Soil Development, Spatial Variability and the age of the Highest Late Pleistocene Lake Lahontan Shorelines, Northwestern Nevada and Northeastern California.

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Introduction

Over the last 1 Ma, the Lake Lahontan basin has been the locus of at least five major lake cycles (Morrison, 1991; Reheis, 1996, this volume). Although many researchers have studied the deposits and lacustrine landforms of the Basin, there has been little agreement as to the age of the highest shoreline features. The debate centers around whether the high shoreline dates from the most recent cycle (Sehoo period) at about 12.7 ka or from the penultimate lake cycle (Eetza period) at about 130 - 350 ka.

I.C. Russell (1885), who accomplished the seminal work on Lake Lahontan, maintained that the uppermost shoreline, which he termed the Lahontan Beach, dated from the most recent lake cycle. Jones (1925) and Antevs (1925) agreed with this interpretation. However, Morrison (1964; 1991) claims that the highest shoreline in the southern Carson Desert area dates from Eetza time. More specifically, Morrison (1991) supports that the high shoreline there dates from the middle Eetza highstand which he estimates to be about 280 ka. This is in contrast to the Pyramid Lake subbasin where Benson (1993) has interpreted features related to the high shoreline to date from ~13.5 ka, or the Sehoo highstand. Based on key soil exposures in the northern subbasins, Mifflin and Wheat (1971, 1979) postulated that the age of the highest shoreline in the northern part of the Basin dated from Sehoo-time whereas the age of the highest shoreline in the southern part of the Basin dated from Eetza-time. They called upon regional, down to the north tilting during the Eetza-Sehoo interpluvial period to explain this relationship.

Determination of the age of the highest shoreline from throughout the Lahontan Basin is important in light of our current effort to determine the isostatic rebound of the Basin resulting from the desiccation of the most recent highstand lake (Adams and Wesnousky, 1994). In order to do this, we needed to be reasonably sure that we were measuring the elevations of the highest constructional shore features dating from the Sehoo lake cycle throughout the Basin. Therefore, we adopted a somewhat simple strategy for determining the age of the high shoreline. We have employed both numerical and relative age-dating techniques to date particular constructional high shoreline features and their associated soils. We then correlated the soil development of these features to other undated high shoreline localities (Adams and Wesnousky, 1995; 1996). For comparison of relative soil development, we have also described a number of paleosols related to pre-Sehoo lake cycles to further test our conclusions about the age of the high shoreline.

Pre-Sehoo pluvial lake deposits and landforms residing well above the Sehoo limit have long been recognized in the Walker Lake subbasin (e.g. Russell, 1885; King, 1993). Marith Reheis is currently studying these features and deposits (see Reheis, 1996, this volume) and has identified some super-elevated lacustrine deposits in the northern subbasins of Lake Lahontan. We recognize that the existence of earlier Pleistocene lacustrine deposits above the late Pleistocene limit complicates our task somewhat and muddles our definition of "highstand". However, we emphasize that the late Pleistocene deposits and landforms are readily distinguishable both in the field and on aerial photographs in terms of better development, continuity and preservation. Therefore, when we use the term "highstand" we are speaking of the readily identifiable upper limit of prominent shorelines found throughout the Basin which were likely formed in the last (Sehoo period) or penultimate (Eetza period) lake cycles.

Methods

The relative development of 27 soil profiles located on high shorelines from throughout the Basin were compared in order to test the hypothesis that the high shoreline of Lake Lahontan dates from more than one lake cycle (Figure 1). Seven additional profiles developed on regressive barriers post-dating the Sehoo highstand at 12.7 ka but older than about 11 ka were also used for comparison. To assess the degree of development of demonstrably pre-Sehoo soils and to compare these to the highstand soils we described and sampled seven more profiles located from descriptions in the literature (i.e. Morrison, 1991; Morrison and Davis, 1984) and from our own travels in the Basin (Figure 1).

Field descriptions of soil profiles included color, texture, structure, consistence, reaction to dilute HCL, root distribution, and the presence and character of clay films and pores. The surficial geology of each site was also described in terms of 1) the type of beach feature in which the soil developed, 2) lithology, rounding and sorting of clasts on surface and at depth, 3) development of desert pavement and rock varnish, 4) degree of dissection or other surficial modifications, 5) aspect, 6) slope, 7) vegetation, 8) amplitude of beach feature and, 9) direction of net shore drift. In general, soil pits were excavated on the flat or gently sloping (< 1°) crests of constructional beach features such as spits, barriers and tombolos. Constructional beach features are ideal locations to examine soil development due to their relative stability resulting from their positive relief with respect to the surrounding landscape.

The paleosols used in this study for comparison with the highstand soils were formed on deposits of diverse sedimentary environments (i.e. multiple parent materials) and may not date from the same period. The two paleosol profiles at Wadsworth Amphitheater and Rye Patch Dam (Figure 1) were located from the literature and are developed in fluvial deposits of the Wyemaha Alloformation (AF) which post dates the Eetza AF, but predates the Sehoo AF (Morrison, 1991; Morrison and Davis, 1984). Considering that the last highstand of the Eetza lake cycle was at about 130 ka (Morrison, 1991) and that the Sehoo lake did not begin to rise until approximately 30 ka (Benson et al, 1995), sediments mapped as the Wyemaha AF in different areas may have been deposited over the span of as much as 100,000 years. Consequently, soils developed on these deposits may differ by tens of thousands of years. In addition, the Wyemaha AF in the Wadsworth Amphitheater consists of coarse sand and gravel, whereas the Wyemaha AF at Rye Patch Dam predominately consists of well-sorted fine to medium sand. Thus, the variation in parent materials may also have contributed to the differences in soil development at this site.

The two pre-Sehoo surface soils described at the Thorne Bar on the southeast side of Walker Lake (Figure 1) are developed in coarse clastic beach deposits, but their absolute age is unknown. The paleosol at Jessup is developed in coarse clastic beach deposits and is overlain by Sehoo shore deposits. The two remaining paleosols, in Quinn River Valley and at Grimes Canyon (Figure 1) are also both developed in coarse clastic beach deposits and are buried by 2 and 9 m of highstand beach deposits, respectively. These last two paleosols are the best developed of all the soils described in this study.

The ages of thirteen of the profiles used in this comparison are known or can be closely approximated. The highstand barrier that fronts the Jessup Playette dates from about 12.7 ka (Adams and Wesnousky, 1996a, this volume). We described and analyzed five separate profiles across the barrier and into the playette as well as two additional profiles from a separate soil pit on the crest of the barrier (Figure 2). The three profiles described in the trench across the crest of the Jessup Playette barrier serve as a micro-catena with which to assess the influence of topographic position on soil development on a single-age surface. Seven additional soil profiles were described on four regressive barriers which postdate the Sehoo highstand but are probably older than about 11 ka (Figure 3) (Curry, 1988; Benson et al, 1992). Soils were described on these regressive barriers to determine whether or not there was a systematic change in the degree of soil development on progressively younger and lower barriers. We also obtained a ^{36}Cl surface exposure age of $\leq$ 15 ka (Fred Phillips, 1995, written comm.) and soils data for a highstand feature in the Lahontan Mountains (Figure 1 and Table 3, Site F-19) that Morrison (1964) had mapped as part of the Eetza AF.

