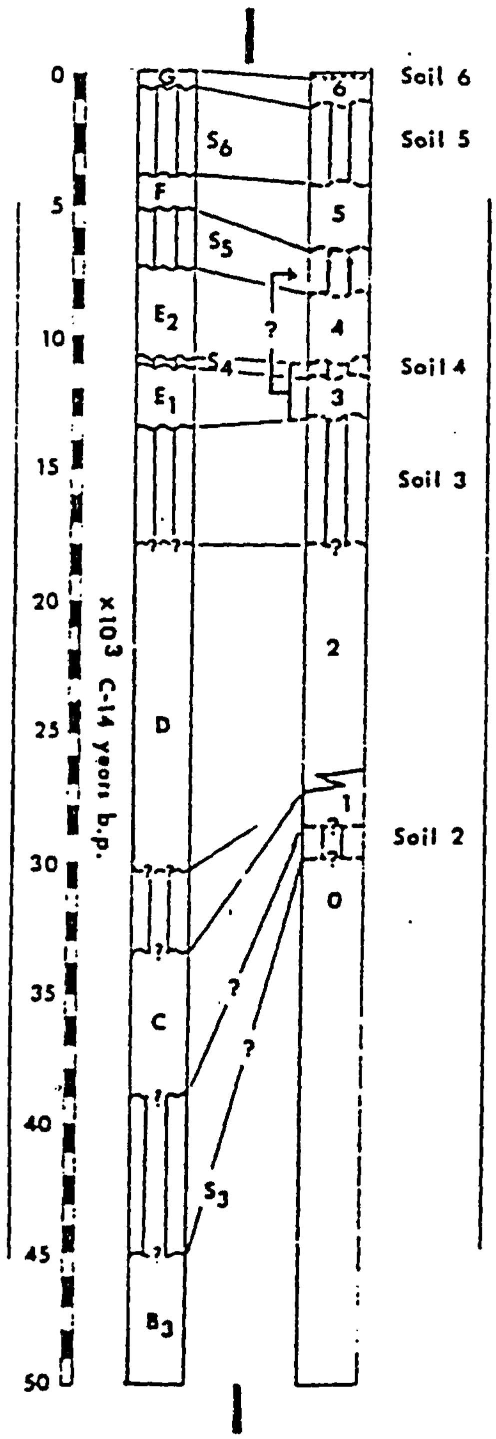

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white in aerial photographs due to exhumation of its substantial petrocalcic horizon. Drainage on the surface is dendritic and well entrenched. At the mountain front, soil 1 contains at least a 4-m-thick calcic horizon, showing dense, laminated carbonate in the upper 2 m to plugged but unlaminated carbonate below. No argillic horizon is preserved. In contrast, near the Tule Springs Ranch the calcic horizon associated with this surface is thinner and lacks carbonate laminae (Stage III calcic horizon of Gile, Peterson, and Grossman, 1966). This suggests that what appears to be a single surface on aerial photographs is actually of several ages. Haynes interpeted the deposits associated with this surface to be a facies of Unit B or older units. Haynes (1981, personal communication) viewed the upper portion of Unit B (B_3 and possibly B_2) to be 40,000 to 60,000 years old and B_1 to be possibly older than this. The Stage IV development of the calcic horizon adjacent to the mountain front seems incompatible with the proposed age of Unit B_3 (and B_2?). A much greater age for the soil, perhaps early Pleistocene, is suggested (Gile and others, 1966; Bachman and Machette, 1977; Hoover, Swadley, and Gordon, 1980). Unit B_3 (and B_2?) at the archeological site and possibly at Tule Springs Ranch instead probably correlate with on the youngest and most distal portions of Surface 1 and the underlying gravels. Unit B_1 and Unit A(?) at the site probably have correlates among the continuum of surfaces grouped by Haynes under Surface 1.

Unit 0

Unit 0 is the oldest and least exposed of the fine-grained sedimentary units defined in the Corn Creek area. Because of its limited exposure and tendency for rapid lateral facies changes, correlation of unit 0 over broad areas is tentative. What has been mapped and described as unit 0 in this thesis may in fact be several distinct pre-unit 1 deposits.

What can with assurance be called unit 0 displays an array of facies similar to those found in unit 2. The reader is referred to the section on unit 2 for a detailed discussion. Here it will suffice to say that both oxidized fluvial sediments and pale-green calcareous mudstones are present. Figure 5 illustrates the lateral facies variation from fan gravels to fan-apron sand silts to mudstones at the center of the basin seen in unit 0. Stratigraphic sections 1 through 3 (appendix) contain representative field descriptions. The calcareous mudstones of units 0 and 2 are indistinguishable; only the presence of soil 2 or a sharp erosional disconformity between the two units serves to distinguish them where exposure is adequate. Fresh-water molluscs can be found in both the mudstones and adjacent fluvial facies, as can manganese oxide staining. A limited amount of secondary carbonate of all types (see chapter on carbonates) is also present. The fluvial facies of unit 0 is distinguishable from overlying units by its greater redness and hardness. Numerous cienaga soils and carbonate nodules after cicada burrows are present, particularly within the calcareous sand-silt facies.

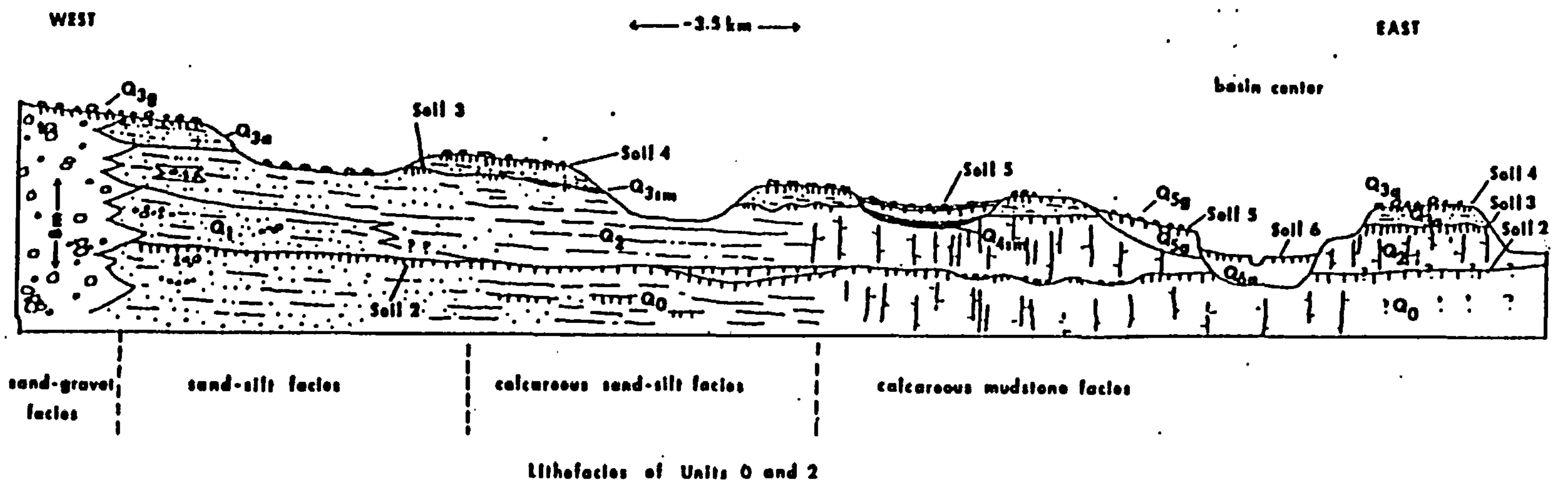
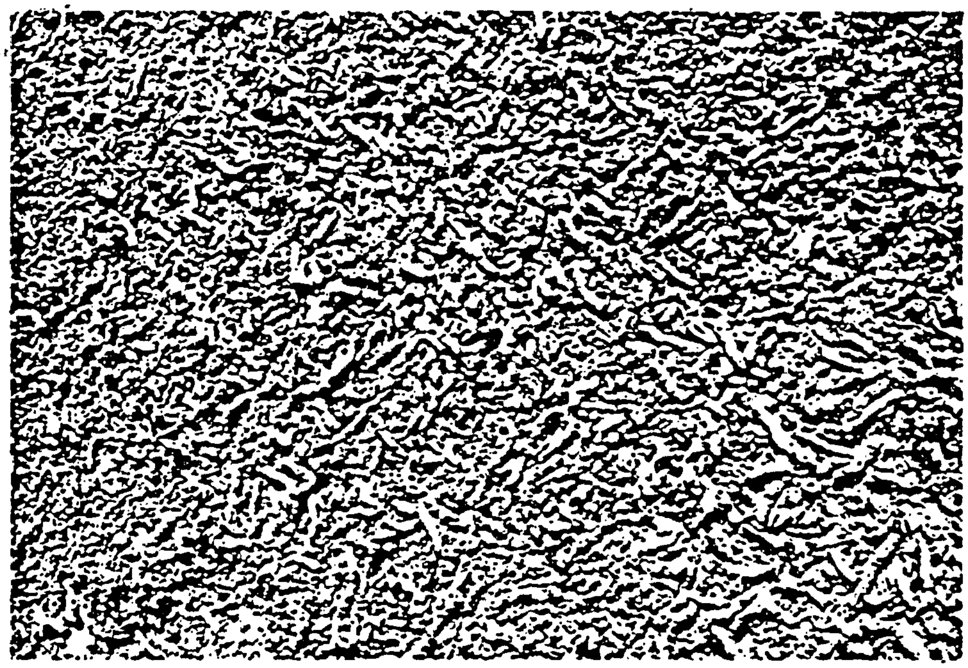


