GUIDEBOOK FOR THE 1982 FRIENDS OF THE PLEISTOCENE ROCKY MOUNTAIN CELL FIELD TRIP TO CENTRAL UTAH

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Part I: Little Valley and Jordan Valley, Utah.
Modified from U.S. Geological Survey Open-File Report 82-845
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Part II: Beaver basin, south-central Utah.
Modified from U.S. Geological Survey Open-File Report 82-850
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PART I: LITTLE VALLEY AND JORDAN VALLEY
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INTRODUCTION

Recent stratigraphic and chronologic studies of exposed deposits in the northeastern Bonneville basin (fig. 1) by us and new radiocarbon dates provided by Meyer Rubin (U.S. Geological Survey) indicate that previous interpretations of Lake Bonneville stratigraphy and history, which have long been accepted, should be substantially modified. Much of the material for this introduction has been excerpted from a report by us that is in review. On this trip we plan to visit localities from which most of our present interpretations were developed by using stratigraphic amino-acid, soil, and dating evidence.

Our interpretations are contrasted with those proposed by Morrison (1965a) in figure 2. Briefly, we conclude (1) that many of the deposits mapped as Alpine Formation by Morrison (1965b, 1965c), Hunt and others (1953), Bissell (1963), Feth and others (1966), and Van Horn (1972a) were deposited during the last lake cycle, rather than during an older lake cycle (Stops LV-2,-4, JV-2), (2) that the lake level during the cycle that predates the last did not reach a level close to the level of the Bonneville shoreline, in contrast to interpretations by Morrison (1965b, 1965c), Hunt and others (1953), Bissell (1963), and Van Horn (1972a) (stops LV-4, JV-2,-4,-6), (3) that the next-to-the-last deep-lake cycle occurred prior to the Wisconsin Glaciation, or about 150,000 ± 25,000 yr ago during marine oxygen-isotope stage 6, as was proposed by Morrison (1975), rather than during early Wisconsin time, (4) that the lake did not undergo a marked, rapid recession from the Bonneville shoreline to a low level followed by a rapid rise back to the Bonneville shoreline during the last lake cycle as was proposed by Morrison (1965c) and Currey (1980), and (5) that evidence for the Draper lake cycle (Morrison, 1965b, 1965c) is not compelling.

In this guidebook, both English and SI units are used. English units are used to designate highway distances (mi) and altitudes (ft) of deposits and shorelines. This will be more convenient for using odometers and for finding altitudes on topographic maps. SI units (m and cm) are used for thicknesses of stratigraphic sections and units.

Stratigraphic nomenclature

The stratigraphic nomenclature of previous workers is not used by us for four reasons. **(1)** The type deposits of the lower member of the Draper Formation are not lacustrine, and elsewhere the lacustrine deposits mapped as Draper are not separable stratigraphically from deposits assigned to the Bonneville Formation. Thus, we believe there is no reason to retain the Draper as a formally defined stratigraphic unit. **(2)** Most of the deposits that were mapped by previous workers as Alpine Formation, including the type deposits near the town of Alpine (Hunt and others, 1953), were deposited during the last lake cycle rather than during an older lake cycle. We recognize deposits of a lake cycle older than the last, but we believe that the name Alpine should not be used for them because of likely confusion. **(3)** The name Bonneville is used for an ancient lake in the northeastern Great Basin during its last few cycles (Lake Bonneville), for the deposits of that lake (Lake Bonneville Group), for the deposits of the last cycle of that lake (Bonneville Formation), and for the highest shoreline of that lake (Bonneville shoreline). To discourage this multiple use, we recommend retaining the name Lake Bonneville for the ancient lake that occupied the northeastern Great Basin intermittently during the Quaternary, and not just for its last few cycles. Also, we retain the term Bonneville shoreline for the highest shoreline of Lake Bonneville, which we find was occupied only during the last lake cycle. (4) Lithostratigraphic classification (American Commission on Stratigraphic Nomenclature, 1970) must be based primarily on the lithologic characteristics of the deposits and not on the basis of genesis, inferrred geologic history, or unconformities, which along with soil stratigraphy are the bases on which Morrison (1965b, 1965c) and others before him defined lithostratigraphic units. We define units on similar bases, as described below; however, we will not use lithostratigraphic classification.

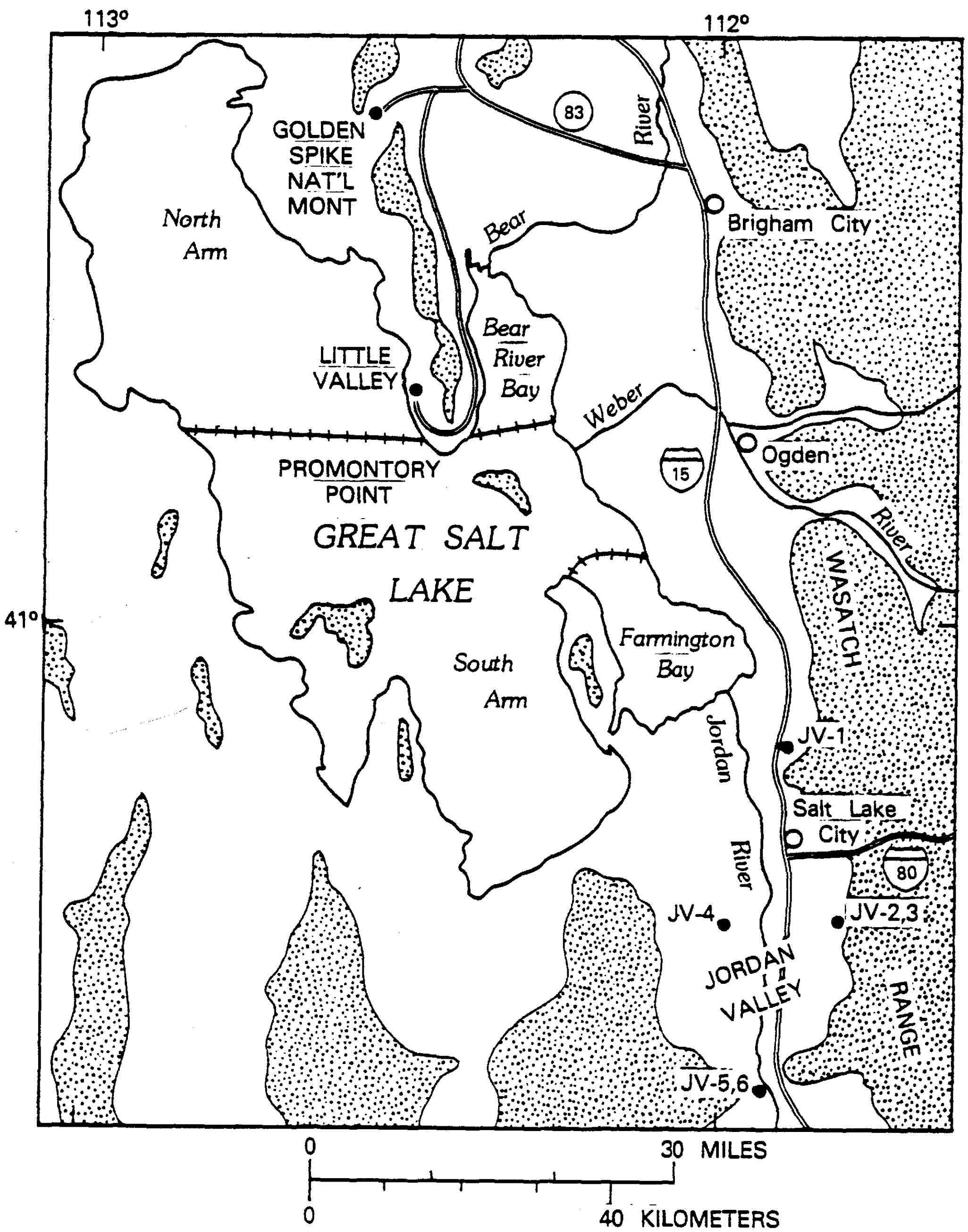


Figure 1.--Map showing field-trip stops and geographic features. Unstippled area was inundated by Lake Bonneville.

The nomenclature that we propose is informal because the new code of the North American Commission on Stratigraphic Nomenclature is still only in draft form. Our classification is similar conceptually to the allostratigraphic classification that the North American Commission is suggesting for use in upper Cenozoic deposits. For deposits in the Bonneville basin, bodies of sediment are classified genetically on the basis of their sedimentary characteristics. Further subdivision is based on the age of the deposits, which is inferred from stratigraphic relations, radiometric ages, and amino-acid evidence. Our fundamental unit is the deposits of a single lake cycle. We also recognize sequences of subaerial deposits and soils that record an interlacustral episode (Morrison, 1965a) when the lake was either nonexistent or small. The term, interlacustral, is used in preference to the more widely used term, interpluvial, to emphasize that it refers simply to an interval between lake cycles, irrespective of cause, whereas interpluvial implies a decrease in precipitation (Flint, 1971).

We refer to the last rise and fall of Lake Bonneville as the Jordan Valley lake cycle. Its deposits are of late Wisconsin age based on radiocarbon dating. The type area for these deposits is the Jordan Valley (fig. 1), where deposits of this lake cycle are well exposed in numerous gravel pits and are in contact with glacial deposits of Pinedale age. The preceding interlacustral interval, which we call the last interlacustral episode, is documented by stratigraphic evidence of a disconformity, subaerial deposits, and a buried soil or soil complex, and by amino-acid measurements of fossil shells from lake deposits above and below the unconformity (tables 3 and 4). The next older lake cycle, which we call the Little Valley lake cycle, is defined by deposits that are well exposed in the large gravel pit at Little Valley near Promontory Point (fig. 1) and at localities in the Jordan Valley. Deposits of the Little Valley lake cycle are not precisely dated; however, based on several lines of reasoning we feel that they are 150,000 ± 25,000 yr old.

History of Lake Bonneville

Our understanding of the history of Lake Bonneville is summarized in figures 2 (upper part) and 3.