In addition to field descriptions of all 41 soil profiles compared in this study, particle size analyses were conducted for eight highstand profiles, seven regressive Sehoo profiles, two Churchill profiles and two profiles developed on the Holocene-age surface of Jessup playette. Particle size analyses for the remaining twenty eight profiles are still pending.

Results

The results section is organized in the following manner: first, descriptions and particle size analyses for soils from the Jessup Playette and its associated barrier are presented in Table 1. Next, soils data for regressive barriers in the Jessup Embayment are presented in Table 2. Third, soils data for highstand soils from around the Lahontan basin are presented in Table 3 and last, soils data for pre-Sehoo soils are presented in Table 4. Interpretations and correlations are presented in the Discussion section.

Discussion

Due to natural variations in soil development factors, each soil profile in this study is different. However, in a gross sense we submit that the soils described in this study can be separated into two main groups. The first group encompasses all of the soils developed on highstand features throughout the Basin and the soils developed on regressive Sehoo barriers in the Jessup Embayment (Figure 1; Tables 1, 2 and 3). We interpret these soils to have developed on highstand and regressive features formed during the Sehoo Lake cycle which reached its highstand at about 12.7 ka (Adams and Wesnousky, 1996a, this volume). The second group encompasses all of the soils that are demonstrably older than the Sehoo Lake cycle. As stated in the methods section these older soils are not necessarily the same age.

There is a certain amount of variability in terms of soil properties within each major group of soils. Considering that Jenny (1941) defined five factors which influence soil development, variability between profiles is to be expected even if they are the same age, because time is just one of the five soil forming factors. The other four factors are topography or relief, parent material, organisms (both plant and animal) and climate (Jenny, 1941). Each of these five factors can significantly influence soil development and will be discussed in terms of how they might be responsible for the spatial variability observed in the Sehoo-age soils.

In this study, soil profiles from the late Pleistocene high shoreline were all examined on the crests of constructional features such as spits, barriers and tombolos. Hence, all of the sites tend to be well-drained and have deep ground water. Most of the features are composed of coarse clastic beach material, but some are composed primarily of sand with minor amounts of gravel. The difference in size and sorting of parent material can influence depth of wetting and water retention which in turn can influence the type and density of vegetation found on a particular landform.

Coarse clastic beach features are different than adjacent contemporaneous alluvial fans in terms of initial character and particle size distribution, hence soil development also differs. Alluvial fans are commonly poorly sorted with grain sizes ranging from clay through boulders (Blair and McPherson, 1994). However, in the Lahontan basin, beach features tend to be composed of well-sorted, clast-supported, coarse clastic sediment with more or less sand forming a matrix between the larger clasts. Tables 1 and 2 show the particle size distributions for eleven C horizons from barriers in the Jessup Embayment that appear to be dominated by sand. However the particle size distributions only reflect the < 2 mm size fraction (fine earth fraction). In actuality, the majority of C horizons (excluding Lower barrier 4 and the two Playette profiles) are composed of greater than 90% gravel and cobbles, with the fine earth fraction accounting for <10% of the total volume of material. When considering the silt and clay sized fractions in comparison to the total particle size distributions of the C horizons, only a very small percentage (< 1) is comprised of clay and silt (Tables 1 and 2).

It has long been recognized that the addition of eolian dust significantly influences soil development in many different climatic regimes (Yaalon and Ganor, 1973; Peterson., 1980; Machette, 1985; McFadden and Weldon, 1987). In semiarid and arid areas, eolian dust influx constitutes a major soil forming process (Reheis et al, 1995). The late Pleistocene soils developed on Sehoo-age features are no exception.

The A and B horizons of the highstand profiles as well as the regressive Jessup profiles contain considerable amounts of fine sand, silt and clay (Tables 1, 2 and 3). There is little evidence of clast weathering in these profiles, therefore we concur with the conclusions of Chadwick and Davis (1990) that virtually all of the fine earth fraction contained in the vesicular A horizons, and most in the underlying B horizons, came from atmospheric sources. Additional evidence in support of an eolian source for the fines includes the common, discontinuous loess blankets that are found on many beach features, especially around the bases of bushes. Chadwick and Davis (1990) introduced the idea that rapid soil formation resulted from temporally limited eolian pulses that they associated with desiccation of the Lake. They also postulated that the degree of soil development has a positive correlation with the amount of upwind playa surface. This idea is exemplified by observations within the Carson Sink where huge plumes of dust are blown north from the surface during spring wind storms. Soils developed on the north side of the Carson Sink are better developed than soils on the south (downwind) side (Chadwick and Davis, 1990).

The amount of calcium carbonate accumulation in soils is commonly used as a relative age indicator (Gile et al, 1966; Machette, 1985). This approach assumes that most of the carbonate is introduced by the addition of calcareous dust. The commonly calcareous Av horizons in the Lahontan basin support this idea. However, when examining soils developed in Lahontan beach gravel, the amount of carbonate present is not a reliable indicator of age. The waters of Lake Lahontan contained a great deal of dissolved carbonate, as evidenced by the amount of tufa and cemented beach rock within the Basin. In stream cuts and artificial exposures, tufa or carbonate coated clasts often extend many meters into the deposit. In the soil forming zone, carbonate is often preferentially concentrated on the undersides of clasts, indicating that the carbonate is affected by soil forming processes. Because much of the carbonate was already present in the parent material (beach gravel) and not due to the slow addition of calcareous dust, the amount of carbonate in a soil profile should not be used to estimate the age of the soil.

Soil development on highstand and regressive barriers in the Lahontan basin is greatly influenced by bioturbation, primarily in the form of rodent burrowing. This effect is readily seen in the Jessup Playette trench (Figure 2) where soil development across the crest of the barrier seems to closely track the depth of rodent burrowing. Near the southeast end of the trench there is a zone of coarse (≤ 25 cm) disc-shaped cobbles that appear to have limited the depth of rodent burrowing. Consequently the profile developed in this area is relatively thin.

The location and density of plants also influences soil development, at least indirectly. Surface vegetation acts as a surface roughness element by trapping eolian material around the bases of plants. Rodents often burrow near the bases of bushes thereby increasing the amount of fines mixed into the profile beneath the bushes. Salt brush is a common constituent of vegetation communities growing on beach features. Peterson (1980) reports that sodium-influenced soils can rapidly develop Bt and even argillic horizons. The concentration of sodium in the leaves of these salt bushes may influence the rate of clay translocation directly beneath the plant. As the plant continues to grow and drop leaves on the ground beneath it, the sodium in these leaves may be incorporated back into the soil causing a local increase in the rate of clay translocation. Evidence for this process is seen where Bt horizons locally thicken beneath individual bushes. As discussed above, variation in the thickness of the Bt horizon may also be due to rodent burrowing.

The high shoreline of Lake Lahontan extends through about 3° of both latitude and longitude. As a result, there are climatic gradients within the Basin which have probably affected soil development. However, we do not yet have a clear understanding of how these gradients have changed through time or what their influence has been on soil development.