Figure 5. Composite cross section showing units, soils, and lithofacies for units 0 and 2 in the Corn Creek Springs area. -- Not to scale.

Cicada burrows and their carbonate pseudomorphs are extremely common in the study area and warrant a short introduction. The burrows are slightly harder than surrounding sediments and finger sized and internally contain thin ribs of sediments due to backfilling by cicada nymphs as they moved among the root systems of plants in search of food (fig. 6). The burrows have been observed in most fine-grained deposits of Pleistocene to early Holocene age from Indian Springs south to Tule Springs. They are common in sandy loam texture but are not found in gravelly sediment or in subaqueously deposited clays such as in Unit D except where pedogenic overprinting has occurred. The burrows are concentrated along a zone of intense bioturbation where associated with a soil (typically most of the C horizon and sometimes the B horizon), and where they are not, the burrows are thinly dispersed over many meters of sediment profile.

Today, cicada burrows are common in Great Basin soils, and they are widely recognized elsewhere (Soil Taxonomy, Soil Conservation Service Soil Survey Staff, 1975, p. 35; Gile, personal communication, 1981). In northern Nevada, the author has seen live nymphs in association with the kind of burrows described above. Carbonate cementation of these burrows and their ecological significance will be discussed in subsequent chapters.

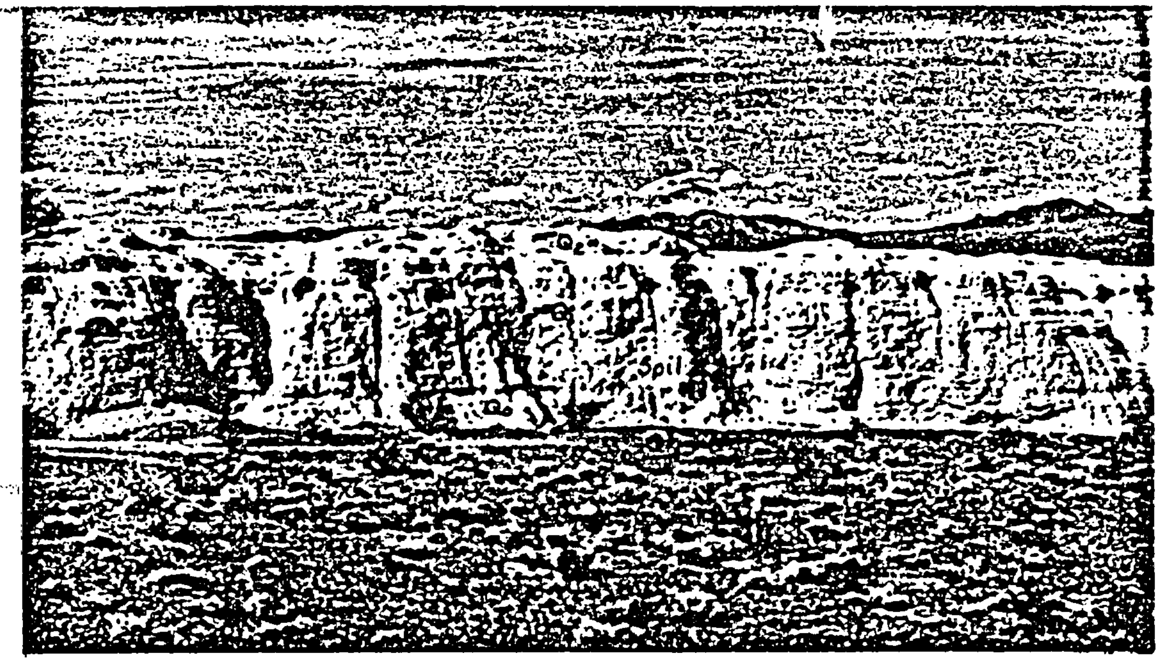
Soil 2 (soil 1 is discussed in the section on Tule Springs Ranch, A7) is found on top of all facies of unit 0, and its upper contact with units 1 and 2, though smooth, is erosional. No calcic horizon is found in association with this soil (table 1; fig. 7).



a

b

Figure 6. Field occurrence in area 7 of finger-size calcareous nodules after cicada burrows. -- a. Surface scatter of carbonate nodules after cicada burrows. b. Cicada nodules weathering out along the Unit B(?)–Unit D contact.



a

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Figure 7. Fine-grained basin margin facies of units 0, 1, and 2 in area 2. -- a. Sand-silt facies, units 0, 1, and 2. b. Calcareous sand-silt facies, units 0 and 2. Note carbonate lag mantling unit 2.

Table 1. Soil 2, area 1, buried paleosol

Location: Corn Creek Flat, Clark County, Nevada; 115°25'07" W., 36°26'22" N.
Classification: Typic Cambiorthid

Horizon	Depth (cm)	Description
		---------------erosional disconformity-------------
B2	0-20	light-yellowish-brown (10YR 6/4d, 5/4m) sandy loam; slightly sticky, slightly plastic; strong effervescence; structure dominated by extensive cicada bioturbation; clear smooth upper boundary and gradual smooth lower boundary
B3	20-55	Very pale brown (10YR 8/3d, in places 7.5YR 7/3d) sandy silt; hard, slightly sticky, slightly plastic; strong effervescence but no calcareous nodules; extensive cicada burrowing; gradual smooth boundary
C1	55+	Very pale brown (10YR 7/3d) sand and (10YR 8/2d) silts; slightly hard; sands are nonsticky, nonplastic; silts are sticky and plastic; well-preserved sedimentary structures, dispersed carbonate nodules, especially along silt beds, probably nonpedogenic

Unit 1

Unit 1 is made up exclusively of brownish fluvial sediments that crop out in a broad zone marginal to more clayey sediments toward the basin center. Unit 1 is readily distinguishable for its evenly interbedded sands and silts (fig. 8), laterally discontinuous gravel lenses, and occasional platy nodules. Extensive bioturbation, molluscs, and soils are totally lacking. Sedimentologically, this unit typifies the sand-silt facies of units 0 and 2, and the reader is referred to a discussion of this facies later in this section. Although most of unit 1 was mapped as a distinct unit, portions of it may be intercalated with rather than overlain by lower unit 2.

Area 1 around Tule Springs Ranch contains what are probably unit 1 sediments. Here, however, the alluvium is formed into distinct channels cut down into older reddish Pleistocene beds. Downdip, the unit thins to a mixture of gravelly sandy silt and cienaga soils. Unit 1 is not known to occur elsewhere in the basin center, probably because erosion preceded unit 2 deposition and because a portion may intercalate with unit 2. No soil or marked disconformity divides unit 1 from overlying strata.

Unit 2

Unit 2, like unit 0, comprises several distinct faces: the sand-gravel (fan) facies, the sand-silt facies, the calcareous sand-silt facies, and the calcareous mudstone facies. These are shown on figures 5 and 6, among others. Because to my knowledge these have not been dealt with in detail in the literature, they will be considered here.