Jordan Valley lake cycle

The history of the Jordan Valley lake cycle is best known because of wide exposure of its deposits and because of a wealth of ^{14}C dates (tables 1 and 2). Beginning before 26,000 yr B.P., at the start of the Jordan Valley lake cycle, the lake rose steadily, with apparently only minor fluctuations, and reached the Bonneville shoreline at about 16,000 yr B.P. The lake remained at the Bonneville shoreline until sometime between about 15,000 and 14,000 yr B.P., being maintained at a stable level by overflow through Red Rock Pass, Idaho. Eventually, catastrophic downcutting of the pass caused the Bonneville flood (Malde, 1968) and resulted in a rapid drop of lake level of about 300 ft. After a period of rapid isostatic uplift, the Provo shoreline was formed and continued to be occupied until about 13,500 yr B.P. Thereafter, the lake level fell and reached the level of Great Salt Lake by 11,000 yr B.P., thus ending the Jordan Valley lake cycle.

Table 1. Previously published radiocarbon dates that are plotted on figure 3.

Age ± 1 s.d.	Laboratory number	Dated material	Altitude (ft)	I.C.[a] (ft)	References
Transgressive deposits					
21,200 ± 1000	L-730	cellulose	4650	-75	Broecker and Kaufman (1965)
20,400 ± 500	L-730	lignin	4650	-90	Broecker and Kaufman (1965)
20,800 ± 300	L-775N	wood	4775	-85	Morrison (1965b)
20,600 ± 500	W-876	wood	4700	-90	Rubin and Alexander (1960)
20,300 ± 500	W-941	wood	4730	-90	Ives and others (1964), Morrison (1965b)
18,900 ± 500	W-982	shells	4850	-15	Bright (1963), Ives and others (1964)
18,500 ± 400[b]	L-774R	shells	4770	-90	Broecker and Kaufman (1965)
18,400 ± 300[b]	L-672A	shells	4770	-20	Broecker and Kaufman (1965)
18,200 ± 400[b]	L-774C	shells	4780	-20	Broecker and Kaufman (1965)
18,100 ± 400[b]	L-774I	shells	4785	-20	Broecker and Kaufman (1965)
17,700 + 500[b]	L-774A	shells	4765	-25	Broecker and Kaufman (1965)
Regressive deposits					
13,900 ± 400	W-899	shells	4705	-15	Bright (1963)
12,860 ± 400	W-2000	shells	4670	-80	Marsters and others (1969)
12,780 + 350	W-943	shells	4725	-135	Morrison (1965b)
12,290 ± 350	W-1824	wood	4305	-65	Ives and others (1967)
12,090 ± 300	W-1338	plant detritus	4730	0	Bright (1966)
12,200 ± 300[b]	L-775K	shells	4820	-120	Morrison (1965b), Broecker and Kaufman (1965)
11,454 ± 600	C-609	charcoal	4310	-52	Jennings (1957)
11,000 ± 700	M-700	dung	4310	-45	Jennings (1957)
10,920 ± 150	W-4395	shells	4230	-52	Miller and others (1980)
10,300 ± 275	I-696	wood	4230	-30	Troutman and Willis (1966)
9,730 ± 350	W-386	plant stems	4235	-20	Rubin and Alexander (1958)

[a] I.C. = isostatic correction

[b] 500 yr has been added to these ages to compensate for the 500 yr subtracted from them by Broecker and Kaufman (1965, p. 539) as their correction for a postulated low initial $^{14}C/^{12}C$ ratio of the lake water. Benson (1978) has shown that for Lake Lahontan the effect is about 160 yr. The effect of contamination of the shells with young carbon probably introduces a greater uncertainty to the ages than does a low initial $^{14}C/^{12}C$ ratio.

Table 2. Radiocarbon dates on wood and charcoal from transgressive deposits of the Jordan Valley lake cycle plotted on Figure 3.
[All dates from U.S. Geological Survey, Radiocarbon Laboratory, Reston, Virginia.]

Age ± 1 s.d.	Laboratory number	Dated material[a]	Altitude (ft)	I.C.[b] (ft)	Site[c]	Stratigraphic Position
26,000 ± 600	W-4893	wood[d]	4310	-15	5	In 0.5-m-thick lens of clay that lies 1.5 m above floor of pit excavated in in fine-grained, topset deltaic beds. Clay lens exposed in 3.5-m-high face 50 m east of Bullion St. at point where powerlines cross face of pit.
22,500 ± 300	W-4898	wood (P)	4525	-50	6	Near base of 0.5-m-thick lens of bluish-gray mud in gravel-bar complex in southwestern corner of the pit. Mud lens lies above 2.5 m of lake gravel that buries soil formed in deposits of the last lake cycle
20,900 ± 250	W-4897	wood (A)[d]	4650	-45	8	In middle of 1.3-m-thick, brown to dark-gray lens of lagoonal mud within gravel and sand of a bar complex. Mud is exposed about one-half way up a 25-m-high face at east end of pit.
19,700 ± 200	W-4421	wood (P)	4740	-52	3	2.5 m below top of 9-m-thick lagoonal deposit exposed at east end of north wall of conveyor trench. Lagoonal deposit interfingers above and below with bar gravel. Sequence lies on steeply northwest-sloping buried soil formed in older lake deposits that are exposed 30 m west of south wall of trench.
19,580 ± 280	W-4445	wood (A)	4730	-105	1	In lagoonal deposits within a gravel-bar complex (see loc. 3b, fig. 3)
18,800 ± 180	W-4695	wood	4800	-70	3	From base of 1-m-thick lagoonal mud that was formerly exposed in main working face when it stood about 50 m east of head of conveyor.
18,600 ± 150	W-4693	wood (P)	4900	-40	7	In 30-cm-thick mud that overlies soil developed in sand and gravel of the Little Valley lake cycle. Mud is overlain by sand and gravel of the Point of the Mountain bar. Sample site, which has been removed by pit operations, was 80 m east of powerline tower on south side of pit.
18,000 ± 150	W-4687	wood[d]	5000	-80	4	In 50-cm-thick, fine-grained alluvium and marsh deposit that is conformably overlain by lake gravel and sand in the pit on south side of road to Holladay Gun Club. Alluvium overlies fan gravel from a small basin (Dry Hollow). Sample from floor of a large trench, where it merges with the main pit.
17,580 ± 170	W-4451	charcoal[d]	5000	-85	4	In 4-cm-thick, organic-rich silt within 1-m-thick fine-grained alluvium that overlies a soil in fan gravel of Dry Hollow. Fine-grained alluvium overlain conformably by 1.2 m of outwash, which is conformably overlain by 2 m of lacustrine gravel. Site of sample, which has been removed by pit operations, was from at the mouth of a large trench at southeast corner of pit on north side of road to Holladay Gun Club. A similar section is still exposed on south wall of trench.
16,770 ± 200	W-4896	wood (P,A)	5100	-95	2	In 30-cm-thick mud that overlies a soil developed in alluvium. Mud overlain by 7 m of lacustrine sand. Exposed in backhoe trench 200 m southeast of entrance to the southernmost pit.

[a] Wood identifications (P = _Picea_; A = _Abies_ or _Juniperus_) by D. J. Christenson, U.S.Department of Agriculture, Wood Products Laboratory, Madison, Wisc. (written commun., 1981).
[b] I.C. = isostatic correction
[c] Locations are given in Appendix.
[d] Small branches (<2 cm in diameter)

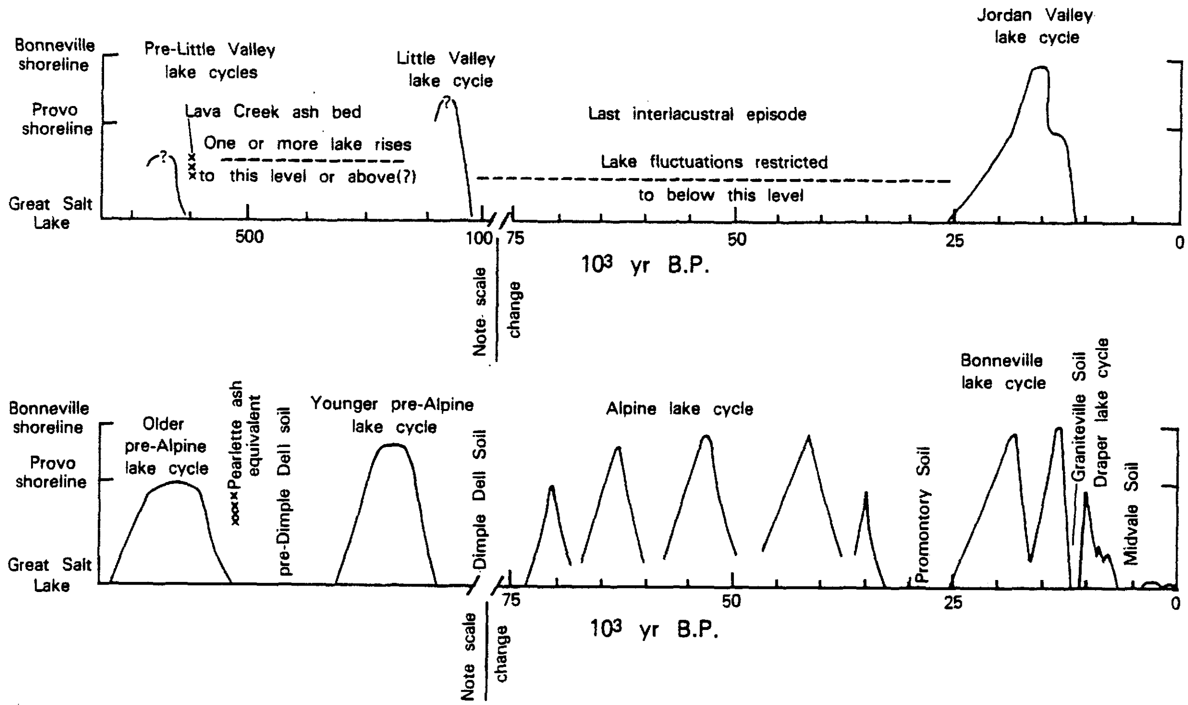


Figure 2.--The history of Lake Bonneville as proposed by us (top) and as interpreted by Morrison (1965a) (bottom).