Pre-Sehoo Soils

The demonstrably older than Sehoo soils described in this study are all better developed than the Sehoo surface soils. The two best developed profiles are those at Grimes Canyon and in Quinn River Valley (Figure 1, Table 4). These soils are developed in coarse clastic barrier gravels, much like the younger surface soils. However, their thickness, amount of clay accumulation, structural grade, consistency and color all indicate that these soils represent development over a much longer period of time than do the surface soils. If these older soils are developed on Eetza deposits then they may be as old as 140 ka or 280 ka (Morrison, 1991). Considering the ubiquitous influence of dust on the younger surface soils, it is not unreasonable to consider that the older soils were also greatly influenced by the introduction of dust. However, once the dust was incorporated into the older profiles it may have had time to chemically weather and dramatically change the character of the soils.

The two pre-Sehoo surface profiles at the Thorne Bar (Figure 1) are apparently not as well-developed as some of the other paleosols (Table 4). However, it is possible that these soils have been somewhat stripped. The original morphology of the landforms is still present, but appears somewhat muted.

Conclusions

The soil correlations made in this study imply that the highstand barriers found throughout the Lake Lahontan basin date from the Sehoo lake cycle. This is in contrast to the conclusions of Morrison (1964; 1991) regarding the age of the highstand in the southern Carson Sink. Soil formation on Sehoo-age beach features is largely a product of the introduction of dust into generally coarse clastic deposits. Spatial variability in soil development appears to be influenced by bioturbation and also the distribution of vegetation. Spatial variability due to the proximity of the profile to dust sources (i.e. playas) is still under investigation.

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Table 1. Soil Data From the Jessup Playette and High Barrier.

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			$CaCO_3$, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
Trench Profiles																
JPT Profile 1																
Av	0	5	10YR 7/3	10YR 5/4	SCL	32.3	47.6	20.1	1CPR, 2MGR	lo,sh	fi	vs, p	es	2vf,fv	1f	aw
2Bw	5	15	10YR 6/4	10YR 4/4	GSL	54.8	35.5	9.7	1,2MCR,SBK	lo,sh	fr	so, ps	0, tdc	0	2vf	cw
3Bk	15	80	10YR 6/4	10YR 4/4	VGS	53.5	42.7	3.8	0	lo	lo	so, po	es, tdc	0	1f	cw
3Ck	80	150+	N.D.		G,C and F	85.5	11.2	3.3	N.A.		NA		tdc	N.A.	0	N.D.
JPT Profile 2																
Av	0	7	10YR 7/3	10YR 5/3	SCL	36.0	50.5	13.5	2CPR	sh to h	fr	ss, ps	es	3f,mv	1f	aw
2Bw	7	20	10YR 6/3	10YR 5/4	GLS	52.5	32.6	15.0	0 to 1MCR	lo to so	lo	so, po	e, tdc	0	2vf to f	cw
3Bk	20	46	10YR 7/3	10YR 6/4	VGS	80.9	14.6	4.5	0	lo	lo	ss, po	es, tdc	0	1 to 2f	cw
3Ck	46	150+	N.D.		G	82.5	12.5	5.0	N.A.		N.A.		tdc	N.A.	0	N.D.
JPT Profile 3																
Av	0	15	10YR 7/3	10YR 5/3	SL	48.5	38.7	12.8	2CPR, 1CPL	so to sh	fr	ss, ps	e	2,3 fv	1f	aw
2Bw	15	33	10YR 6/4	10YR 4/4	GSL	60.2	31.1	8.7	0 to 1MCR	lo to so	lo	so, ps	0 to e, tdc	0	2vf to f	cw
2Bk	33	60	10YR 7/3	10YR 5/4	GSL	61.2	30.8	8.0	0 to 1MSBK	lo to so	lo	so, po	es, tdc	0	2f	cw
2B'w	60	95	10YR 6/4	10YR 4/4	G TO VGSL	55.1	35.5	9.4	0 to 1MSBK	lo to so	lo	so, ps	e, tdc	0	1f	gw
3Ck	95	200+	N.D.		G	81.8	12.6	5.7	N.A.		N.A.		tdc	N.A.	0	N.D.
JPT Profile 4																
A	0	11	10YR 7/2	10YR 4/3	SL	44.4	47.3	8.3	2CPR, 1MPL	lo to so	lo	so, po	e	1fv	1f	aw
2Av	11	35	10YR 7/3	10YR 5/3	SCL	34.4	52.5	13.1	2CPR to 2MPL	so to sh	lo	ss, ps	es	2fv	1f	cw
3Bw	35	65	10YR 6/4	10YR 4/4	SCL	37.6	47.2	15.2	0 to 1M, CSBK	so to sh	lo	so, ps	0 to e	2fv	1f	gw
3C	65	150+	N.D.		N.D.	38.9	54.5	6.6	N.A.		N.A.		0	N.A.	0	N.D.
JPT Profile 5																
Av	0	28	10YR 8/3	10YR 5/4	SC	5.8	62.3	31.9	2CPR to 3CPL	so to sh	fi	ss, p	es	3fv	2vf to f	cw
2BC	28	48	10YR 6/4	10YR 5/4	SCL	37.2	51.0	11.7	0 to 1MCR	lo to so	lo	ss, ps	0	0	1f	cw
2C	48	170+	10YR 6/4	10YR 4/4	SCL	33.3	58.8	8.0	N.A.		N.A.		0	N.A.	0	N.D.
Soil Pit Profiles																
JPBP Profile 1																
Av	0	8	10YR 7/2	10YR 4/2	SCL	40.1	49.7	10.2	2CPR to 2F,MPL	so to sh	fr	ss, ps	0 to e	3fv	1 to 2vf	aw
2Bw	8	46	10YR 6/4	10YR 4/4	VGLS	50.2	40.9	9.0	0 to 1FSBK	lo to so	lo to vfr	so, po	0 to e, tdc	0	2vf	cw
2Ck	46	77	10YR 8/3	10YR 6/4	EGS	68.1	22.9	9.0	N.A.	lo	lo	so, po	ev, tdc	0	2vf	cw
2C	77	170+	N.D.		G	94.9	3.1	2.0	N.A.		N.A.		tdc	N.A.	0	N.D.
JPBP Profile 2																
Av	0	6	10YR 7/2	10YR 5/3	SCL	29.3	55.8	14.9	3CPR, 2MPL	so to sh	fr	ss, ps	0 to e	3 fv	1vf	as
2Bt	6	15	10YR 5/3	10YR 4/4	GSCL	44.0	42.8	13.2	0 to VF,FCR	lo	fr	ss, ps	0	0	2vf to f	aw
2Bk	15	25	10YR 7/3	10YR 5/4	VGS	63.9	31.0	5.1	0 to 1VFCR	lo	lo	so, po	ev, tdc	0	2vf to f	as
matrix free zone	25	34	N.A.		G	No fine fraction			N.A.		N.A.		tdc	N.A.	1vf	as
4Bk	34	57	10YR 7/3	10YR 5/4	VGS	57.7	41.0	1.3	0	lo	lo	so, po	ev, tdc	0	1vf	cw
4Ck	57	200	N.D.		G	94.7	2.8	2.5	N.A.		N.A.		tdc	N.A.	0	N.D.

Table 2. Soil Data From Regressive Barriers in the Jessup Embayment.