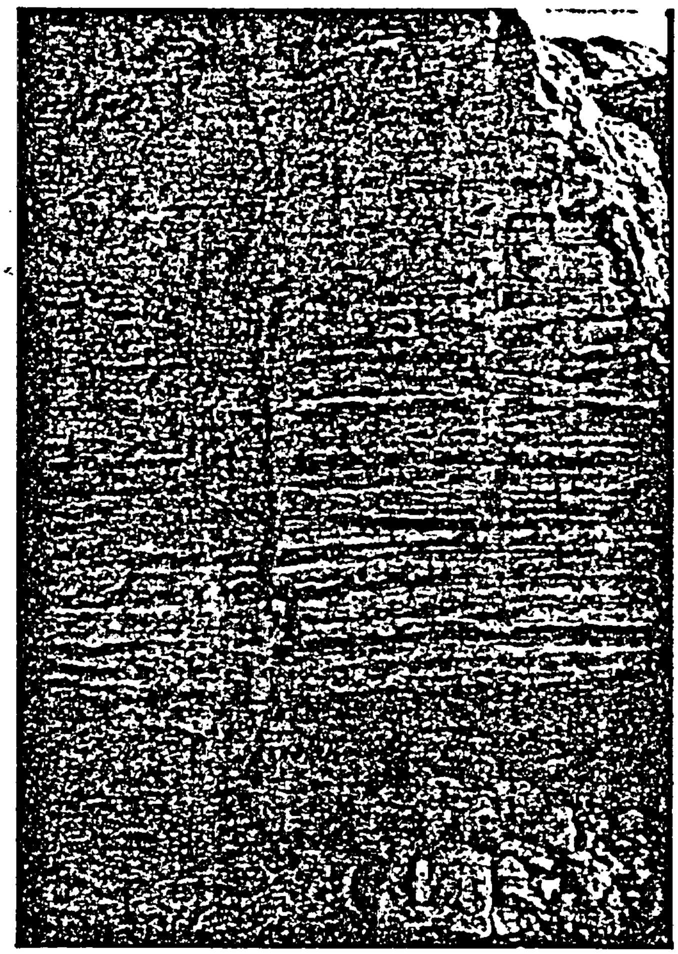


Figure 8. Distinctive sand–silt facies, units 0 and 1, area 1. -- Silt layers are off-white, whereas sandy beds are dark brown. This facies is also found in units 0 and 2.

The sand-gravel or fan facies makes up most of the basin surficial deposits. Clasts in this alluvium are dominantly limestone and are often imbricated and in grain-to-grain contact. Matrix-supported debris flow deposits appear to be largely absent. The calcareous lithology does not readily weather to the clays needed to generate debris flows. The described gravel exposures are also distant from the mountain fronts and are in areas of low gradient. Dissection of piedmont gravels in the study area is very limited, and most flow over them is in unentrenched anastomosing channels.

The sand-silt facies intertongues with distal piedmont gravels and is present in all units except 4, 5, and 6. This facies is well exposed along the west-southwest fringe of Corn Creek Flat, as well as just west of Tule Springs Ranch. It is inferred that the sand-silt facies once fringed all the fine-grained flats in Las Vegas Valley. This facies has been variously referred to in the literature as a "sand flat" (Peterson, 1981), "fan skirt" (Peterson, 1980), and "transition facies" (Motts, 1970). I prefer to use sand-silt facies, as with other lithofacies designations employed in the thesis, because it is sufficiently descriptive but carries no genetic connotation.

The most distinct field characteristic of the sand-silt facies is that it contains distinct divisions of fine sand to coarse silt interbedded with clayey silt. This is amply illustrated in figure 8. The contact between the two textures can be sharp and erosional or gradational and fining upward. The fining-upward sequences generally range from 18 to 25 cm in thickness and grade from granule layers of finely imbricated clay chips and limestone and chert detritus upward through fine sand

and silt to laminated clayey silts draped over the top. The silt and sand are both planar bedded and ripple cross bedded.

As seen in figure 8, the coarser sandy layers tend to be darker (10YR 7/3d) and to weather recessively. Compositionally, the sands are roughly 83 percent calcite detritus, with the balance of quartz, chert, and minor feldspar, hornblende, and epidote (table 2, sample 9). Within sand layers, ripple cross-bedding is very common, with foresets dipping up to 25 degrees. These bed forms along with the preservation of abundant, imbricated, soft clay chips imply lower flow regime conditions. The imbricated grains and the orientation of granule- and gravel-filled channels indicate valleyward flow direction. Overall, the beds have the appearance of rapid aggradation rather than erosion. Sets are subparallel, broadly lenticular with very little evidence of deep scour.

The clayey silts tend to be lighter (10YR 8/2d) and more resistant to erosion than the sand. They are usually parallel laminated, with only occasional cross-laminae. Silt beds average 5 to 10 cm in thickness and are laterally continuous over several meters or more.

There is an overall lack of bioturbation, secondary calcification, or molluscs within this facies, although this facies in unit 2 shows some cicada burrowing. Soils are also lacking, an observation that conforms with the overall aggradational mode apparent from the bed boundaries (and thus no hiatuses).

The fining-upward cycles and bed forms argue for deposition by lower flow regime, discontinuous ephemeral streams that once flowed off the low-gradient flat off the adjacent fan surface. The sand-silt

Table 2. Composition of selected sand samples. -- 200 points per sample

r < 5 grains; t < 1%.

Sample Number	% non-$CaCO_3$ in sand Frac.	Composition in %, noncarbonate portion							Provenance
		Quartz	Chert	Biotite	Feldspar	Horne-blende	Epidote	Non-opaque	
4	37	63	7	3	t	t	-	40	Q_{6a} - arroyo fill, A_2
5	19	68	21.9	t	1-3	r	2-3	2-3	Q_{3a}, fine sand, A1
9	27	79	14	t	t	t	r	-	Q_1, fine sand, A1
10	23	62	29	r	t	t	-	-	Q_2, sand, calcareous sand-silt facies, A1
19	27.1	65-70	25-30	1-2	t	t	-	3-5	Qe_1, channel sands, A6
20	34.7	74	10	t	3	t	r	12	Qe_1, mollusc-rich channel sand, A6
30	42.8	65	10	t	t	t	-	20-30	Q_{6e}, coppice dune sand, A5
31	46	62[a]		15	t	t	-	20	Q_{5a}, arroyo fill silt, A6
32	48.8	50[a]		8	1-2	1-2	-	7	Q_{6a}, arroyo fill sandy-silt, A2
35	35.5	83	7	t	t	t	-	32	Q_{5e}, dune sand near Corn Creek Spr.

a. Quartz and chert combined.

facies dips 1–2 degrees, slightly less than the dip on the modern gravelly fan surfaces. The comparative lack of bioturbation and the absence of molluscs suggest that biotic activity in this zone was relatively low. If the sand–silt facies is grouped with that of the calcareous sand–silts, which differ mostly due to secondary calcification, this transitional zone of subaerially deposited fine-grained sediments is roughly 1 km wide. This estimate is based on outcrops around Corn Creek Flat (figure A-1, in appendix), the only place where these facies are continuously exposed.

The calcareous sand–silt facies lies basinward from the sand–silt facies; the boundary is marked by the first occurrence of secondary carbonate nodules. In kind the two facies are similar, both showing the distinctive sand–silt beds. But the calcareous sand–silt units are generally finer grained, grading laterally to exclusively silts and clays. Granule-size clay chip layers so common updip also disappear. Silty sand beds average 1 to 5 cm in thickness and extend 5 to 10 m laterally. They tend to be softer than the clayey silt beds and thus erode differentially. Sands are compositionally similar to those of one sand–silt facies (table 2, sample 10). Parallel laminations predominate; infrequent ripple cross-beds show up to 1.5-cm wavelengths. The clayey silts tend to be whiter (10YR 8/1 to 8/2d) than the sands (10YR 8/3 to 7/3d). They commonly contain impressions of small broken twigs.

Carbonate nodules are widely dispersed throughout the calcareous sand–silt facies. Small finger-shaped nodules pseudomorphic after cicada burrows (fig. 5) and platy nodules found mostly in silt beds predominate in this facies. This preferential distribution of nodules is discussed in detail in the section on carbonates. Here it is sufficient to observe that the nodules are widely dispersed in the proximal portion of the facies, gradually coalescing into ledges basinward. Cicada burrows, both calcified and uncalcified, disrupt large thicknesses of strata at random intervals, suggesting that both the cicada nymphs and the plant roots they feed on must have been common. Burrowing is especially extensive at the top of unit 2 in this facies, a probable relict of the soil 3 pedogenesis that followed the deposition of unit 2. Lack of molluscs, the bioturbation by terrestrial insects, and the sand–silt beds indicate that deposition was subaerial. The carbonate, as will be later argued, probably indicates the presence of a high water table during unit 2 deposition. Cienaga soils increase in frequency toward the basin center, paralleling the trend toward finer sediments in that direction. These incipient soils, however, do not occur with the carbonate such as to suggest a pedogenic association.