Morrison (1965c) and Currey (1980) infer a major lake recession during the last lake cycle from two lines of evidence. Morrison (1965c) found features in Little Valley that he interpreted as evidence of subaerial erosion over a large range in altitude, and he considered this as grounds for recognizing a profound lake recession. At stops LV-1, -2, and -3, we interpret the evidence differently and do not find Morrison's argument compelling. Currey's interpretation of a marked lake recession during the last lake cycle is based on (1) morphostratigraphic evidence that the Bonneville shoreline was occupied twice during the last lake cycle, and (2) theoretical factors that concern the differential isostatic rebound of the Bonneville and Provo shorelines. The morphostratigraphic evidence is drawn only from altitudes near the Bonneville shoreline, however, we believe that the argument for lake recession requires supporting evidence from other places within the altitudinal range of the inferred fluctuation. In our studies, we have not found stratigraphic evidence that is consistent with Currey's interpretation. With respect to the differential rebound of Bonneville and Provo shorelines, we believe that the observed differences in altitude can be explained without requiring a marked recession during the last lake cycle. As discussed by Passey (1981), a period of isostatic uplift occurring between the formation of the Bonneville and Provo shorelines offers an explanation for the 17-m maximum differential rebound of these features measured by Currey (1980). Furthermore, the interpretation of the Provo shoreline as an isochronous feature is problematical because (1) some features identified as the Provo may date from older lake cycles or from the earlier part of the last lake cycle, and (2) rates of rebound following the Bonneville flood probably controlled the time at which a coast would have been stable enough for a shoreline to form.

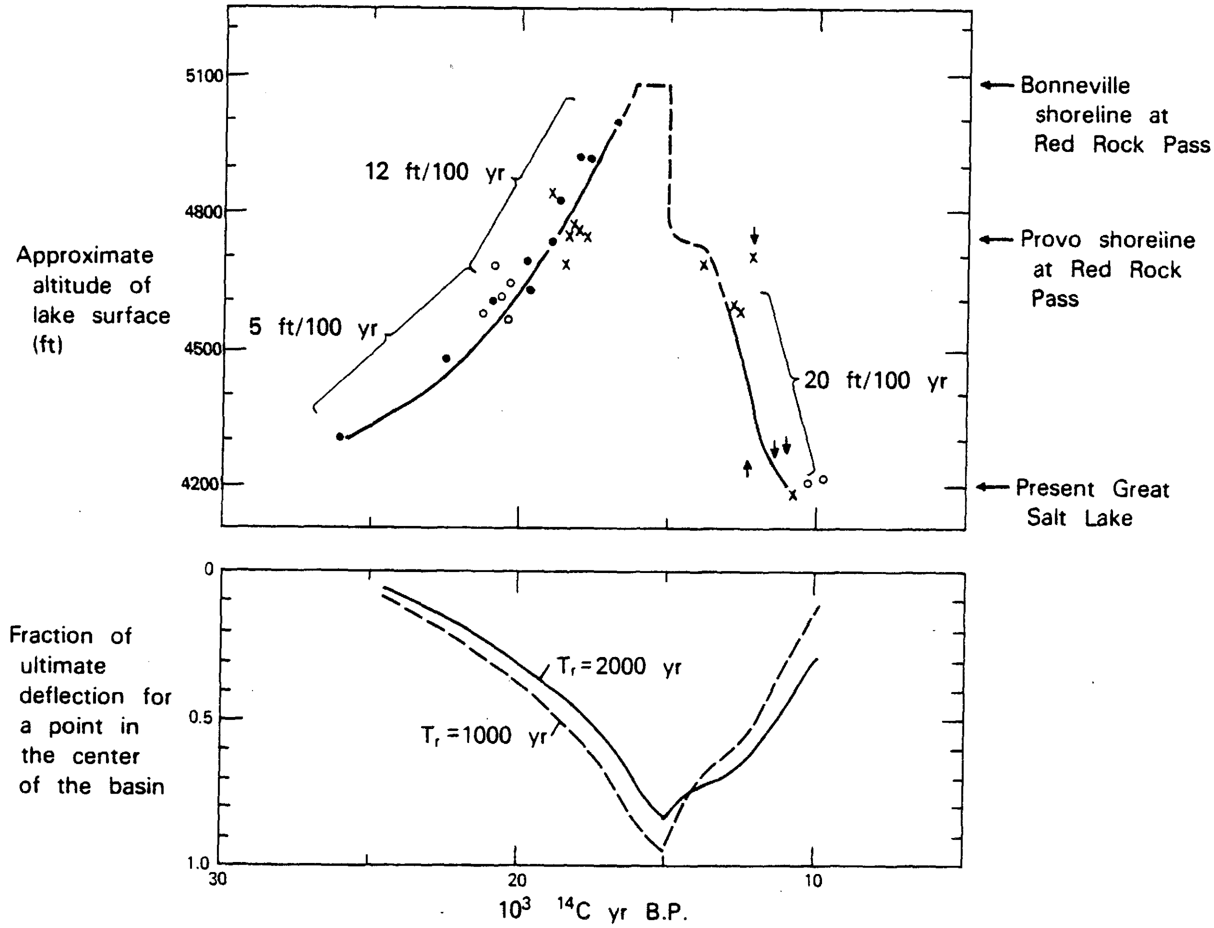


Figure 3.--Lake-level history of the Jordan Valley lake cycle as inferred from stratigraphic and geomorphic relations and from radiocarbon ages (top) and isostatic deflection as a fraction of the ultimate deflection expected for a point in the center of the basin based on the lake-level history (bottom). The altitudes of the dated samples are approximately corrected for the effect of isostatic deformation. New radiocarbon dates of wood and charcoal ( ) are listed in Table 2; previously reported ages of wood and plant debris ( ) and of gastropod shells ( ) that we regard as reliable, or nearly so, are listed in Table 1. The symbol indicates dates on materials that were deposited above lake level. The symbol indicates a date on wood that may have been deposited in deep water. Errors of dates, which are given in Tables 1 and 2, are generally ± 500 yr or less. Rates are mean rates of lake rise and fall calculated over the indicated altitudinal ranges. The isostatic deflection is calculated by the method of Crittenden (1963a, 1963b). The two values of the relaxation-time constant T_r, 1000 and 2000 yr, used here are similar to values suggested by Walcott (1970) and Passey (1981).

Table 3. Mean ratios (± 1 std dev) of alloisoleucine to isoleucine of shells of several genera from deposits of Lake Bonneville.

[Data are from McCoy (1981); all samples analyzed at the Amino-Acid Geochronology Laboratory, University of Colorado. Different preparation procedures used in the fall of 1980 resulted in higher ratios than those measured on the same samples at other times (McCoy, 1981). We list these measurements separately in this table and identify them in Table 4.]

Lake cycle and genera	Mean Ratios of Alloisoleucine/Isoleucine							
	Determinations other than fall 1980				Determinations of fall 1980			
	N[a]	Free	N	Hyrolysate	N	Free	N	Hydrolysate
Jordan Valley lake cycle								
Lymnaea	47	0.20 ± .04	50	0.11 ± .03	31	0.21 ± .04	33	0.15 ± .04
Amnicola	35	.25 ± .03	35	.15 ± .04	19	.26 ± .03	20	.19 ± .04
Little Valley lake cycle								
Lymnaea	1	.52	2	.30 ± .02	11	.50 ± .02	10	.33 ± .08
Amnicola	14	.53 ± .04	13	.34 ± .03	27	.62 ± .09	28	.44 ± .06
Younger pre-Little Valley lake cycle								
Amnicola	24	.61 ± .04	22	.43 ± .04	12	.67 ± .09	12	.57 ± .07
Older pre-Little Valley lake cycle								
Lymnaea?	--[b]	--	--	--	2	1.03 ± .13	2	.81 ± .04
Physa	--	--	--	--	6	1.11 ± .06	6	.64 ± .13

[a] N = number of samples analyzed
[b] -- = no data

Table 4. Ratios of alloisoleucine to isoleucine of shells from deposits of Lake Bonneville.
[All data is from McCoy (1981); analyses were made in the Amino-Acid Geochronology Laboratory, University of Colorado.]

Sample site	LYMNAEA OR PHYSA[p] JORDAN VALLEY Number	Free	Hydrolysate	LYMNAEA OR PHYSA[p] LITTLE VALLEY OR PRE-LITTLE VALLEY* Number	Free	Hydrolysate	AMNICOLA JORDAN VALLEY Number	Free	Hydrolysate	AMNICOLA LITTLE VALLEY OR PRE-LITTLE VALLEY* Number	Free	Hydrolysate
LV-1							AAL-1588	0.26 ± .01	0.18 ± .03	AAL-1586*	0.62	0.42
										AAL-1587*	.81 ± .04	.64 ± .07
										AAL-1589*	.58 ± .03	.43 ± .02
										AAL-1590*	.62 ± .02	.41 ± .01
										AAL-1591*	.58 ± .03	.44 ± .03
LV-3	AAL-756	0.25 ± .03	0.16 ± .01	AAL-757	.52	0.29 ± .02	AAL-1761[a]	.24 ± .01	.21 ± .01			
				AAL-1611[a]	.46 ± .02	.33						
LV-4	AAL-1269	.17 ± .01	.09 ± .01							AAL-1247	.51 ± .01	.31 ± .01
										AAL-1612[a]	.67 ± .07	.41 ± .02
LV-5	AAL-1265	.16 ± .02	.09 ± .01				AAL-1264	.22 ± .01	.16 ± .01			
	AAL-1266	.17	.11				AAL-1265	.22 ± .01	.14 ± .01			
	AAL-1267	.17 ± .02	.12 ± .01				AAL-1266	.23 ± .01	.17 ± .01			
	AAL-1269	.17 ± .01	.08 ± .01				AAL-1267	.22	.08			
	AAL-1270	.16 ± .01	.10 ± .01				AAL-1268	.22	.16			
							AAL-1269	.24	.13			
LV-6	AAL-1757[a]	.24					AAL-1757[a]	.27 ± .03	.24 ± .03	AAL-1756[a]*	1.03 ± .13	.81 ± .04
LV-7										AAL-1594	.50 ± .01	.38 ± .01
										AAL-1758[a]	.50 ± .02	.40 ± .02
										AAL-1600	.57 ± .04	.35 ± .04
										AAL-1595*	.59 ± .02	.42 ± .03
										AAL-1598*	.63	.46
										AAL-1599*	.57 ± .06	.42 ± .01
										AAL-1759[a]*	.72 ± .06	.57 ± .08
										AAL-1760[a]*	.58 ± .01	.53 ± .03
LV-8										AAL-1597	.51	.35
JV-1	AAL-1624[a]	.16 ± .03	.12 ± .02				AAL-1624[a]	.18				
JV-4	AAL-1620[a]	.22 ± .02	.19 ± .02	AAL-1621[a]	.50	.38				AAL-1621[a]	.71 ± .05	.49 ± .01
				AAL-1622[a]	.50	.38				AAL-1622[a]	.57 ± .02	.46 ± .01
				AAL-1623[a]	.52 ± .01	.39 ± .03				AAL-1623[a]	.62 ± .03	.30 ± .02
JV-6	AAL-1629[a]	.23 ± .01	.13 ± .02							AAL-1628[a]	.67 ± .04	.40 ± .03
				AAL-1625[a]*	1.14 ± .05	.61 ± .13[p]				AAL-1630[a]	.55	.40 ± .01
				AAL-1626[a]*	1.03 ± .13	.66 ± .01[p]						

[a] Analyzed in fall, 1980. Analyses made in fall, 1980, were higher than those made at other times on the same samples. See explanation in Table 3.
[p] Physa
* Samples of pre-Little Valley age

Table 5. Secondary calcium carbonate content, estimated duration of soil formation, and estimated ages of parent materials of four buried soils developed in deposits of Little Valley age.