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			$CaCO_3$, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
Lower Barrier Profiles																
Cl-36 Exposure																
Avk	0	12	2.5YR 6/3	10YR 3/3	SL	57.6	36.8	5.6	1FPL to 1FSBK	lo to so	lo	so,ps	es	3fv	1,2f	aw
2Bwk	12	21	10YR 6/3	10YR 4/3	VGSCL	25.9	61.7	12.4	2MSBK	sh	fr	so,ps	e to es, tdc	2vfir	2vf	aw
2Bk	21	41	10YR 6/4	10YR 4/3	VGSL	38.4	53.7	7.9	0 to 1FSBK	lo	lo	so,po	es, tdc	1fir to 0	1 to 2vf	aw
2BC	41	51	10YR 7/3	10YR 4/4	EGS	49.0	41.7	9.3	0	lo	lo	so,po	ev, tdc	0	2vf to f	aw
3Ck	51	150+	N.D.		G		N.D.		N.A.		N.A.		tdc	N.A.	0	N.D.
Lower Barrier 3																
LB-3 Profile 1																
Av	0	14	10YR 7/4	10YR 5/3	S	68.5	25.3	6.2	3VCCPR, 1CPL	lo	lo to vfr	so,po	0 to es	3fv	1vf	aw
2Bk	14	39	10YR 7/3	10YR 5/4	VGS	71.4	15.7	13.0	0 to 1FSBK	lo to so	lo	so,po	es, tdc	0	1vf,f	cw
2Ck	39	55	N.D.		VGS	92.5	4.9	2.6	N.A.		N.A.		0, tdc	N.A.	0	aw
3Ck	55	150+	N.D.		G	95.5	3.4	1.1	N.A.		N.A.		0, tdc	N.A.	0	N.D.
LB-3 Profile 2																
Av	0	9	10YR 7/2	10YR 4/2	GSCL	47.0	45.4	7.7	2CPR	lo to sh	lo	so,ps	es	3fv	0	aw
2Bk	9	16	10YR 7/3	10YR 5/3	GLS	73.1	13.4	13.4	0 to 1MCR	lo to so	lo	so,po	es, tdc	0	2f	cw
2Ck	16	30	N.D.		G	87.7	4.8	7.6	N.A.		N.A.		0, tdc	N.A.	0	aw
3Ck	30	150+	N.D.		G	97.6	2.6	0.8	N.A.		N.A.		0, tdc	N.A.	0	N.D.
Lower Barrier 4																
LB-4 Profile 1																
Av	0	10	10YR 7/2	10YR 5/3	SCL	48.9	42.3	8.9	2CPR	so to sh	lo	so,po	0 to e	3fv	1f	cw
2Btk	10	23	10YR 6/2	10YR 5/3	VGSCL	66.7	11.8	21.5	0 to 1MCR	lo to so	fr	so,ps	es, tdc	0	1,2f	gw
2Ck	23	105	N.D.		G	92.2	4.8	3.0	N.A.		N.A.		0, tdc	N.A.	1,2f;1m	as
3C	105	132	N.D.		GS	91.1	6.8	2.1	N.A.		N.A.		0,0	N.A.	0	as
4C	132	200+	N.D.		S	91.8	8.2	0.0	N.A.		N.A.		0,0	N.A.	0	N.D.
LB-4 Profile 2																
Av	0	10	10YR 7/3	10YR 4/3	SL	49.5	44.0	6.4	0 to 1CPR	so to sh	lo	so,po	e to es	3fv	1f	cs
2Bw	10	30	10YR 6/3	10YR 5/4	EGS	77.3	14.6	8.2	0 to 1MCR	lo to so	lo	so,po	0 to e, tdc	0	1,2f	aw
2Ck	30	120	N.D.		G	89.1	10.9	0.0	N.A.		N.A.		0, tdc	N.A.	1,2f	as
3C	120	140	N.D.		GS	91.1	6.8	2.1	N.A.		N.A.		0,0	N.A.	0	as
4C	140	200+	N.D.		S	91.8	8.2	0.0	N.A.		N.A.		0,0	N.A.	0	N.D.
Lower Barrier 11																
LB-11 Profile 1																
Av	0	12	10YR 6/2	10YR 5/3	SCL	39.3	42.0	18.7	2CPR to 2MPL	so to sh	fr	so,ps	es	3fv	1f	aw
2Bk	12	40	10YR 7/3	10YR 5/3	VG,CS	79.2	20.2	0.6	0 to 1MCR	lo	lo	so,po	es, tdc	0	1,2f	cw
2Ck	40	200+	N.D.		G	92.8	6.1	1.2	N.A.		N.A.		s, tdc	N.A.	0	N.D.
LB-11 Profile 2																
Av	0	12	10YR 7/3	10YR 4/3	SL	47.9	34.8	17.3	0 to 2CPR	lo to so	lo	so,po	es	2,3fv	1f	cw
2Btk	12	24	10YR 7/3	10YR 5/3	GSC	39.2	34.6	26.2	0 to 2M,CSBK	so to sh	fr	ss,ps	es, tdc	2fv	1f	gw
2Ck	24	200+	N.D.		G	95.0	3.4	1.6	N.A.		N.A.		0, tdc	N.A.	0	N.D.

Table 3. Soil Data From Highstand Barriers in the Lake Lahontan Basin .