The calcareous mudstone facies occupies the basin center. Gritty clay dominates lithologically, and the clays are generally pale olive green (5YR 8/1d to N/8). The clays show strong prismatic structure, from fine to coarse, and tend to weather spheroidally to angular blocky. Sedimentary structures are lacking, except for vague laminations (fig. 9). Bioturbation may account for the lack of structure, because carbonate can sometimes be found pseudormophic after small burrows. Molluscs collected from several localities in this facies indicate marshy areas with seasonal ponds and emergent vegetation (table 3, samples 3, 4, 7, 26).

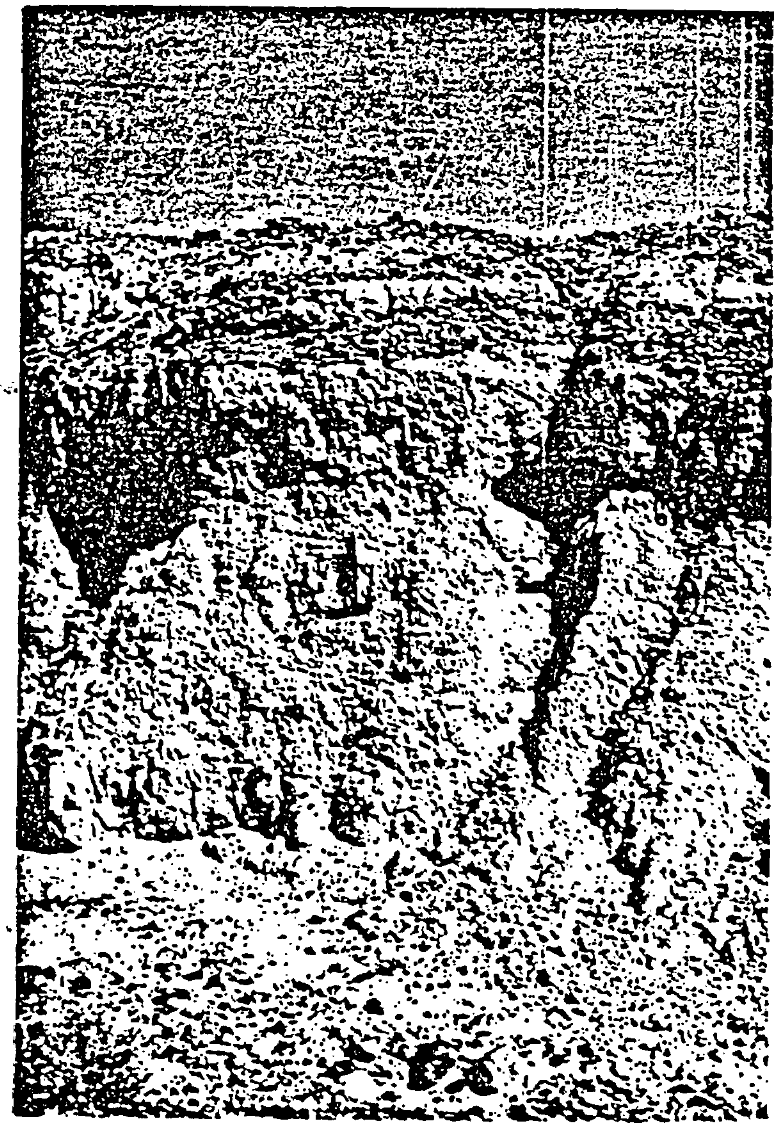


Figure 9. Greenish calcareous mudstones of unit 2 capped by brown silt and gravel of unit 3, -- Soil 3, which normally lies between units 2 and 3, is largely eroded.

Table 3. Ecological interpretation of mollusc assemblages collected from surficial deposits in the Corn Creek area. -- Study done by W. L. Pratt

Sample	Area	Unit	Interpretation
3	A6, green mudstones	E_2	Quiet, well-oxygenated water with emergent vegetation
4	A2, green mudstones	2	Seasonal pond with emergent vegetation at least around edges, marshy areas nearby
5	A2, green mudstones	0	Quiet water with thick vegetation, seasonally dry margins
6	A7, green mudstones	E_2	Marshy area with seasonal ponds and a small flowing stream
7	Indian Springs mudstones	2	Marshy area with seasonal ponds and probably a helocrene spring flow nearby
8	A5, white partings in mudstones	E_2	Marshy area with seasonal ponds and a helocrene spring flow nearby
9	A5, top of mudstones	D	Marshy area without standing water
10	A6, stream gravels	E_2	Permanent well-oxygenated water with vegetated margins and marshy borders along some edges
20	A6, stream gravels	E_2	Flowing stream with some stream action, marshy border
26	A6, green mudstones	D	Permanent, well-oxygenated water and seasonal ponds in areas, but too few specimens for accurate estimate

Whitish (10YR 8/1 to 8/2d) sandy silt layers are also present in unit 2, particularly toward the top. These are soft to slightly hard, massive to finely cross-bedded sand mixed with molluscs fragments. These layers are usually discontinuous laterally but may represent major desiccation events such as those noted by Haynes (1967, p. 27) at the Tule Springs site. Such a record would be in keeping with deposition in very shallow, possibly seasonal ponds. A major white parting, which includes broken molluscs and clay breccia, can often be found along the unit 0—unit 2 contact in area 2. Molluscs collected from a whitish layer at the top of unit 2 in area 5 were interpreted by W. Pratt to indicate marshy conditions without bodies of standing water (table 3, sample 9).

Secondary carbonate is far more common in the calcareous mudstone facies than in any other. Morphology varies from dispersed nodules to semi-continuous or continuous ledges. Different forms are recognized, several of which are found only in this facies. Most prevalent are mottled carbonate nodules of varying shapes and sizes and with no obvious pseudomorphism. These tend to coalesce in up to 0.5-m-thick, erosion-resistant ledges toward the middle of unit 2. Also present are rhizoconcretions after roots and rod nodules possibly pseudomorphic after fallen reeds. See the section on carbonates for a detailed discussion.

Where not eroded, the uppermost portion contains evidence of soil 3 pedogenesis. In most areas this is manifested by no more than a zone of extensive cicada bioturbation. Such burrowing commonly accompanies pedogenesis in the Great Basin, particularly where sagebrush is prevalent (Hugie and Passey, 1963). This occurs between 30 and

100 cm below the surface, usually within the Cca horizon. Erosion subsequent to soil 3 pedogenesis is interpreted to have removed the A, B, and portions of the C horizons.

Area 3 contains a well-developed argillic horizon near the top of unit 2, interpreted to belong to soil 3 (see discussion of area 3). A bioturbated and partially calcified zone underlies it.

Unit 3

Unit 3 is divided into two facies: silty alluvium, 3a, and coarse gravel, 3g. The former is one of the most widespread and easily recognized units in the area. Where continuous sections occur, unit 3a is sandwiched between unit 3g capping gravels and the whiter sediments of unit 2 (all facies). It is distinctly browner, less calcareous, and softer and therefore more erodible than unit 2. As such, unit 3 is generally preserved only under sinuous gravel outcrops of unit 3g (fig. 10), which have protected it from deflation and fluvial erosion. Unit 3a may therefore have been deposited as a more extensive sandy silt sheet then present outcrops of the unit would suggest.