Soil and location	Secondary calcium carbonate content (g/cm^2)[a,b]	Estimated duration of soil formation (10^3 yr)[c]	Time since burial (10^3 yr)[d]	Estimated age of parent material (10^3 yr)
Type Dimple Dell Soil (Morrison, 1965a), near Draper (NW1/4, SE1/4, sec. 15, T. 3 S., R. 1 E.)	53 ± 7	106 ± 14	19.5	126 ± 14
Type Promontory Soil (Morrison, 1965b), (Stop LV-3)	52 ± 5	104 ± 10	20	124 ± 10
Upper buried soil in Moffat pit, near Kearns	48 ± 13	96 ± 26	22.5	119 ± 26
Upper buried soil in Pioneer pit (Stop JV-4)	47 ± 11	94 ± 22	18	112 ± 22

[a] Amount of secondary calcium carbonate (g) is given for a 1-cm^2 column of soil through all horizons. Secondary calcium carbonate content was determined by using the method of Machette (1978).

[b] Range in values results from uncertainties in determining the calcium carbonate content of the parent material, which for all four soils consists of a loess mantle and the underlying sand and(or) gravel. A value of 12.5 ± 7.5% calcium carbonate is assumed for the loess parent material of three of the soils; whereas, a value of 6.25 ± 1.25% is assumed for the original loess mantle of the type Promontory Soil, because the carbonate content of this loess is better known.

[c] Estimated duration of soil formation was determined by dividing secondary calcium carbonate content by 0.5 $g/cm^2/10^3$yr which is the mean rate of secondary calcium carbonate accumulation in four soils formed in deposits of the Jordan Valley lake cycle that are estimated to be about 12,000 yr old (R. R. Shroba, unpublished data, 1982).

[d] Time since burial is the time at which the lake reached the altitude of the buried soil as estimated from Figure 3.

For instance, average uplift rates as high as 6 to 14 m/1000 yr immmediately following the flood (fig. 3) may have precluded development of marked shoreline features at the same time that a shoreline was being formed in areas with lower rebound rates.

We will not visit localities from which evidence has been cited for a rise of the lake almost to the Provo shoreline after 10,000 yr ago following a marked recession late in the last lake cycle (fig. 2). However, radiocarbon dates suggest that the lake was at a low level by 11,000 yr ago (Miller and others, 1980) and that fluctuations after 11,000 yr ago were no higher than the Gilbert shoreline, whose altitude ranges from 40 to 100 ft above present Great Salt Lake (4200 ft; Currey, 1980; Miller and others, 1980).

Last interlacustral episode

Deposits of the last interlacustral episode include alluvium, loess, eolian sand, and colluvium. The episode is also represented by soils or soil complexes. Such deposits and soils can be assigned to the last interlacustral with certainty only where amino-acid ratios (tables 3 and 4) demonstrate that they are underlain by deposits of the Little Valley lake cycle (Stops LV-1,-3,-4, JV-4,-6). In other words, the deposits are physically indistinguishable from those that date from still older interlacustrals. In addition to subaerial deposits and soils, a disconformity with relief of from less than 1 m to more than 100 m (Stops JV-1,-2) is evidence of subaerial erosion and landscape incision that occurred during this episode.

The buried soils that date from the last interlacustral are better developed than are surface soils that have formed in deposits of the Jordan Valley lake cycle, where both have similar parent material, geomorphic position, and climate. The lowest altitude at which we have found a buried soil of the last interlacustral, 4425 ft, suggests that during this episode the lake did not exceed this altitude.

Little Valley lake cycle

The Little Valley lake cycle is the name given to the next-to-the-last rise and fall of Lake Bonneville. During this time, the lake probably did not exceed a level much higher than 200 to 230 ft below the altitude of the subsequent Bonneville shoreline. The highest deposits of the Little Valley lake cycle that we find occur at least 160 ft (stop JV-2) and generally 300 ft or more (Stops LV-4, JV-1,-4) below the level of the Bonneville shoreline. We find no stratigraphic evidence from which to interpret a series of rises and falls of the lake during this time, as was inferred by Morrison for his Alpine lake cycle.

Several lines of evidence suggest that the deposits of the Little Valley lake cycle are about 150,000 yr old and are broadly equivalent in age with oxygen-isotope stage 6 of the marine record (Shackelton and Opdydke, 1973).

(1) Shells from a lacustrine sand of Little Valley age in Little Valley (Stop LV-4; fig. 8) have ^{230}Th ages of 93,000 ± 10,000 yr and >105,000 yr (L-775L, L-775M; Kaufman and Broecker, 1965). These are probably minimum ages because the shells could have absorbed ^{234}U after death (Kaufman and others, 1971).

(2) By assuming that secondary calcium carbonate accumulated in soils during the last interlacustral at an average rate equal to that during latest Pleistocene and Holocene time, the length of time represented by buried soils that formed in deposits of the Little Valley lake cycle prior to burial by deposits of the Jordan Valley lake cycle ranges from 70,000 to 120,000 yr (table 5, R. R. Shroba, unpublished data, 1982). To this can be added the time since burial of the soil by deposits of the Jordan Valley lake cycle. The resulting age range of the Little Valley deposits is from 90,000 to 145,000 yr.

(3) Calcic horizons in the buried soils of the last interlacustral episode are similar in morphology and in amount of secondary calcium carbonate to the calcic horizons in relict soils that formed in deposits of middle Pleistocene age in New Mexico (Bachman and Machette, 1977). Also, the best developed interlacustral Bt horizons are more enriched in clay than those of soils that are formed in 150,000-yr-old Bull Lake Till near West Yellowstone, Montana, (Pierce, 1979) and in tills of Bull Lake age at other localities in the Rocky Mountains (Shroba and Birkeland, in press). In short, the buried soils are more like soils elsewhere in the Rocky Mountains at least 150,000 yr old than those that are a few tens of thousands of years old.

(4) Age estimates from amino-acid ratios depend on assumptions about past temperatures; however, little is known about paleotemperatures during Quaternary time. Alternately, by assuming an age for a deposit, the equation that relates extent of epimerization to time and temperature can be solved for temperature. The credibility of the assumed age can then be judged in light of the calculated temperature values. By assuming that the Little Valley lake cycle is 140,000 yr old, McCoy (1981) calculates an effective diagenetic temperature difference of $-9.5 \pm 1.0^{\circ}$C between the time intervals of 140,000 to 11,000 yr ago and 11,000 yr ago to the present. On the other hand, if the Little Valley lake cycle were 70,000 yr old, or of early Wisconsin age, the effective diagenetic temperature difference between the time intervals of 70,000 to 11,000 yr ago and 11,000 yr ago to the present would be about -6°C. A decision on which value is more realistic is difficult because independent estimates of late Quaternary temperature changes have a large uncertainty, and most apply to only short intervals of time compared with the periods of interest here. For instance, from amino-acid analyses of shell samples whose ages are reliably known, McCoy (1981) estimates that the mean annual temperature between 15,000 and 11,000 yr ago was at least 7°C less than at present. Because the latter half of this time period includes the time of the rapid fall of the lake, which occurred while temperatures were presumably greater than those during the lake maximum, temperatures at 15,000 yr ago were probably more than 7°C less than at present. Other evidence (summarized in McCoy, 1981 and in Porter and others, in press) suggests that temperatures in the Cordillera were lowered by 8°C to as much as 16°C relative to the present during at least parts of the Wisconsin. Thus, the temperature difference implied by the older age is not unreasonable, although it is larger than most previously published estimates of maximum temperature decreases during late Pleistocene time (summarized in Flint, 1971).

(5) Amino-acid ratios of shells from deposits in a small basin near Thatcher, Idaho, that are older than the Jordan Valley lake cycle (Bright, 1963) offer some perspective for estimating the age of the deposits of the Little Valley lake cycle based on amino-acid data. A tephra in the Thatcher deposits resembles a tephra of late Pleistocene age from the Yellowstone area (G. A. Izett, oral commun., 1981); hence the tephra near Thatcher is at least 70,000 yr old, which is the age of the youngest known silicic eruption in the Yellowstone area (J. D. Obradovich, written commun., 1970, *in* Christiansen and Blank, 1972). Shells of *Valvata* 1.0 and 1.5 m above the tephra have alloisoleucine to isoleucine (aIle/Ise) ratios in the total hydrolysate of 0.25 ± .06 and 0.27 ± .04 (AAL-1765, AAL-1766; McCoy, 1981), which are intermediate between ratios of *Lymnaea* (measured in fall, 1980) from deposits of the Jordan Valley and Little Valley lake cycles (table 3). Furthermore, limited data suggest that the rate of isoleucine epimerization in *Valvata* is similar to that in *Lymnaea* (McCoy, 1981). Thus, even though Thatcher basin has a slightly lower mean annual temperature than do areas in the main part of the Bonneville basin, the deposits of the Little Valley lake cycle are probably appreciably older than at least 70,000 yr. However, Miller and Hare (1980) present evidence that the rate of isoleucine epimerization is greater in *Valvata* than in *Lymnaea*.