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			CaCO3, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
D-28																
A	0	5	2.5Y 6/3	2.5Y 4/3	VGSL		ND		0 to 1FSBK	lo, sh	ND	so, po	0	0	2f	as
Av	5	14	2.5Y 6/3	2.5Y 4/3	SCL		ND		2FSBK	so, sh	ND	ss, ps	0	2fv	2f	as
2Bw	14	25	10YR 6/2	10YR 4/2	VGSCL		ND		0 to 1FSBK	lo, so	ND	ss, ps	es, tdc	0	2f	cw
2Ck	25	100+	NA		EGS		ND		NA		NA		es, tdc	0	2f ≤ 80	ND
EM-33																
Av	0	3	2.5Y 6/3	2.5Y 5/3	L		ND		1FPL, 1FCR	lo,sh	fr	so, ps	e	3vf,fv	1vf	aw
2Bw	3	14	2.5Y 7/3	2.5Y 5/4	VGSL		ND		1FSBK	lo, sh	fr	so, po	e	2vfv	2f	cw
2Bk	14	26	10YR 7/4	10YR 6/4	EGS,LS		ND		0 to 1FCR	lo	lo	so, po	es, tdc	0	1vf	aw
2C	26	100+	NA		EGS		ND		NA		NA		tdc	0	0	ND
OM-10																
Av	0	4	2.5Y 6/3	10YR 3/3	SL	47.3	44.4	8.3	1CPR,1FPL	lo, so	ND	so, ps	0	2vf,fv	2vf,f	aw
2Bw	4	30	10YR 7/3	10YR 4/3	VGSL	39.1	50.5	10.4	0 to 1MCR	lo, so	fr	so, ps	0	2vf,f	2vf,f	gw
2Bk	30	41	2.5Y 6/3	2.5Y 4/3	EGSL	45.4	44.6	10.0	0 to 1MCR	lo, so	lo, fr	ss, ps	es, tdc	2vf,fv	2,3vf,f	gw
2C	41	100+	NA		EGS		ND		NA		NA		es, patchy	0	0	ND
EM-26N																
Avk	0	17	2.5Y 6/3	2.5Y 4/3	GSL		ND		2FPL, 1MSBK	so, sh	ND	so, ps	es	2fv	1,2vf	cw
2Bk	17	37	2.5Y 7/3	2.5Y 5/3	VGSL		ND		0 to 1FSBK	lo, so	ND	so, ps	ev, tdc	0	1vf	gw
2Ck	37	100+	NA		EGS		ND		NA		NA		ev, t,thc	0	0	ND
HRC-1																
Avk	0	8	2.5Y 6/3	2.5Y 4/3	GSCL		ND		1FPL, 1FSBK	so, sh	ND	ss, po	e, patchy	2fv	1vf	as
2Bw	8	28	10YR 4/3	10YR 5/4	EGSCL		ND		0 to 1FCR	lo, so	ND	s, p	0	0	2vf,f	cs
3Ck	28	100+	NA		GCO		ND		NA		NA		e, tdc	0	2vf ≤70	ND
G-18																
Av	0	6	2.5Y 6/3	2.5Y 4/3	S		ND		0 to 1MCR	lo	ND	so, po	0	2fv	0	cw
2Bw	6	19	2.5Y 7/3	2.5Y 6/4	SCL		ND		1MCR, 1MSBK	lo, so	ND	so, po	e	2fv	1f	cw
2Bk	19	25	2.5Y 7/3	2.5Y 4/4	SCL		ND		2MCR	so, sh	ND	ss, p	es	2fv	1f	cw
2C	25	100+	NA		S		ND		NA		NA		0	0	0	ND
KP-16																
A	0	3	10YR 5/3	ND	S		ND		0	lo	ND	so, po	0	0	0	aw
Bw1	3	28	2.5Y 6/3	10YR 4/3	LS		ND		1MGR	lo, so	ND	ss, ps	0	0	1m	aw
Bw2	28	41	10YR 5/4	ND	S		ND		0	lo	ND	so, po	0	0	1m	gw
C	41	100+	NA		GS		ND		NA		NA		0	0	0	ND
CS-11b																
Av	0	8	10YR 7/2	2.5Y 5/3	SC		ND		2MPR, 2FPL	sh, h	fr	ss, ps	ev, tdc	2vfv	1vf	aw
2Bt	8	23	2.5Y 5/4	2.5Y 4/4	SCL		ND		1FCR	s, sh	lo	so, p	es, tdc	0	1vf	cw
2Bw	23	44	2.5Y 5/4	2.5Y 4/4	GS		ND		0 to 1FCR	lo	lo	so, po	es, tdc	0	0	cw
2Ck	44	100+	NA		VGS		ND		NA		NA		es, thcc	0	0	ND

Table 3 continued. Soil Data From Highstand Barriers in the Lake Lahontan Basin.

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			CaCO3, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
L-4																
Av	0	9	10YR 7/2	ND	SCL		ND		1MPR, 1FPL	lo,so	ND	ND	es	2vfv	ND	cw
2Bw	9	55	2.5YR 6/3	ND	VGSL		ND		1MGR	lo,so	ND	ND	es	NA	1,2f	dw
2C	55	100+	ND		ECS		ND		NA		NA		ND	NA	0	ND
KP-7																
A	0	9	10YR 5/3	ND	SL		ND		1MPR	so, sh	ND	ND	0	1vfv	1f	cs
2Bt	9	36	10YR 4/4	ND	VGSCL		ND		2MSBK	so,sh	ND	ND	0	NA	1f	gw
2Ck	36	80+	ND		C		ND		NA		NA		es, tdc	NA	NA	ND
L-26																
Av	0	10	10YR 7/2	ND	CL		ND		1MCR	lo,so	ND	ND	es	2fv	ND	aw
2Bw	10	40	10YR 6/4	ND	VGSL		ND		1MGR to 0	lo	ND	ND	es, tdc	NA	ND	cw
2Ck	40	100+	ND		EGS		ND		NA		NA		tdc	NA	ND	ND
FCM-7																
Av	0	2	10YR 7/2	ND	SCL		ND		1MPR	h,vh	ND	ND	es	2mv	ND	cw
2Bw	2	50	2.5YR 6/3	ND	GLS		ND		1,2FCR	lo,so	ND	ND	es, tdc	NA	ND	gw
2Ck	50	100+	ND		VGS		ND		NA		NA		tdc	NA	ND	ND
R-24																
Av	0	5	10YR 6/3	ND	GCL		ND		1MPR	sh, h	ND	ND	0	1mv	ND	aw
2Bt	5	11	10YR 4/3	ND	VGSCL		ND		1MGR	lo, so	ND	ND	0, tdc	NA	ND	aw
2Btk	11	40	10YR 4/3	ND	EGSCL		ND		2MSBK	so, sh	ND	ND	0, tdc	NA	ND	cw
2Ck	40	100+	ND		EGS		ND		NA		NA		tdc	NA	ND	ND
CS-41																
Av	0	8	10YR 7/3	ND	VGSL		ND		1MCR	lo,so	ND	ND	es	2mv	ND	aw
2Bw	8	30	10YR 6/3	ND	VGSL		ND		1MGR	lo	ND	ND	e, tdc	NA	ND	cw
2C	30	250+	ND		EGS		ND		NA		NA		tdc	NA	ND	ND
CS-27																
Av	0	6	10YR 7/2	ND	SCL		ND		2MPL	so, sh	ND	ND	es	2mv	ND	cw
2Bw	6	26	10YR 6/4	ND	GLS		ND		1MCR	lo	ND	ND	es, tdc	NA	ND	gw
2Ck	26	100+	ND		EGS		ND		NA		NA		tdc	NA	ND	ND
F-6																
Gravelly sand	0	4	10YR 6/3	ND	GS		ND		0	lo	ND	ND	0	0	ND	aw
2Bw	4	25	10YR 6/3	ND	GS		ND		0 to 1MGR	lo	ND	ND	0	NA	ND	cw
2Ck	25	100+	ND		CS		ND		NA		NA		0, tdc	NA	ND	ND
F-19																
Av	0	6	10YR 6/3	10YR 3/2	GCL	36.9	35.7	27.4	2FPL, 2FSBK	so, sh	fr	ss, ps	e	2,3vfv	1f	aw
2Bw	6	15	2.5Y 7/3	2.5Y 4/4	VGL	39.1	47.7	13.2	0, 1FSBK	lo, so	lo, fr	ss, ps	e	1vfv	2vf,f	cw
2Bk	15	22	2.5Y 7/3	2.5Y 4/4	VGL	40.5	49.1	10.4	0, 1FCR	lo, so	lo	so, ps	es, tdc	1vfv	2vf,f	cw
2Ck	22	50	NA		G		ND		NA		NA		tdc	NA	0	ND

Table 3 continued. Soil Data From Highstand Barriers in the Lake Lahontan Basin.