A typical field description of this homogeneous unit follows: very pale brown (10YR 7/4d, 6/3 m) laminated clayey silts in beds up to to to 10 cm thick interlayered with cross-bedded, grayish fine to medium sand; generally lacks coarse sand or gravel except where intercalated with capping unit 3g or along scours on disconformity with unit 2; soft to slightly hard; slightly sticky; slightly plastic; weak platy; violent effervescence but contains no carbonate nodules; carbonate coatings on rootlet and small insect burrow molds; in places thoroughly

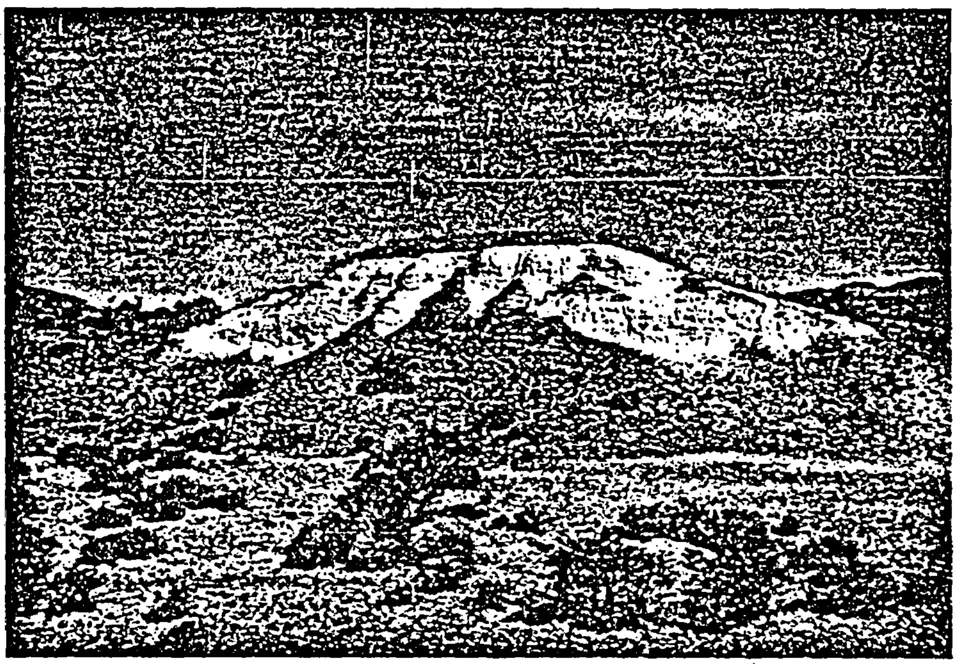


Figure 10. Topographically inverted channel gravels of unit 3g overlying white mudstones of unit 2

disrupted by cicada insect burrowing; sharp, wavy erosional disconformity with unit 2; 1.5 to 2 m thick.

Bioturbation by cicada nymphs is particularly prevalent in unit 3, so much so that sedimentary structures are disrupted over broad exposures. No secondary calcification of these has been observed. Burrowing may be simply from pedogenic overprinting associated with soil 4 (table 4), but the disruption over 2 m of thickness suggests that bioturbation occurred with deposition rather than postdated it.

Unit 3a is compositionally about 80 percent limestone detritus in one sample taken (table 3, sample 5). Opaque secondary carbonate detritus is lacking. The remaining 20 percent of the grains are mostly quartz and chert with trace amounts of biotite, epidote, hornblende, and plagioclase. The quartz detritus, as for all Pleistocene units, has two morphologies: well-rounded grains with remnant overgrowths and euhedral, bipryamidal quartz. The rounded quartz is clearly reworked sand from Paleozoic and Mesozoic formations. The euhedral quarts is both with and without inclusions. The former probably comes from veins or vug fillings. Clear quartz may be from a volcanic source, as are the biotite, hornblende, and feldspars already noted.

Unit 3g gravels typically cap the highest outcrops in the Corn Creek area, at times as much as 6 to 7 m above the modern wash level. The field description for this unit is as follows: Dominantly grayish limestone gravel with very pale brown (10YR 7/3d) silt matrix; gravels imbricated and vaguely cross-bedded; up to fine cobble, mainly limestone, minor chert and quartzite, rounded to subrounded; silty at

Table 4. Soil 4, area 1, relict paleosol

Location: Corn Creek Flat, Clark County, Nevada; 115°25'37" W., 36°26'20" N.
Classification: Typic Calciorthid

Horizon	Depth (cm)	Description
Av	0-3	Very pale brown (10YR 7/3d) loam; slightly hard, slightly sticky, slightly plastic; weak platy, structure stronger downwards, vesicular; violent effervescence; clear wavy boundary
B21ca	3-9	Strong-brown (7.5YR 5/6d) and yellowish-red (5YR 6/6) on pebble undersides; gravelly loamy sand; nonsticky, nonplastic, generally hard due to carbonate cementation; clay skins visible on clast undersides; clear wavy boundary
B22ca	9-15	Same colors as above; sandy gravel; nonsticky, nonplastic, rare clay skins on stones visible; carbonate rinds on stone undersides up to several millimeters in thickness; gradual wavy boundary
B3ca	15-27	Light-brownish-gray (10YR 6/2) gravel; soft, nonsticky, nonplastic; powdery, reddish iron oxide coatings on some rocks; weakly cemented by carbonate with continuous rinds around rocks; gradual irregular boundary
Clca	27+	Light-brownish-gray (10YR 6/2d) small cobble limestone in sparsely sandy matrix; nonsticky, nonsticky; carbonate as powdery coating on stone bottoms
		------------------pit to 80 cm------------------

top, sandier downwards; no secondary carbonate nodules; sharp, wavy boundary with unit 3a where not intercalated.

The narrow, sinuous outcrop pattern of unit 3g suggests that the gravels define paleostream channels. Being less erodible than the underlying fine-grained units, subsequent erosion has left unit 3g gravels in an inverted topographic position. The long narrow outcrops tend to parallel the general trend of the modern drainage. Mountainward, these strips of gravel broaden into a continuous sheet covering the comparatively undissected fan facies. Basinward, the gravels narrow and disappear, either due to nondeposition or Holocene erosion.

On aerial photographs the gravels of unit 3g appear very dark due to the desert varnish present on the nonlimestone clasts on the surface. The desert pavement is smooth and tightly packed (fig. 11), although bars and swales are still evident both texturally and topographically. Limestone clasts are deeply etched, leaving the contained fossil hash in relief. Chert, quartzite, and argillaceous limestone are varnished as darkly as 10YR 3/2 (very dark grayish brown).

Soil 4 is usually developed in the gravels of unit 3g and is associated with this surface. It contains a Stage I to Stage II calcic horizon and a thin cambic horizon constituted of reddish clay coatings over limestone clasts (table 4).

Haynes (1967, p. 45) designated the surface as No. 2 and correlated it with Unit D and also possibly with Unit E at Tule Springs. In the Corn Creek area, however, this surface lies above unit 2, separated from it by soil 3 and unit 3a. See description of stratigraphy of area 5 for a detailed discussion of the age of this surface and unit 3.

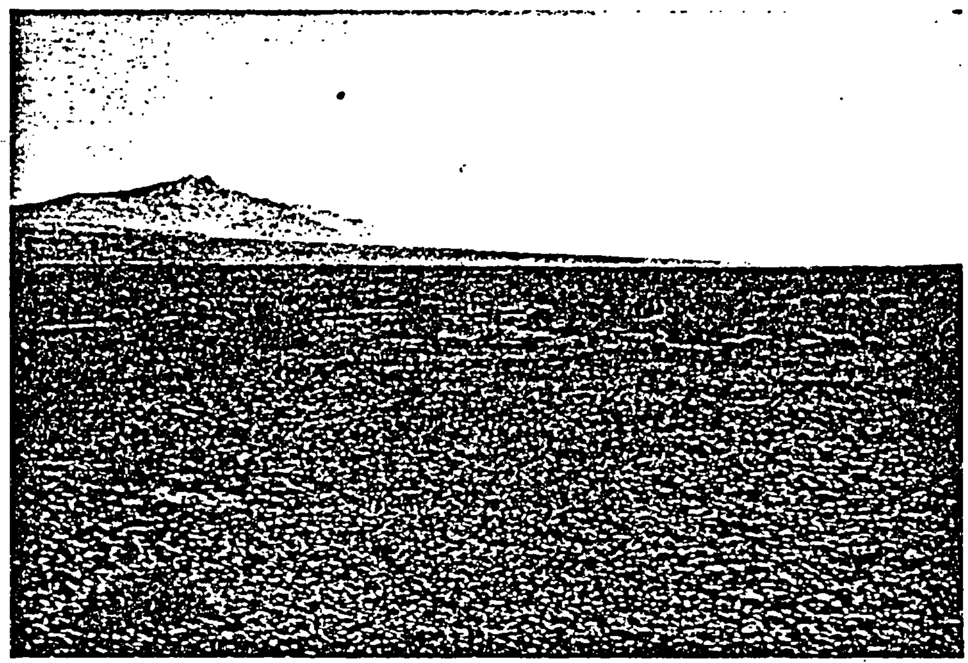


Figure 11. Surface of unit 3g showing desert pavement development associated with soil 4

Unit 4

Two major facies of unit 4 are recognized in the Corn Creek Springs area: black organic-rich clayey silt overlain by brownish, fine sandy silt (Section 9, in appendix). In areas 2 and 7 the black mats assume a bowl shape inset into older strata; this occurs some 2 m below the top of unit 3g in area 2. Although no sandy spring-conduit beds such as those described by Haynes (1967) have been found in association, the shape of the black mats is suggestive of a spring cauldron. They possibly lie in one of several depressions filled by water from a single spring source no longer exposed. Along the lower contact, clay fragments scoured up from older beds are often contained in the silty black mat. The organic mat is generally dark grayish brown (10YR 4/2d) and is a clayey silt at the base grading upward to lighter grays and eventually to soft-brown sandy silt (Section 9, appendix). These sediments probably constitute eolian and fluvial infilling of the formerly vegetated depression after spring desiccation.