In summary, several lines of evidence suggest that the Little Valley lake cycle occurred sometime between 70,000 and 150,000 yr ago. From radiocarbon dating, the Jordan Valley lake cycle appears broadly synchronous with a major, mid-latitude episode of glaciation (marine isotope stage 2). Similarly, the Little Valley lake cycle also may have been contemporaneous with a major glaciation, perhaps either marine isotope stage 4 or 6, using the chronology of Shackelton and Opdyke (1973). Judging from the buried soil and amino-acid data from the Thatcher area, the most likely correlation is with marine isotope stage 6, which is about 150,000 ± 25,000 yr old.

Pre-Little Valley lake cycles

Deposits of at least two pre-Little Valley lake cycles are known from Little Valley (Stops LV-6,-7,-8) and Jordan Narrows (Stop JV-6), where they have been identified by their amino-acid ratios (table 4; McCoy, 1981). The oldest lake cycle interpreted from the shore record immediately underlies the 600,000-yr-old Lava Creekash in Little Valley (stop LV-6). Deposits of the one or more pre-Little Valley lake cycle(s) are probably on the order of 400,000 yr old based on amino-acid measurements (McCoy, 1981).

Climatic implications of proposed lake history

The lake history proposed here has several climatic implications for the region.

(1) Either the effect of Pleistocene climates on lakes in the Great Basin, or the climate itself, may have differed from place to place. In particular, the chronology of the Jordan Valley lake cycle differs from that proposed by Benson (1978) for Lake Lahontan. From radiocarbon dates on tufa and gastropods, Benson infers that Lake Lahontan was at its highest level from 25,000 to 22,000 yr B.P. and again from 13,500 to 11,000 yr B.P. In contrast, our studies suggest Lake Bonneville was still only at a low level 22,000 yr B.P.; it was close to its maximum level by about 16,000 yr B.P.; it was falling rapidly by 13,500 yr B.P.; and it had receded to a very low level by 11,000 yr B.P. The reality of these differences, of course, depends on the accuracy of the dates in the two basins.

(2) To the degree that the maximum rise of Lake Bonneville was limited by overflow at Red Rock Pass during the Jordan Valley lake cycle, the time when the highest level would have been achieved under the prevailing climatic conditions is indeterminate. Even so, climatic conditions caused the point of overflow to be reached by 16,000 yr B.P., and changing conditions presumably caused the steady fall in lake level that was taking place by 13,500 yr B.P.

(3) Changes in the size of the tributary basin of Lake Bonneville, chiefly by capture of the Bear River, may also have influenced lake levels, because the Bear presently provides 14% of the inflow of surface water to the Bonneville basin (Bright, 1963). Amino-acid analyses and a tephra, discussed earlier, suggest that lake sediments unrelated to Lake Bonneville were accumulating in the Thatcher basin, Idaho, through which the Bear River now flows, as recently as sometime between the Little Valley and Jordan Valley lake cycles. If true, the diversion of the Bear River offers a possible explanation for the higher level attained during Jordan Valley than Little Valley time, provided that the Little Valley lake was not controlled by a threshold at Red Rock Pass that was substantially lower than that during Jordan Valley time.

(4) If the Jordan Valley lake cycle is an accurate analogue, then older lake cycles probably were relatively brief and were broadly synchronous with major mid-latitude glaciations. However, we find that the last two lake cycles were separated by a long interlacustral episode that included the last interglacial as well as the early and middle parts of the Wisconsin Glaciation. This inference is at odds with the early Wisconsin conditions indicated by the marine record (Shackelton and Opdyke, 1973) and by glacial sequences in the midwestern United States (Johnson, 1976), which together imply widespread glaciation. To the extent that glacial conditions might be expected to be generally matched by lacustrine conditions in the Great Basin, the lack of persistent lakes during the Wisconsin is anomalous. Therefore, we infer that the global cooling that accompanied mid-latitude glaciations was not the sole cause of major rises of Lake Bonneville. More likely, other effects of glacial climates, such as the shifting and concentration of storm tracks that would alter the rate and distribution of precipitation, affected the timing and magnitude of lake fluctuations. For instance, during early and middle Wisconsin time, very low precipitation rates might not have provided sufficient runoff to maintain a high lake in the Bonneville basin, in spite of low temperatures. A subsequent increase in precipitation rate during late Wisconsin time, but not necessarily to a rate greater than today's, if coupled with low temperatures would have caused the lake to rise.

FIELD-TRIP GUIDE

THURSDAY, SEPTEMBER 16

Camp on private land 3 mi southwest of Golden Spike Monument. Golden Spike Monument is located about 32 mi west of Brigham City. Drive 24 mi west of Brigham City on Utah-83 to the road junction by the Thiokol Plant. Turn left, following the signs to Golden Spike National Historic Site, which is 8 mi west of the junction. Follow the FOP signs to the camp site.

FRIDAY, SEPTEMBER 17 — LITTLE VALLEY (Leaders W. E. Scott and W. D. McCoy)

Leave camp by 7:30 a.m. and retrace route to 6 mi east of Golden Spike Monument. As the road straightens and flattens, take a hard (330^{o}) right turn onto a paved road. Stay on this road for 34 mi along the east side and the south end of the Promontory Mountains to the small salt plant at Saline. Continue 5 mi north along the west side of the Promontory Mountains, through a gate, and past the abandoned town site near Little Valley Harbor, and follow the FOP signs to the gravel pit in Little Valley. Park in the lower part of the pit.

CAUTION: Little Valley is private land. The landowner is a sheep rancher who uses this area for winter range and the pits for lambing. Because of the extreme fire danger in the fall and the value of the range to the landowner, please do not smoke, do not park your car with its hot muffler or catalytic converter near vegetation, and do not start a fire to cook a hot lunch!

The bedrock in the Promontory Mountains consists of sedimentary rocks of Precambrian to late Paleozoic age. The north end is underlain by carbonate and other sedimentary rocks of the Pennsylvanian and Permian Oquirrh Formation; the south end is underlain by sedimentary rocks of Precambrian and Cambrian age. Roadcuts at the southern end of the range expose Precambrian Mineral Fork Tillite. In Little Valley, the north valley wall is composed mostly of quartzite; whereas the south valley wall contains carbonate rocks and quartzite.

The altitude of the road to Little Valley stays mostly within about 200 ft altitude of Great Salt Lake. The Bonneville and Provo shorelines are locally visible higher on the slopes of the Promontory Mountains. Gravel bars, spits, and tombolos related to recessional(?) shorelines of the Jordan Valley lake cycle lie along the road and between the road and Bear River Bay to the east.

Great Salt Lake

The construction of causeways, which restrict lake circulation, has divided the lake into 4 bodies of water (fig. 1) that differ in salinity and other physical and biological characteristics. Bear River Bay and Farmington Bay, which receive a significant amount of fresh-water inflow relative to their sizes, are less saline than the south or north arms. The south arm is less saline than the north arm, which receives no direct inflow from a major drainage. Total dissolved solids in the surface water of the south arm during the last decade have ranged from about 120 to 200 g/L; whereas the north arm brine contained 300 to 350 g/L, and was nearly saturated with respect to sodium chloride (Sturm, 1980). Because of this salinity difference, each arm supports different species of algae and bacteria. The north arm contains a large amount of red algae, which give the water a reddish-pink color (Sturm, 1980).

The following discussion is taken from Arnow (1980), who reviewed the water budget and the historic water-surface fluctuations of Great Salt Lake.

Great Salt Lake has fluctuated within a range of about 20 ft in historic time (1847-1978). The historic high was 4211.5 ft in 1873; the historic low was 4191.35 ft in 1963. The present lake-surface altitude is about 4200 ft; seasonal fluctuations in level range between 1 to 3 ft. The lake level would presently be about 5 ft higher were it not for consumptive use of water in the basin.

Surface water accounts for about 66% of the total annual input of water to Great Salt Lake. Of this, about 92% of the average annual surface inflow is from three rivers: the Bear (59%), the Weber (20%) and the Jordan (13%). Average (1931-1976) annual evaporation from Great Salt Lake is about 45 in., based on estimates from pan-evaporation studies.

Stratigraphy of Lake Bonneville deposits in Little Valley

The pit in Little Valley was excavated to provide fill material for the construction of the 13-mi-long Southern Pacific railroad crossing of Great Salt Lake between Promontory Point and Lakeside on the west side of the lake (Newby, 1980). The earthfill embankment was constructed between 1955 and 1959 at a cost of $53 million. Material from Little Valley and from another valley to the south was used to fill a trench dredged in the soft lake-bottom clays; the upper part of the embankment was constructed of stone from two quarries, one just south of Little Valley and one near Lakeside. Conveyor belts moved the material from Little Valley to the boat harbor, where it was loaded onto bottom-dump barges for transport to the dump site.

The pit in Little Valley exposes Lake Bonneville deposits from an altitude of 4500 ft, which is about 300 ft above Great Salt Lake, to about 5160 ft, which is about 120 ft below the local altitude of the Bonneville shoreline (fig. 4). At maximum lake level, the valley was occupied by a rectangular bay, open to the west, that was about 3.5 km long and 1.5 km wide. In studying the deposits in Little Valley, one should keep in mind that units deposited on slopes of the valley have considerable dips, and, therefore, the faces of successively lower benches may expose the same units rather than expose deposits that are stratigraphically lower.

Our interpretations of the stratigraphic relations differ significantly from those of previous workers, which were described in guidebooks of several past field trips to Little Valley including the Friends of the Pleistocene in 1960 by H. D. Goode, INQUA in 1965 (Morrison and Goode, 1965), and G.S.A. in 1975 by H. D. Goode. The main difference is that we have assigned many deposits to the last lake cycle which others have interpreted as having been deposited during older lake cycles. Our evidence is based on physical and soil stratigraphy, radiocarbon dating, and, especially, amino-acid ratios of fossil gastropod shells, which are abundant in many deposits, particularly in basal, transgressive gravel deposits and in sandy and silty deposits of nearshore zones and lagoons.

Our plan is to spend the day hiking through the pit and visiting key localities (fig. 4) that we have found useful in interpreting lake history.