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			$CaCO_3$, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
F-9																
Av	0	4	2.5Y 7/3	2.5Y 4/4	GSL	35.7	51.1	13.2	2FSBK, 1FPL	so, sh	fr	ss, ps	e	2fv	1vf	aw
2Bw	4	22	10YR 5/4	10YR 3/3	EGL	35.8	43.1	21.1	0 to 1FSBK	lo, so	lo, fr	so, ps	0	0	1vf,f	cw
2Bk	22	32	10YR 5/3	10YR 3/3	EGL	48.0	44.0	8.0	0 to 1FSBK	lo	lo	so, ps	e, tdc	0	1,2vf,f	cw
2Ck	32	100+	NA		G		ND		NA		NA		tdc	0	0	ND
F-7																
Av	0	5	10YR 6/3	10YR 4/3	SL		ND		0 to 1FPL	lo, so	fr	so, po	0	2,3vfv	1vf	cw
2Bw	5	17	10YR 6/4	10YR 4/4	VGSL		ND		0 to 1MSBK	lo, so	lo, fr	so, po	0	1vfv	1,2vf	cw
2Bk	17	34	10YR 7/4	10YR 4/4	VGLS		ND		0 to 1MSBK	lo, so	lo	so, po	0,e,tdc	0	2,3vf,f	gw
2C	34	100+	NA		G		ND		NA		NA		0	0	0	ND
CC-4																
Av	0	9	10YR 6/3	10YR4/3	VGSL		ND		0,1F,MSBK	lo, so	ND	so, ps	0	2,3fv	1,2vf	cw
2Bw	9	22	10YR6/3	10YR 4/3	EGSL		ND		0 to 1FSBK	lo	ND	so, ps	tdc	0	3vf,f	gw
2Bk	22	40	10YR 5/3	10YR 4/3	EGLS		ND		0 to 1FSBK	lo	ND	so, ps	es, thdc	0	3vf,f	gw
2Ck	40	100+	NA		G		ND		NA		NA		thdc	0	0	ND
F-29																
Av	0	8	10YR 6/3	10YR 4/4	SL		ND		1FSBK	lo, so	ND	so, ps	0	3fv	1f	as
2Bw	8	22	10YR 5/4	10YR 4/4	GS		ND		0 to 1VFSBK	lo	ND	so, po	0	0	2f	cw
2C	22	100+	NA		GS		ND		NA		NA		0, tdc	0	0	ND
WL-5c																
sand	0	3	2.5Y 8/3	2.5Y 5/4	S		ND		1FCR	lo, so	ND	so, po	0	ND	ND	aw
Avk	3	9	2.5Y 8/2	2.5Y 5/4	GSL		ND		3FSBK,1MPL	sh	ND	ss, ps	es	0	ND	cw
2Btjk	9	20	2.5Y 8/2	2.5Y 7/4	VGSCL		ND		2F,MSBK	sh	ND	s, ps	es, tdc	0	ND	aw
2Ckq	20	90+	NA		EGS		ND		0		NA		e	0	ND	ND

Table 4. Soil Data From Pre-Sehoo Age Lacustrine and Related Deposits in the Lake Lahontan Basin.

Horizon	Depth (cm)		Color[1]		Texture[2]	Size (% wt)			Structure[3]	Consistency[4]			$CaCO_3$, effervescence[5] (matrix, clasts)	Pores[6]	Roots[7]	Lower Boundary[8]
	Top	Base	Dry	Moist		Sand	Silt	Clay		Dry	Moist	Wet				
Fluvial Deposits																
Wadsworth Amp.																
Btk1$_b$	0	19	10YR 5/3	10YR 4/3	L	43.2	32.0	24.8	2MPR, 2FSBK	lo, sh	ND	s, p	e, es	0	1fvf,f	cw
Btk2$_b$	19	52	10YR 6/4	10YR 5/4	SCL	59.1	18.8	22.1	2FSBK to 2FPL	sh, h	ND	ss, p	e, es	0	1f	gw
C1$_b$	52	90	NA		SL	66.7	24.8	8.5	NA		NA		0	0	0	gw
C2$_b$	90+		NA		S	86.9	9.5	3.6	NA		NA		0	0	0	ND
Rye Patch Dam																
Btk$_b$	0	36	10YR 6/4	10YR 5/4	SC		ND		3FPR, 3FSBK	sh, h	ND	s, p	es	0	0	cw
Bk$_b$	36	60	10YR 6/4	10YR 5/4	SC		ND		2FPR,2F,MSBK	sh	ND	s, p	es	0	0	gw
C$_b$	60+		NA		ND		ND		NA		NA		0	0	0	ND
Beach Deposits																
Quinn River Valley (OM-10)																
Bt$_b$	0	47	10YR 6/4	2.5Y 5/4	VGSL	58.6	26.8	17.4	2FSBK	sh, h	fi	s, p	es, patchy	ND	0	cw
Btk1$_b$	47	100	10YR 5/6	10YR 5/8	VGCL	33.6	30.2	36.2	3VF,FSBK	h,vh	fi	s, p	es, tdc	ND	0	dw
Btk2$_b$	100	175+	10YR 6/4	10YR 4/6	VGSCL	54.7	19.9	25.4	2FSBK to 2FPL	sh,h	fr to fi	s, p	es, tdc	ND	0	ND
Jessup paleosol																
Bt1$_b$	0	15	2.5Y 6/3	2.5Y 5/3	SC		ND		3MSBK, 3FPL	h, vh	ND	s, p	e, patchy	0	0	aw
Bt2$_b$	15	60	10YR 6/4	10YR 5/4	GSC		ND		2MPR, 3MSBK	sh, vh	ND	s, p	es, patchy	0	0	gw
Ck$_b$	60	250+	NA		GS		ND		NA		NA		es, patchy	0	0	ND
Grimes Canyon																
Bt1$_b$	0	57	10YR 5/3	10YR 5/4	EGSC		ND		2FSBK	sh, h	ND	s, p	0,e, patchy	0	0	cs
Bt2$_b$	57	155	10YR 6/3	10YR 5/3	EGSC		ND		3F,MSBK	vh, eh	ND	s, p	e,es, patchy	0	0	cs
Bt3$_b$	155	192	10YR 5/3	10YR 4/3	EGSC		ND		3MSBK	eh	ND	s, p	es	0	0	cs
Bedrock	NA		NA		NA		NA		NA		NA		NA	NA	NA	mantle?
Thorne Bar- mid																
sand	0	3	2.5Y 6/2	10YR 4/4	S		ND		0	so	ND	so, po	e	0	ND	aw
Avk	3	9	10YR 7/3	10YR 5/4	SL		ND		2MPL, 2MCR	sh	ND	ss, po	es	0	ND	aw
2Btjk	9	16	2.5Y 7/3	10YR 5/4	L		ND		1MCR	so	ND	ss, ps	es, ev	0	ND	cw
2Bk1	16	30	10YR 7/3	10YR 5/4	LS		ND		0 to 1MCR	lo	ND	so, po	ev	0	ND	cw
2Bk2	30	45	10YR 7/3	10YR 6/4	S		ND		0	lo	ND	so, po	ev	0	ND	dw
3Bqk	45	64	10YR 6/4	10YR 5/4	S		ND		0 to 1MCR	lo, sh	ND	so, po	ev	0	ND	dw
3Cqk	64	100+	10YR 6/3	10YR 5/3	S		ND		0	lo	ND	so, po	e, es	0	ND	ND
Thorne Bar- upper																
sand	0	3	2.5Y 7/3	10YR 5/4	S		ND		0	lo	ND	so, po	0	0	0	aw
Av	3	8	2.5Y 8/3	10YR 6/3	SL		ND		2FPL,3FCR	so	ND	so, po	e	3vf, fv	1f,m	cw
Bt	8	16	10YR 8/3	10YR 6/4	L		ND		1FPL, 2MSBK	sh	ND	s, ps	es	3vf	2f, 3vf	cw
2Btjk	16	31	10YR 7/3	10YR 6/4	VGSL		ND		1,2F,MSBK	so	ND	s, ps	es	0	3vf, 1,f	cw
2Bky	31	55	10YR 7/3	10YR 6/4	EGLS		ND		1FSBK	so	ND	s, po	e	0	3vf, 1f	as
3Bkq	55	95	10YR 6/3	10YR 6/4	EGS		ND		0	lo	ND	so, po	e	0	1f	as
4Ckq	95	110+	2.5Y 8/2	2.5Y 7/3	EGS		ND		0	lo	ND	so, po	e	0	0	ND