The black mats also occur as broad, flat deposits, as in areas 3 and 4. All appear laterally extensive, as does the basin-center black mat of area [illegible], up to several tens of meters or more. Carbonate, ranging from isolated nodules to continuous travertine ledges, is often found in association, as are green clays. Travertine is particularly common in the vicinity of Corn Creek Station (area 4) in association with fault-controlled(?) spring deposits. Petrographically, the travertine is brownish, semi-opaque, micritic calcite cementing clay and silt. The presence of vague silt-size spheres indicates possible algal activity.

Round tubes about 2 cm in diameter and projecting perpendicular to the ground surface from the travertine may be molds of sedges or tules.

It should be noted that Haynes (1981, personal communication) disagreed with the interpretation that the massive carbonate described above is travertine, noting that it lacks the layering commonly seen in travertines. He continued to ascribe it to Unit D (unit 2) in which massive carbonate ledges are quite common on Corn Creek Flat.

Unit 5

Unit 5 includes a varied array of post-Pleistocene deposits. On the valley margins, unit 5 is made up of brown silt (unit 5a) and gravel (unit 5g) accumulated as terrace fill. Within several of the larger drainages and deep incisions into Pleistocene strata, as many as three distinct cut or fill terraces occur at least several meters below unit 3g, but well above the modern wash level. Toward the basin center, older Pleistocene units are buried under a sheet of unit 5a silt. Unit 5g gravels are topographically inverted, but to a lesser extent than unit 3g. The gravel ridges are usually narrow and sinuous and parallel modern drainage. Unit 5e includes inactive dune sands in the Corn Creek Station area, where contained hearths dated by Haynes fall near the age obtained on unit 5a in this study.

Several other objective criteria aside from topographic position distinguish unit 5a/g/e from older units. These include:

1. The presence of detritus derived from carbonate nodules, both in the gravels and in the finer fraction. Grain counts show that such

detritus constitutes up to 30 percent of the total. Gravels in the valley center contain up to 50 percent reworked carbonate.

2. Low total carbonate (limestone and secondary carbonate detritus) percentage. Units 5a/e and 6a/e (recent) range from 35 to 50.6 percent noncarbonate, whereas the Pleistocene units range from 19 to 27 percent noncarbonate by weight (table 2).

3. High biotite content in units 5a/e and 6a/e, in one sample up to 15 percent of the grains counted.

4. Lack of secondary calcification except that due to soil 5 pedogenesis. Sedimentary structures are as a consequence well preserved.

Because no representative stratigraphic profile is given for unit 5a in the appendix, one is included here: Sandy silt; very pale brown (10YR 7/3d); sandy silt with occasional cleaner calcitic sands; cross- and parallel-laminated but no sharp distinction between sand and silt beds; soft to slightly hard, sticky and plastic; no secondary carbonate except as rootlet molds; no molluscs or bioturbation. Thickness at least 2 m.

Soil 5 is preserved atop the already-mentioned inverted gravels on inset terraces and above the brown silts that infilled the desiccated springs. The soil presented in table 5 is developed on a gravelly parent material; the calcic horizon is Stage I to Stage II by the Gile and others (1966) classification.

Unit 6

Unit 6 is qualitatively identical to unit 5, containing all the same facies, implying that the depositional setting for both was similar.

Table 5. Soil 5, area 1

Location: Corn Creek Flat, Clark County, Nevada; 115°25'32" W., 36°26'18" N.
Classification: Typic Calciorthid

Horizon	Depth (cm)	Description
Av	0-2	Very pale brown (10YR 8/3d, 6/4m) silt loam; slightly hard, sticky, slightly plastic; weak, thick platy; vesicular; calcareous; clear wavy boundary
B2ca	2-3	Very pale brown (10YR 8/3d) gravelly sandy loam; slightly hard, nonsticky, nonplastic; oxidized mottles and coatings on tops of stones, reddish yellow (7.5YR 6/6d); discontinuous powder coatings of carbonate on stones; clear wavy boundary
C1ca	3-40	Very pale brown (10YR 7/3d, 7/4m) gravelly sand; soft to slightly hard, nonsticky, nonplastic; up to 60 percent by volume gravel; carbonate coating on stone undersides; gradual irregular boundary
IIC2ca	40-70+	Grayish limestone gravel with minor chert and quartz; discontinuous carbonate coatings on clasts, diminishing downward; gravel imbricated and in grain-to-grain contact

Surface: On inset fill terrace, 6 m below unit 3g capping gravels and 2.8 m above modern wash. Bar-and-swale topography well preserved; gravels in swales packed into moderately tight desert pavement. Moderate varnishing and etching of stones with some reddening of stone undersides.

Petrographic analysis of unit 6 sands is presented in table 2. Unit 6a/b includes only the most recent deposits, ones immediately adjacent or bottoming the modern washes. Unit 6e includes large and small coppice dunes in the Corn Creek dune field and along vegetated ridges in the basin center. No dates have been obtained from unit 6a.

Soil 6 is the incipient soil developed atop unit 6 in all its manifestations. The profile presented in table 6 is the maximum development usually seen for this soil. The profile was taken on fine-grained arroyo fill roughly 1.5 m above the modern wash level.

Table 6. Soil 6, area 2

Location: Corn Creek Flat, Clark County, Nevada; 115°26'10" W., 36°28'50" N.
Classification: Typic Torrifluvent

Horizon	Depth (cm)	Description
$A1_{ca}$	0-1	Very pale brown (10YR 7/3) sandy silt; weak platy surface crusts; soft, slightly sticky, slightly plastic; strongly effervescence; split by desiccation cracks; clear wavy boundary
$A3_{ea}$	1-3	Very pale brown (10YR 7/3d) clay loam; moderate, medium platy; slightly hard, sticky, plastic; dispersed, dark-gray organic matter; clear smooth boundary
C_{ca}	3+	Very pale brown (10YR 7/3) clay loam; weak, medium subangular blocky breaking to a fine crumb; soft to slightly hard, stocky, plastic; fine laminations and cross-beds preserved; layers of calcareous but no visible carbonate

STRATIGRAPHY OF AREAS

The study area was divided into eight separate portions. The first seven cover Corn Creek Flat and south; the eighth encompasses Cactus Springs and Indian Springs. See figure 2 for the precise locations.

Area 1

Area 1 contains the most extensive outcrops of Pleistocene strata in the study area. The section is nearly complete here (fig. 12), and most of the facies of units 0 and 2 can be easily seen.

The limits of modern erosion are in part controlled by the varied lithologies of the Pleistocene strata. Ten to 12 m of downcutting has occurred in the soft, noncalcareous sand-silt facies of units 0, 1, and 2. In the adjacent sand-gravel facies, incision decreases abruptly and the wash gradients steepen. This probably due to the coarseness of this facies and to the relatively low competence of the dissecting ephemeral streams that flow from the bajada surfaces.