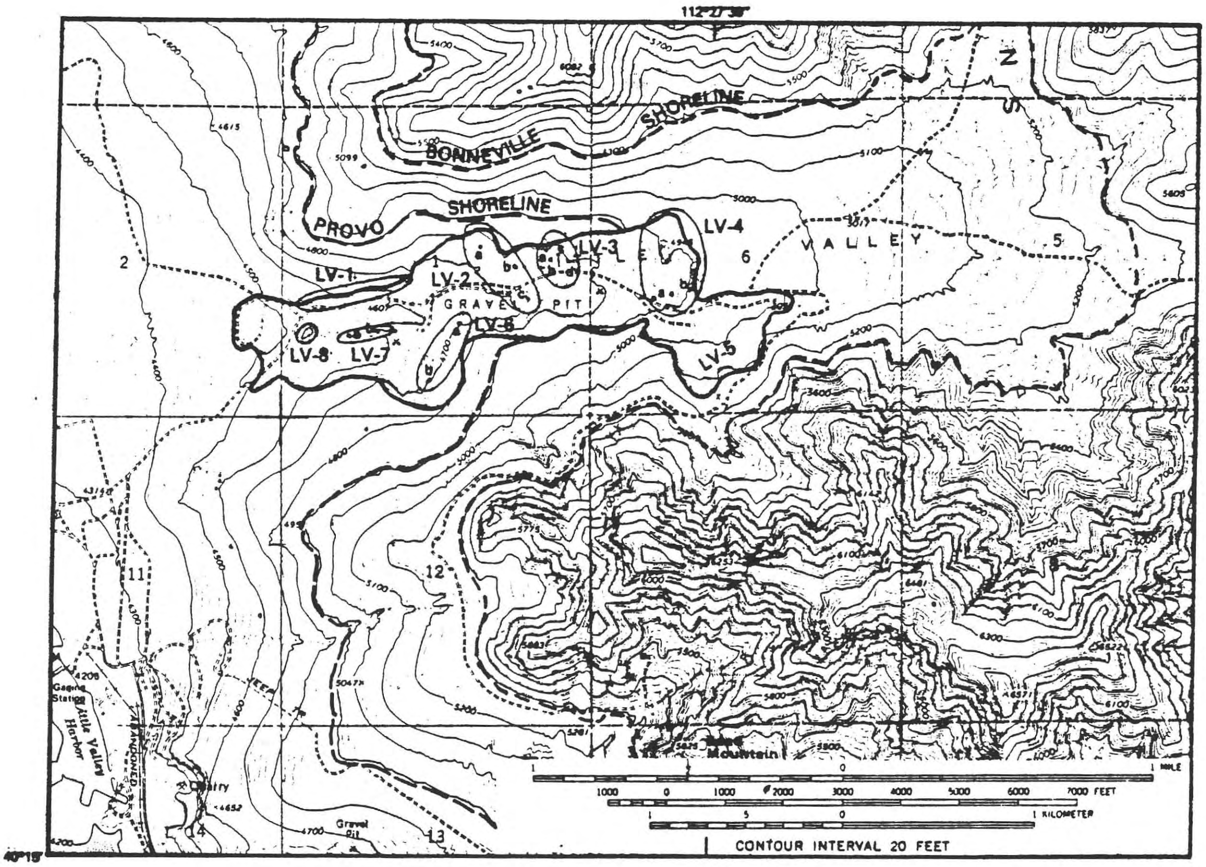


Figure 4.--Topographic map of Little Valley taken from the Pokes Point 7.5-minute quadrangle. The Bonneville and Provo shorelines are shown by the dashed lines. Areas of field trip stops are circled and numbered. Locations of some sections shown in figures 5 to 11 are shown by the lower case letters.

STOP 1 — West end of north wall

For about 300 m along the west end of the north wall of the main pit (fig. 4), sediments of two lake cycles are locally exposed; alluvium and a buried soil having a Bt/Cca profile occur between the two lake units (fig. 5).

Deposits of the Jordan Valley lake cycle and a weak soil formed in them lie below about 1.5 m of spoil. The uppermost part of the Jordan Valley unit is sand and gravel that probably was deposited on a beach during the fall of the lake. A coarse-grained unit that contains many angular cobbles and boulders forms a bed of variable thickness within the deposits of the Jordan Valley lake cycle. The underlying, laminated marly silt is deformed below the lenses of coarse material, suggesting that the fines were saturated when the coarse material was deposited. We interpret the coarse-grained bed as a debris-flow deposit, derived from the steep valley wall above, that entered shallow lake water. The debris flow may have been triggered by minor fluctuations in lake level, which is a common cause of small failures in the slopes around modern-day reservoirs. Our interpretation is in contrast to Morrison's (1965c), who thought that these deposits and other evidence farther east suggested a rapid fluctuation in lake level during the last lake cycle.

LV - 1 West end of the north wall

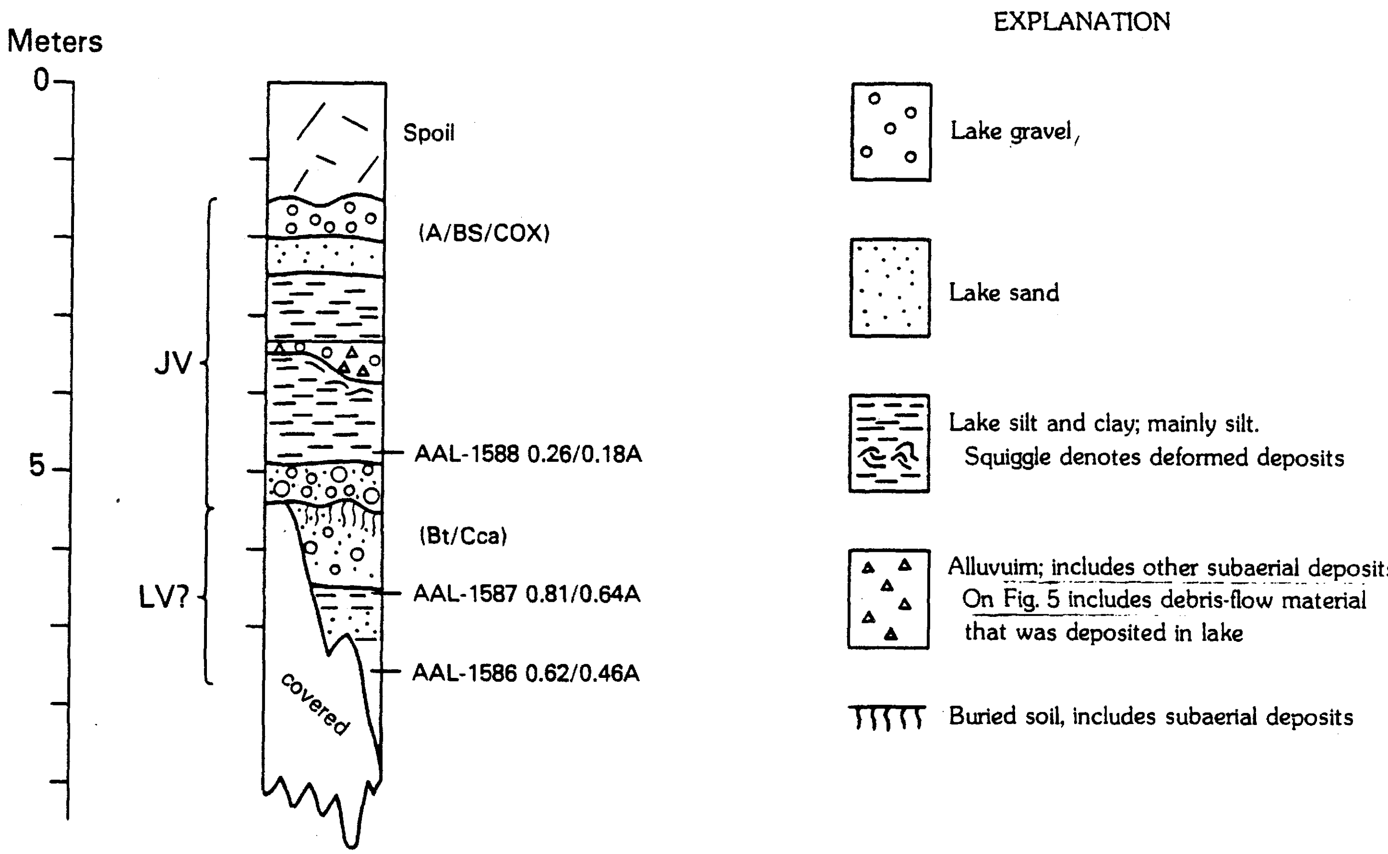


Figure 5.--Composite stratigraphic column of the deposits exposed at Stop LV-1--west end of the north wall of the main pit. Amino-acid samples are identified by AAL-number and are given with their statistical errors in Table 4. L=Lymnaea, A=Amnicola. The lithologic patterns used here also are used in figures 6, 7, and 9 to 11. JV = deposits of the Jordan Valley lake cycle; LV = deposits of the Little Valley lake cycle.

The base of the deposits of the Jordan Valley lake cycle is a coarse, bouldery beach gravel that has tufa coats on some stones. Gastropods are common throughout most of the unit, but are abundant in the lower fine-grained unit. Amino-acid ratios of these shells are characteristic of ratios of shells in other deposits of Jordan Valley age (fig. 5, tables 3 and 4).

Deposits of an older lake cycle are locally exposed in the face. They consist of gravel and sand that overlie laminated silt and clay. A soil formed in these deposits has a 60-cm-thick, pale-reddish-brown Bt horizon and a 50-cm-thick, stage I to II Cca horizon. Stratigraphically, the unit below the buried soil appears to be of Little Valley age; however, the amino-acid results are inconclusive. Two samples of shells from the lower unit gave quite different ratios. The high ratios of the upper sample (AAL-1587) may be due to a shallow depth of burial (<1 m), which promoted a higher effective diagenetic temperature than that for the more deeply buried sample. The ratio of the lower sample (AAL-1586) is higher than ratios of samples of Little Valley age, and suggests that these deposits may be of pre-Little Valley age.