Note: Descriptions and abbreviations follow criteria in Soil Survey Divisions Staff (1993), except: Av = vesicular A horizon.
1) From Munsell Soil Color Charts (1990).
2) G, gravelly or gravel; VG, very gravelly; EG, extremely gravelly; Co, cobbly or cobbles; ECo, extremely cobbly; F, flaggy or flagstones; S, sand; LS, loamy sand; SL, sandy loam; SCL, sandy clay loam; CL, clay loam; SC, sandy clay; SL, silt loam.
3) 0, single grained; 1, weak; 2, moderate; 3, strong; VF, very fine (very thin); F, fine (thin); M, medium; C, coarse (thick); VC, very coarse (very thick); GR, granular; CR, crumb; Pl, platy; PR, prismatic; CPR, columnar; ABK, angular blocky; SBK, subangular blocky.
4) **Dry:** lo, loose; so, soft; sh, slightly hard; h, hard; vh, very hard; eh, extremely hard. **Moist:** lo, loose; vfr, very friable; fr, friable; fi, firm. **Wet:** so, non-sticky; ss, slightly sticky; s, sticky; po, non-plastic; ps, slightly plastic; p, plastic.
5) **Matrix**: 0, not effervescent; slightly effervescent; es, strongly effervescent; ev, violently effervescent. **Clasts:** tdc, thin discontinuous carbonate coatings; th, thick coatings; cc, continuous coatings on undersides.
6) vf, very fine; f, fine; m, medium; 1, few; 2, common; 3, many; ir, irregular; v, vesicular.
7) vf, very fine; f, fine; m, medium; 1, few; 2, common; 3, many.
8) a, abrupt; c, clear; g, gradual; d, diffuse; s, smooth; w, wavy; i, irregular.

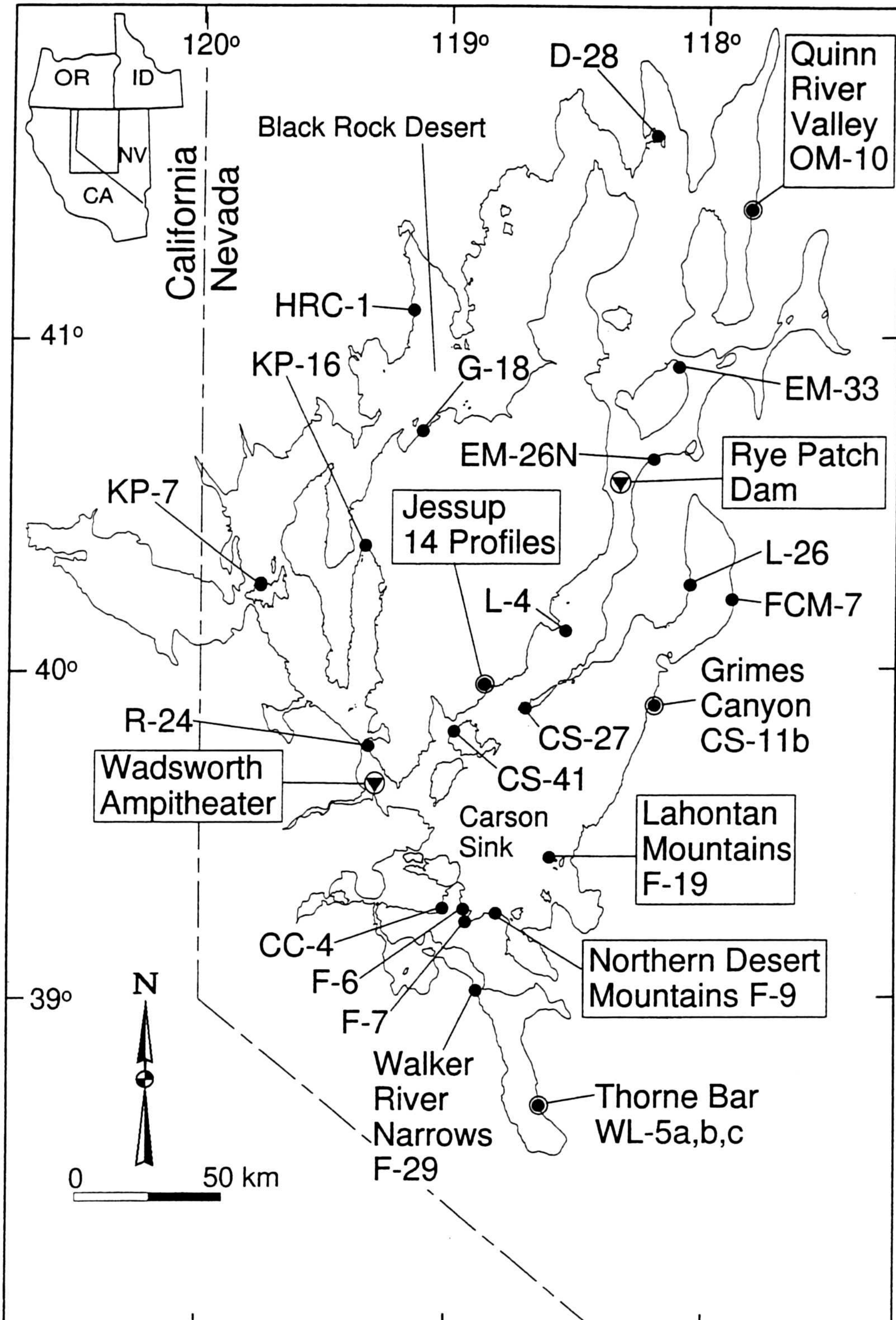

Figure 1- Location map of the Lake Lahontan basin at its last highstand at about 12.7 ka. Black dots are locations of existing soil pits and field reconnaissance descriptions. Circled black dots are locations of paleosols associated with beach deposits and younger soils. Circled inverted triangles are locations of paleosols not associated with beach deposits. Boxed labels are soil profiles that have been fully described, sampled and analyzed in the lab.