Dissection also decreases basinward from the sand-silt facies. This must be due in part to the extensive carbonate litter that armors most of the outcrops in the basin center. The carbonate nodules come in all descriptions, accumulated as lag after deflation and fluvial erosion removed from the softer host sediments. Widespread deflation is evident in the broad flats of badlands littered with only wind-faceted carbonate rubble standing up to several centimeters in relief above the

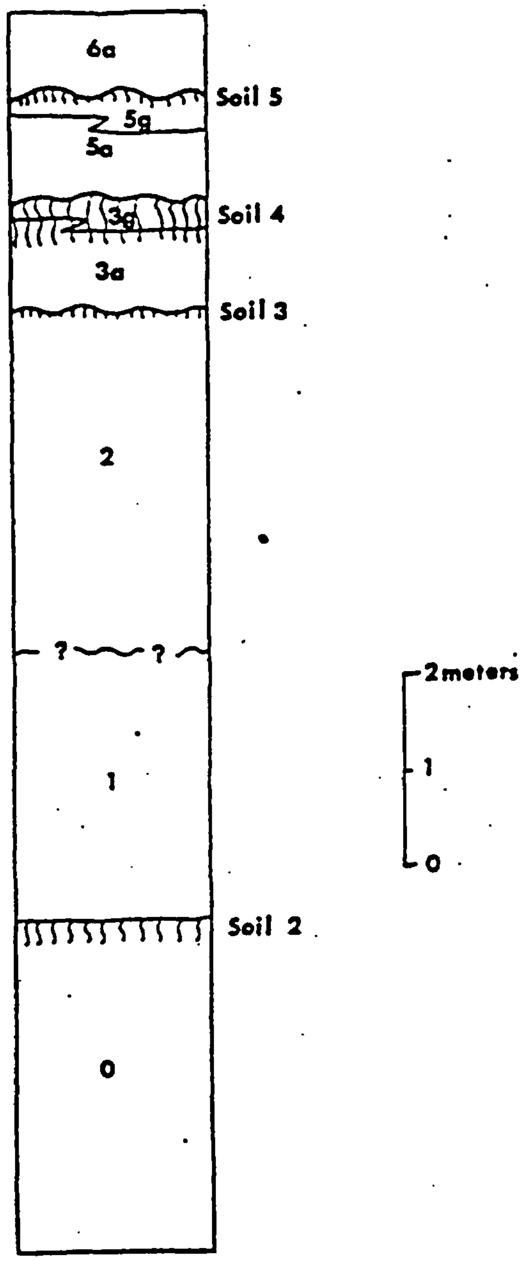


Figure 12. Stratigraphic column, area 1

surface. These surfaces, which often lack any trace of fluvial erosion, are generally developed on carbonate ledges that first appear in the middle of unit 2. Most outcrops are eroded to this level toward the basin center.

Unit 3g gravels underlain by unit 3a silts stand as erosion outliers throughout area 1 (fig. 10). The outlier caps appear to correlate with dark surfaces covering the sand-gravel facies fringing the dissected badlands. On aerial photographs, unit 3g outcrops delineate sinuous paleochannels and broader gravel splays that encroached over the area at the end of the Pleistocene or beginning of the Holocene. The paleochannels parallel modern stream courses, suggesting that the drainage configuration during unit 3g deposition was similar to that of today. Paleocurrent directions of all units in area 1 are approximately southwesterly.

Unit 0 and soil 2 have limited exposure, as shown in profile 1 across the area. Soil 2 (fig. 7) is thoroughly churned by cicada burrowing, whereas in unit 1 burrowing is only dispersed. Within the sand-silt facies, units 0, 1, and 2 are difficult to distinguish and are not always separated by sharp disconformities. However, toward the middle of the basin, unit 2 is distinctly whiter and more calcareous than other units. Soil 3 is represented by a remnant calcic horizon and by a marked increase in cicada burrowing toward the top of unit 2. Only the lowest portion of the pedon is therefore preserved.

The inferences about the capillary fringe origin of carbonate are based largely on observations made in this area. In all other areas, except area 7, the sand-silt facies has been eroded. As such, the lateral variation in carbonate cementation cannot be fully appreciated in other than area 1.

Toward the basin center, outcrop heights gradually decrease until Pleistocene sediments are buried under an undetermined thickness of Holocene fill. The gradients of modern washes are slightly less than the dip of Pleistocene strata, except for the sand–gravel facies where the reverse is true. The Holocene fill is dotted by gravel-capped erosion remnants (unit 5g) standing as much as 2 m above the adjacent fine-grained fill (unit 5a). These gravels are fresher than those of unit 3g, and they contain stream-rounded carbonate nodules, suggesting that they were deposited after erosion of the calcareous Pleistocene deposits on the flat margins had begun. It is not clear how these gravel outliers correlate with the numerous cut-and-fill terraces that border the larger washes passing through the dissected badlands. At least three such distinct Holocene terrace fills are evident, all grouped under unit 5a/g.

Area 2

The complete Pleistocene section is exposed in area 2, including several unit 4 spring mats (fig. 13). Erosion has removed the sand–silt facies of units 0 and 2, but shallow exposure of the other facies occur in several of the washes (fig. 14). One of these wash exposures is depicted in figure A-2 (appendix). Unit 0 has tentatively been identified as those sediments capped by a moderately developed soil shown in figure 14. Unit 3a/g stands as erosional remnants in the manner described for area 1.

controlled phreatic environment by evaporation and evasion of CO_2 off of a capillary fringe. He noted that cement in the vadose zone tends to be more pendular or asymmetrical, which does not appear to be the case with carbonate here.

Genesis of Secondary Carbonate

Haynes (1967) recognized several possible sources for the dense carbonate in Unit D (unit 2). Some carbonate may have been precipitated in the bottom muds of shrinking lakes near the end of Unit D deposition (Haynes, 1967, pp. 32, 78). Amorphous nodules of dolomitic composition found in Unit D are interpreted to reflect this process. Carbonate may also have been precipitated off a capillary fringe (Haynes, 1981, personal communication) (fig. 33). Some cementation in the upper 30 cm of Unit D was interpreted to be the result of S_4 pedogenesis (Haynes, 1967, p. 32).

The nodular carbonate in both study areas is a mixture of sand, silt, and clay detritus (usually 70 percent by weight of the entire nodule) cemented by micritic calcite. In this respect it is like many lacustrine marls. Where not recemented, however, marls are generally soft and are found in rather uniform, massive beds. In contrast, the carbonate in this area occurs as hard, dispersed to nearly coalesced nodules often displaying pseudomorphism. This clearly suggests that the carbonate is largely if not completely secondary cementation rather than a primary precipitate from a lake.

The carbonate does not appear to be pedogenic either, except where found in proximity with other soil horizons (or with

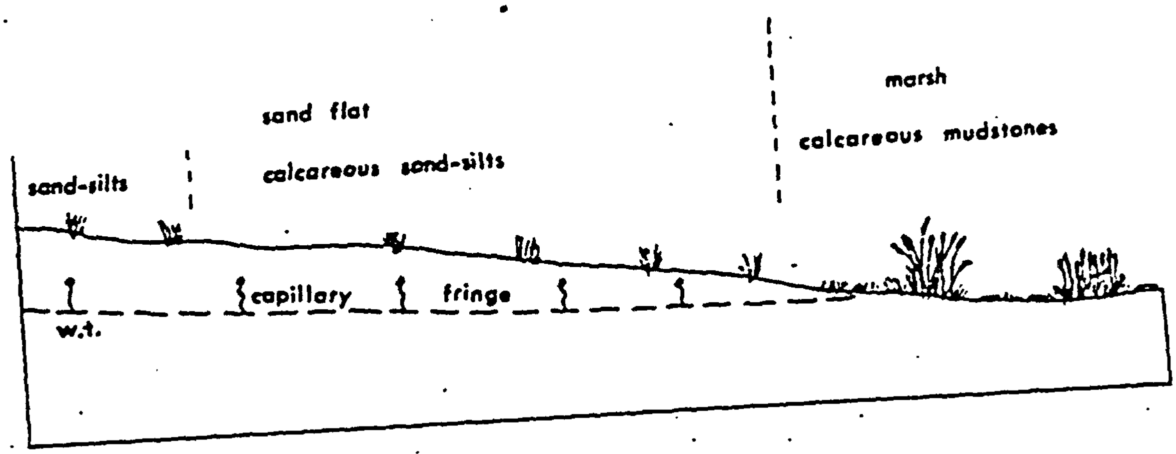


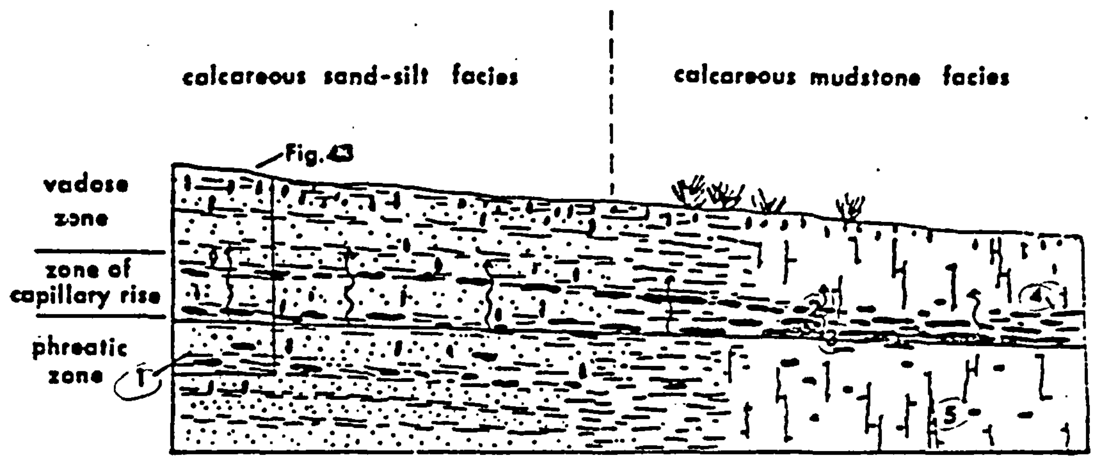
Figure 33. Relationship of sedimentary facies to emergent water table in Unit D time