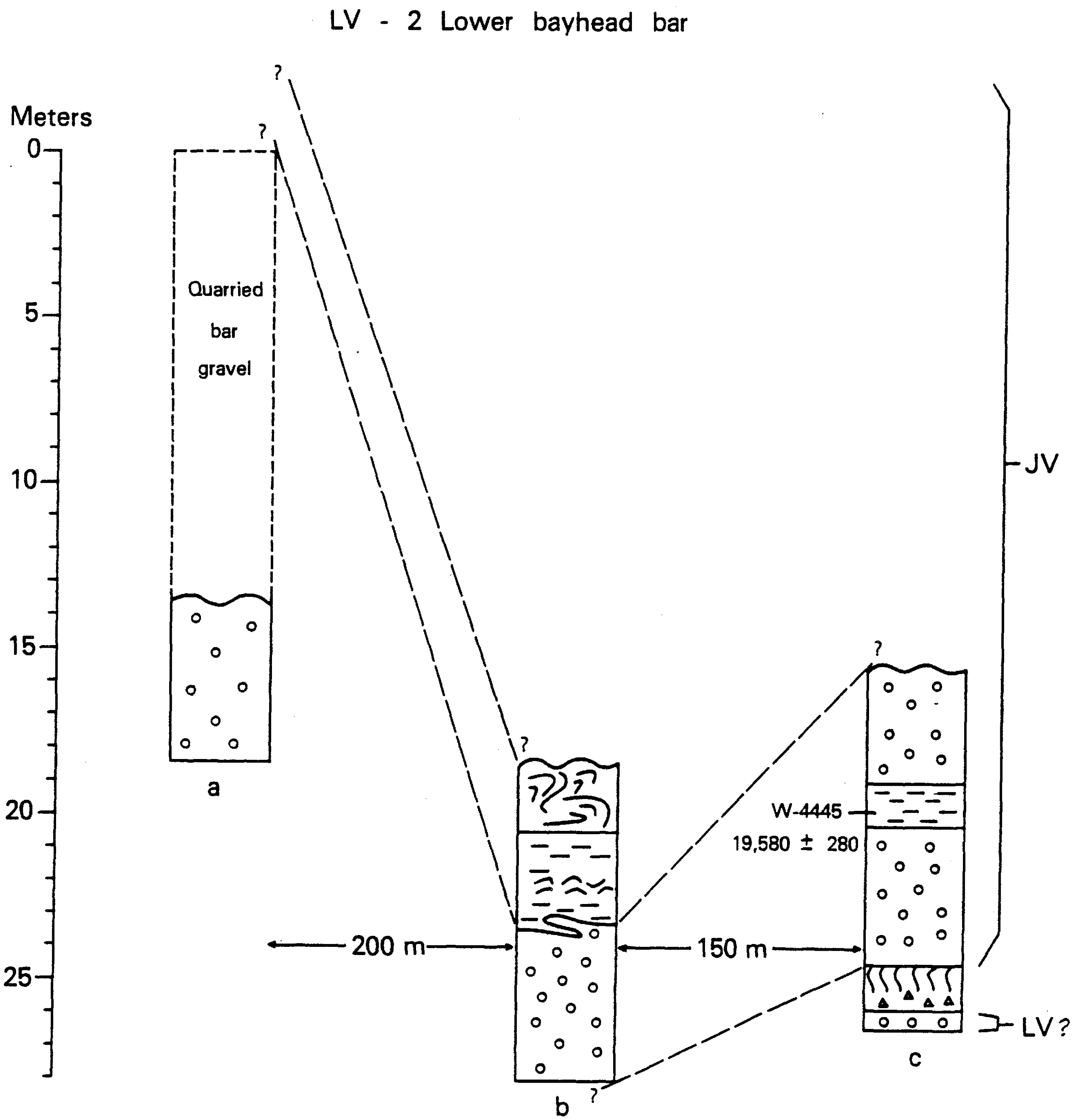


Figure 6.--Three diagrammatic stratigraphic sections at Stop LV-2--lower bayhead bar. The sections are located on figure 4.

Eastward, the units of LV-1 change in thickness and character. Some units are cut out by regressive deposits, others by channels of post-Jordan Valley age. Locally the buried soil betweem the two lake units is missing and the units are difficult to differentiate. Shell-bearing lake deposits of pre-Jordan Valley age found along the wall have amino-acid characteristics similar to those of the lower unit at LV-1. If these older deposits are of pre-Little Valley age, then the Little Valley lake cycle is unrecorded in this section of the pit. However, abundant evidence for the Little Valley lake cycle exists higher in the pit.

STOP 2 — Lower bayhead bar

This is the lowest of three gravel bars that were deposited near the head of the bay that occupied Little Valley. The lower and upper bars are clearly visible on pre-pit aerial photographs; the middle bar is less distinct. Based on statigraphic, amino-acid, and ^{14}C evidence, we assign the lower and upper bars to the Jordan Valley lake cycle and the middle bar to the Little Valley lake cycle.

Much of the lower bar (figs. 4 and 6) has been quarried; however, some of the large, tufa-cemented deposits remain. On the north valley wall the bar overlies fan gravel, which contains several buried soils.

On both the front and back sides of the bar, fine-grained deposits conformably overlie the bar gravel, and locally some of these fine-grained sediments are folded and highly contorted. Apparently, the material was saturated when it slid off the bar. Similar materials found throughout the pit on the slopes of bars and on the valley walls also were deformed by sliding.

In the center of the pit (LV-2c) wood from lagoonal mud that probably was deposited behind this bar, or behind a bar in the same complex as this bar, has an age of 19,580 ± 280 ^{14}C yr B.P. (W-4445).

Morrison (1965c) interpreted this bar as being of Alpine age. However, we think that it is a transgressive bar of Jordan Valley age because fine-grained deposits of Jordan Valley age conformably overlie and locally interfinger with the bar gravel. In addition, if the bar were deposited during an older lake cycle, we find it hard to imagine how a soil or subaerial deposits, as will be seen at Stop LV-3, could have been eroded from the lagoon side of the bar prior to deposition of the fine-grained deposits.

STOP 3 — Middle bayhead bar and the type Promontory Soil of Morrison (1965c)

In this excavation, a gravel bar of Little Valley age is well exposed in cross section. The bar is draped by marly silt, the upper part of which has been deformed by sliding (fig. 7).

Amino-acid ratios of shells from silt lenses in the bar gravel and from the marly silt are characteristic of the Little Valley and Jordan Valley lake cycles, respectively (tables 3 and 4).

A buried soil, the type Promontory Soil of Morrison (1965c), lies between these units and is formed in bar gravel, loessial colluvium, and loess. The soil has a weak Bt horizon of variable thickness. Locally, the Bt is thin and eroded; on the back side of the bar the Bt is thick and is formed in loess and/or loessial colluvium. The Bt overlies a stage III K horizon (fig. 8). A 1 cm^2-column through the profile contains 52 g of secondary calcium carbonate; the estimated duration of formation of this soil is 104,000 ± 10,000 yr (table 5; R. R. Shroba, unpublished data, 1982).

Morrison and Goode (1965) interpret three fluctuations of Alpine age from exposures in this area; we don't agree. We believe that the bar was deposited during a single event. The base of the bar is not exposed presently, but trenching in 1978 revealed a basal sand that overlies a soil developed in fan gravel. The sand grades upward to the bar gravel and a few marly silt lenses are interlayered in the upper part of the bar. These lenses contain abundant snails and are probably shallow-water deposits. This sequence appears to record the building of a gravel bar over shallow-water, sandy deposits. As the bar grew, lenses of marly silt were deposited on both flanks of the bar. For instance, average uplift rates as high as 6 to 14 m/1000 yr immediately following the flood (fig. 3) may have precluded development of marked shoreline features at the same time that a shoreline was being formed in areas with lower rebound rates.

LV-3 Middle bayhead bar

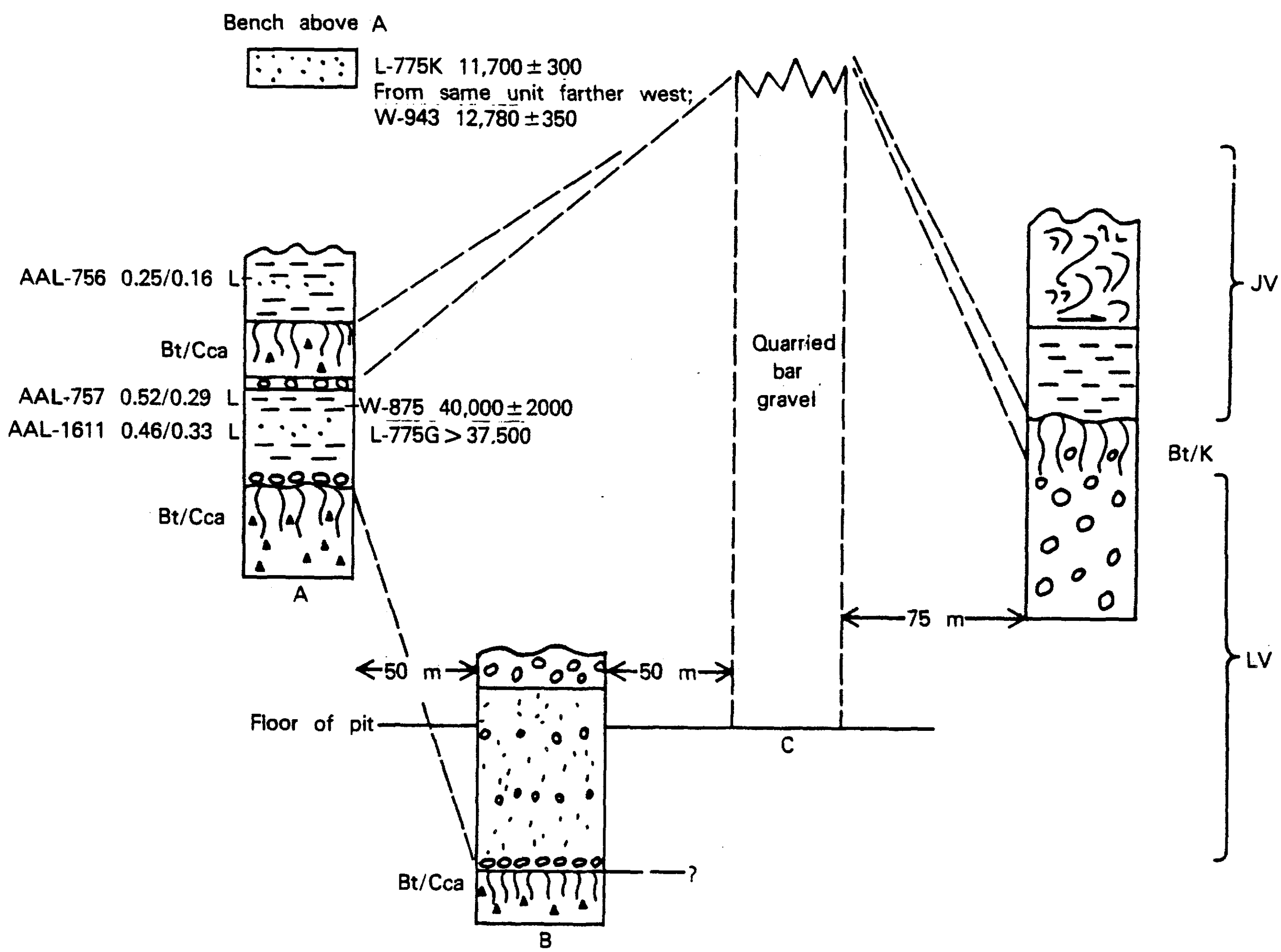


Figure 7.--Four diagrammatic stratigraphic sections at Stop LV-3--middle bayhead bar. The type Promontory Soil of Morrison (1965c) is located about 50 m north of section d, and is traceable to section d. The lower part of section b was exposed in a trench excavated in 1978.