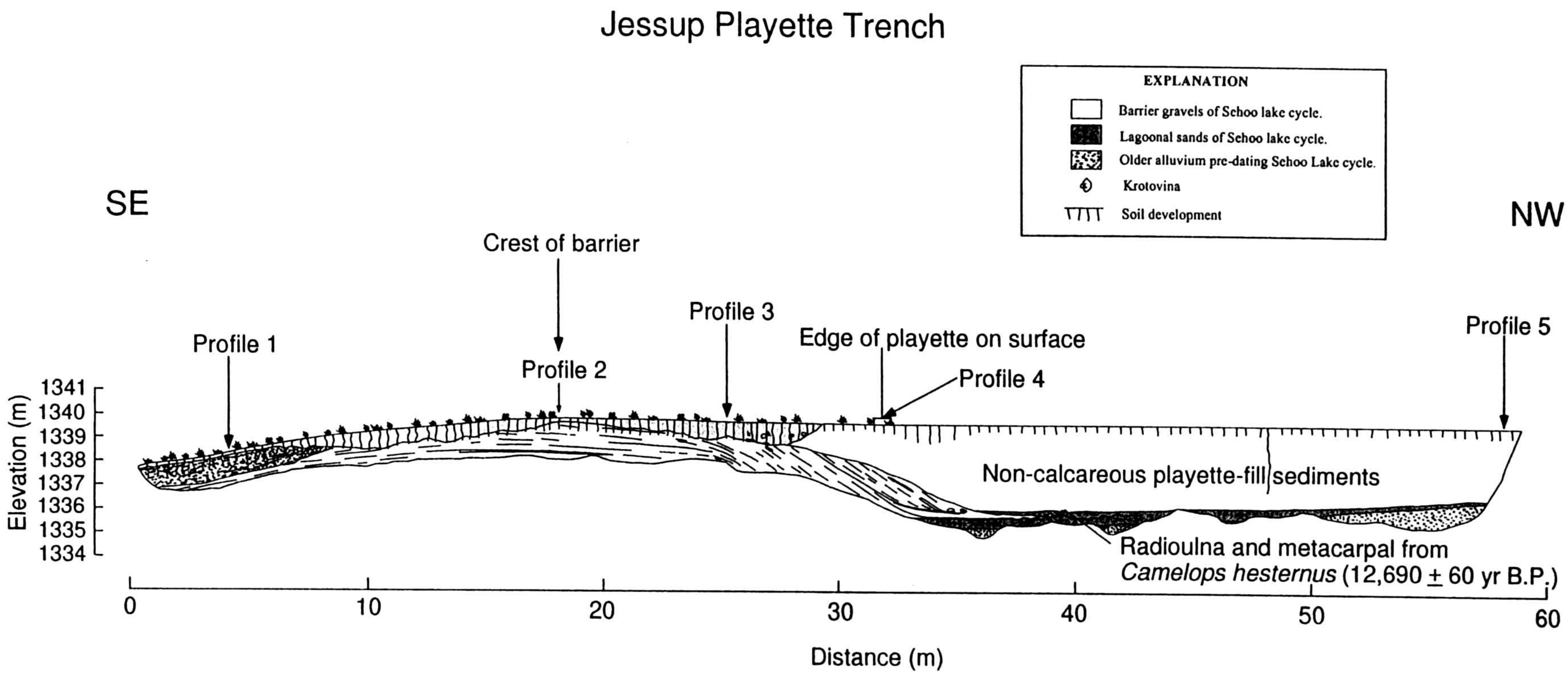

Figure 2. Simplified log of the Jessup Playette trench showing the location of the described soil profiles and salient features related to soil development. This view is looking to the southwest, but all soils were described on the northeasr wall of the trench and their locations projected to the southwest wall. The location of the camel bones was also projected from the northeast wall to the southwest wall. No vertical exageration.

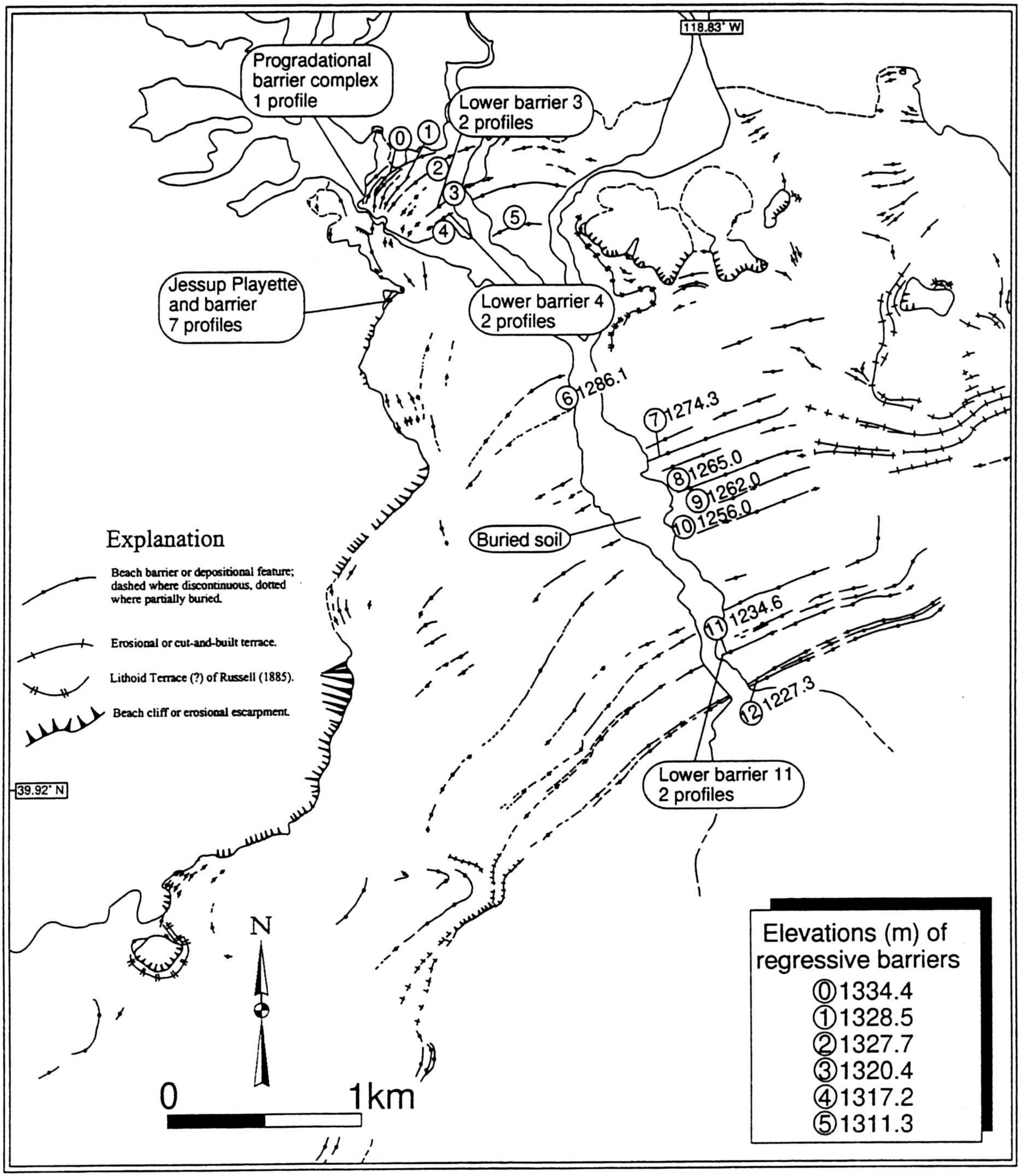

Figure 3. Sketch map of the Jessup Embayment showing the locations of soil profiles with respect to beach barrier features.