disconformities, suggesting the erosion of them). Carbonate of the basin-margin facies is dispersed over meters of thickness rather than concentrated in discrete layers. The numerous and mature A and B horizons one would expect with such a distribution are lacking. As noted before, microscopically the carbonate appears to be nonpedogenic. Toward the basin center, prominent ledges of carbonate of units 0 and 2 have no associated B horizon (where the section is extant under unit 3). Although erosion and the formation of soil 3 are inferred to have followed the deposition of unit 2, accumulation of this large volume of carbonate cannot be reasonably accounted for in such a short span by normal pedogenesis. Haynes's (1967) data indicate a hiatus of at most 7,000 years (20,000 to 13,000 years B.P.) between Units D (unit 2) and E_1 (unit 3?). Some of the cementation in Unit D (unit 2), however, may be attributed, as Haynes suggested, to pedogenic overprinting.

Several lines of evidence point to a capillary fringe origin for the carbonate. First is its megascopic distribution. The occurrence of nodular carbonate within the lateral facies is bounded by a distinct and smooth upper limit. This boundary dips slightly less toward the basin center than does the host strata. Thus the carbonate boundary crosscuts stratigraphic boundaries (fig. A-1, in appendix). In the lateral facies on area 1, carbonate first appears in unit 0, whereas basinward it is found at about the middle of unit 2. Carbonate was therefore being precipitated during and probably after unit 2 time, not as a primary precipitate but by secondary overprinting that crosscut several stratigraphic boundaries. This distribution follows the pattern expected of a paleowater table, one several meters below the surface in the marginal fine-grained facies and one alternately emergent and subsurficial toward the basin center (figs. 33 and 34). In map view, the line defining the outermost occurrence of secondary carbonate is very regular where strata are well exposed, as in area 1.

A closer view of the carbonate tends to support this interpretation. In vertical exposures, the degree of cementation is distinctly zoned in all facies, although the zonation is most obvious in the calcareous sand–silts. In unit 0 and lower unit 2, platy carbonate and cicada burrow nodules are dense and well cemented. In the transition zone above (fig. 35), cementation decreases. Nodules are crushable with the hands but still erode from the outcrop in distinct forms. At the top of the transition zone, only the exteriors of cicada burrows are cemented, showing that cementation proceeded from the outside inward. Secondary nodules disappear near the top of unit 2, although all the primary forms and structures they mimicked below persist. Hard cicada nodules in a thoroughly bioturbated zone at the very top of unit 2 are interpreted, based on their position rather than morphology, to belong to the C horizon of S_3. Figures 33, 34, and 35 show the proposed relationship of the cementation zones to the position of the water table. The well-cemented zone is seen to have been closest to the water table. Cementation decreases upward as capillary moisture probably once did.

Semeniuk and Meagher (1980) described a similar pattern of cementation off of a capillary fringe in coastal southwestern Australia. Carbonate in that area was precipitated in a variety of forms in sands within a 1.5-m capillary zone above the water table. Varieties included rhizoconcretionary, mottled, massive, laminary, and breccioid. The



Explanation

1. Mixed platy and cicada nodules.
2. Mottled carbonate, in places showing overprint of pedogenic carbonate.
3. Massive ledges of carbonate grading updip into semi-continuous ledges in the sand-silt facies.
4. Recumbent rod nodules, possibly molds of fallen reed.
5. Dispersed carbonate in both units 0 and 2 resulting from probably older water table lows.

Figure 34. Carbonate morphologies in relation to a lowered water table during and after Unit D time

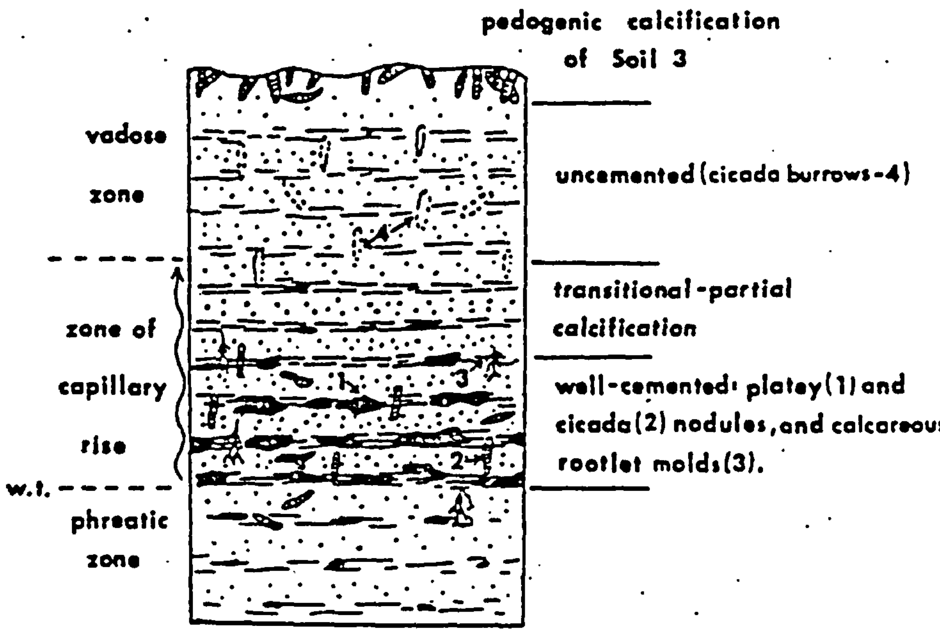


Figure 35. Zones of carbonate cementation and their postulated positions relative to the capillary fringe and water table. -- Capillary draw of solutions saturated with Ca^{+} and HCO_3^{-} may have been from sandier conduit beds toward silt layers, burrows, and rootlet canals.

carbonate morphologies seen in the calcareous mudstones best match the Australian forms, except for the absence of late-stage laminar carbonate developed on massive ledges in the Corn Creek mudstones. In the Australian example, seasonal fluctuations of the water table tended to distribute the carbonate over a broad vertical exposure. Short-term fluctuations like this, as well as longer term ones, may account for the wide vertical dispersal of carbonate in the Corn Creek area. A substantial portion of the dense ledges in the calcareous mudstones of unit 2 may have been precipitated not when the bodies of standing water were present but only after the final lowering of the water table in post-unit 2 time.

Hunt (1966, p. 87) noted the presence of carbonate nodules in perched gravels and in fine-grained strata on the edge of a Death Valley playa 1.5 to 2 m above the present capillary fringe. From this he inferred the former presence of a water table at that height.

Sedimentary textures and degree of induration exercised some control on the distribution of carbonate nodules in a pattern befitting secondary cementation by migrating ground water. In the sand-silt and calcareous sand-silt facies, segregated sand and silt occur in 5- to 10-cm intervals. The smaller pore size in the silt beds set up a stronger capillary draw than did the coarser sand. The sands probably served as conduit beds to ascending solutions saturated with Ca^{+2} and HCO^{-}. These were drawn toward the silts and then were evaporated or CO_2 lost or both. Carbonate precipitated at nucleation centers set up at various intervals along the continuous silts. Not all silt beds are cemented, and carbonate where it does occur in the lateral facies rarely extends more than several meters laterally. Platy nodules sometimes protrude into adjacent sand beds.

Preferential cementation of cicada burrows and other forms can be similarly explained. Uncalcified burrows are usually harder and more tightly packed than the surrounding undisturbed strata. Such a packing differential would, as in the case of the sand-silts, cause solutions to be drawn toward the smaller pores of the burrow sediment. The disrupted margins of the burrow may have served as conduits to passing solution, as did the inner tube of the rod nodules. Perching would then have occurred in the adjacent fine-grained or tightly packed sediments. Patterson (1967) reported a similar affinity of cement-bearing solutions for fine-grained beds.

Within more homogeneous sediments such as the calcareous mudstones, the distribution of carbonate is less patterned. Mottled carbonate can be randomly dispersed or arranged into distinct beds and semi-continuous ledges. The lack of internal structure in these nodules reflects the bioturbated condition of the calcareous mudstones.