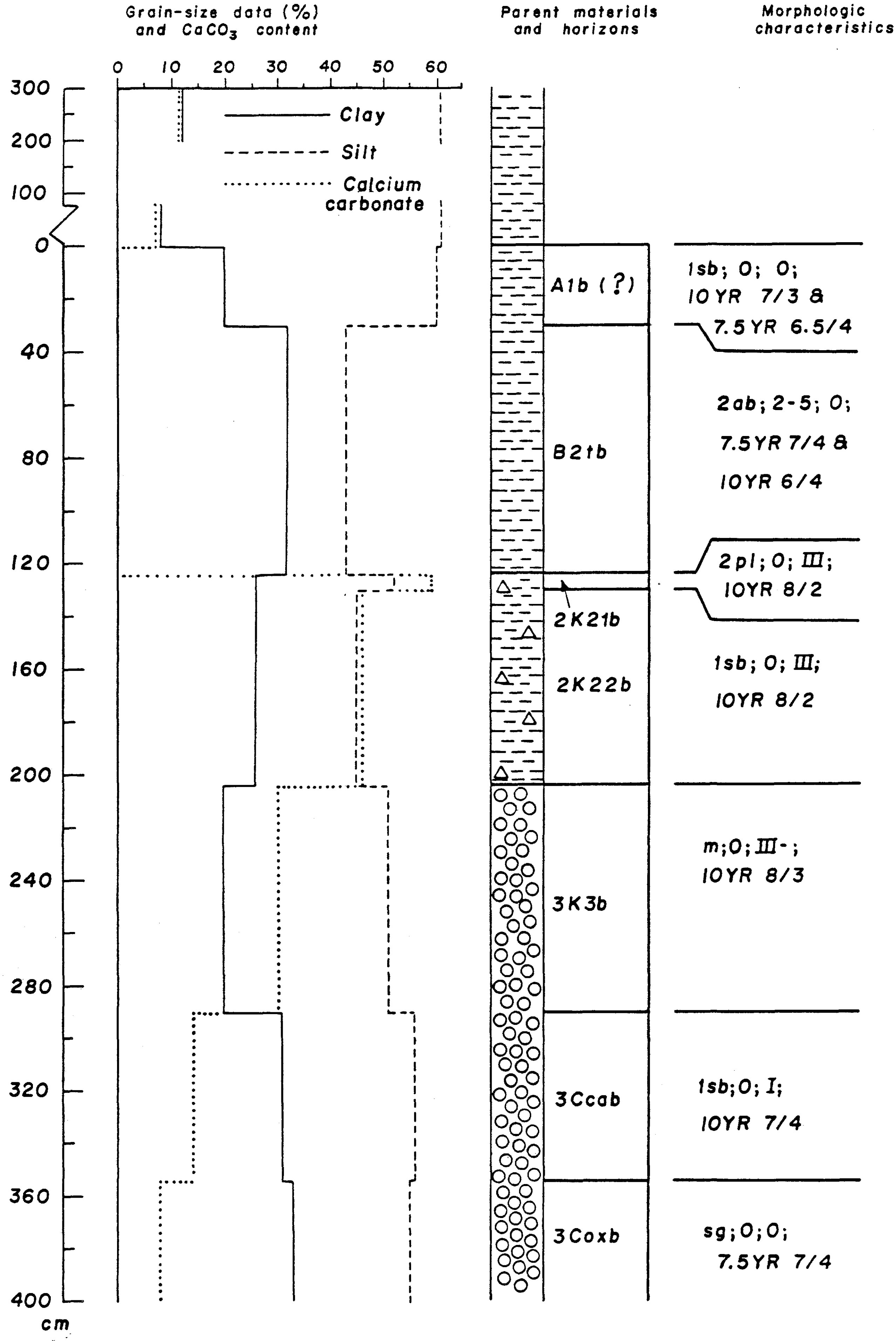

Grain-size data (%) and $CaCO_3$ content
Parent materials and horizons
Morphologic characteristics
0 10 20 30 40 50 60
300
200
100
0
40
80
120
160
200
240
280
320
360
400
cm
Clay
Silt
Calcium carbonate
A1b (?)
B2tb
2K21b
2K22b
3K3b
3Ccab
3Coxb
1sb; 0; 0;
10YR 7/3 &
7.5YR 6.5/4
2ab; 2-5; 0;
7.5YR 7/4 &
10YR 6/4
2pl; 0; III;
10YR 8/2
1sb; 0; III;
10YR 8/2
m; 0; III-;
10YR 8/3
1sb; 0; I;
10YR 7/4
sg; 0; 0;
7.5YR 7/4

Figure 8 (on facing page).--Morphologic and analytical data for the type Promontory Soil at Stop LV-3. Parent materials consist of loess (1) over loessial colluvium (2) over bar gravel (3). The soil is overlain by several meters or more of marly lacustrine silt. The following information applies to this figure as well as to the other soil figures in this guidebook. The centimeter scale to the left of the analytical data is depth below, or height above, the top of the profile. Analyses were performed on material less than 2 mm in diameter. Clay data is for particles less than 2 microns; silt data is for particles 2-53 microns. Soil-horizon nomenclature generally follows that of the Soil Survey Staff (1975) and Birkeland (1974). Exceptions include the use of Bs for cambic B (color and/or structural B) horizons and arabic numerals to designate different parent materials in a profile. Morphologic characteristics listed to the right of the soil horizons include grade and type of structure, clay film morphology, carbonate morphology, and dry Munsell color. Criteria used for distinguishing the grade and type of structure conform to those of the Soil Survey Staff (1975, p. 474-476). Abbreviations for the grade and type of structure are as follows: m-massive, sg-single grain, 1-weak, 2-moderate, 3-strong, gr-granular, pl-platy, sb-subangular blocky, ab-angular blocky, and pr-prismatic. Arrows ( ) indicate the grade and type of structure produced by breaking intact peds. Slashes (/) between symbols indicate differences in the degree of development of morphologic characteristics in the upper part of a horizon versus the lower part. Dashes (-) are used to indicate the range in the degree of development or the range in values for a particular morphological characteristic. The letters nd indicate no data. Morphologic characteristics for various morphogenetic stages of clay film development in soils on this field trip are summarized in Table 6. Stages in the sequence of carbonate accumulation follow those of Gile and others (1966). Carbonate stages with plus signs (+) indicate strong development whereas those with minus signs (-) indicate weak development.

STOP 4 — Upper bayhead bar

The upper bayhead bar is a transgressive bar of Jordan Valley age that is conformably overlain by marly silt and clayey silt that was deposited in a lagoon behind the bar and also in deep water while the lake stood nearer the Bonneville shoreline. The high face on the east side of the excavation exposes a thick section of fine-grained alluvium and colluvium of post-Lake Bonneville age that buries the fine-grained mantle of lake sediments on the bar. At the south end of the excavation, the bar lies on a buried soil formed in gravelly alluvium, which overlies lacustrine sand (fig. 9). The sand contains snail shells that have ratios of alloisoleucine to isoleucine (aIle/Ile) similar to those of shells from the bar gravel of Little Valley age at Stop LV-3.

Shells from this sand unit have a variety of radiometric ages (Broecker and Kaufman, 1965) that show the problems in interpreting radiocarbon dates in excess of 20,000 yr on shells. Radiocarbon ages are 29,000 ± 1600 yr (L-775L) and 25,400 ± 2500 yr (L-775M). ^{230}Th ages of the first sample are 89,000 ± 8000 yr and 97,000 ± 6,000 yr, with a "best" age of 93,000 ± 10,000 yr; ^{230}Th ages of the second sample are 128,000 ± 25,000 yr and 212,000 ± 35,000 yr with a "best" age of >105,000 yr. Considering the ^{230}Th and amino-acid evidence, the radiocarbon ages must reflect contamination with young carbon. Due to the possible addition of ^{234}U after death (Kaufman and others, 1971), these ^{230}Th ages probably should be regarded as minimum ages. This sand is the highest deposit in Little Valley that we can demonstrate is of Little Valley age. It lies about 400 ft below the local altitude of the Bonneville shoreline.

Table 6.--Morphogenetic stages of clay film development.
[The following is an informal classification that was developed for use on the soils in this guidebook.]

Stage	Typical clay film morphology [1]
0	Stones and matrix lack clay films
1	Very few (<5%) to few (5-26%), thin clay films on stones; matrix lacks clay films
2	Very few to few, thin clay films on stones and sand grains
3	Common (25-50%), thin to thick clay films on stones, sand grains, and ped faces
4	Many (50-90%), moderately thick to thick clay films on stones, sand grains, ped faces, and pore walls
5	Continuous (>90%), thick clay films on stones, sand grains, ped faces, and pore walls

[1] Criteria for distinguishing relative abundance and thickness of clay films are from Birkeland (1974, p. 271).

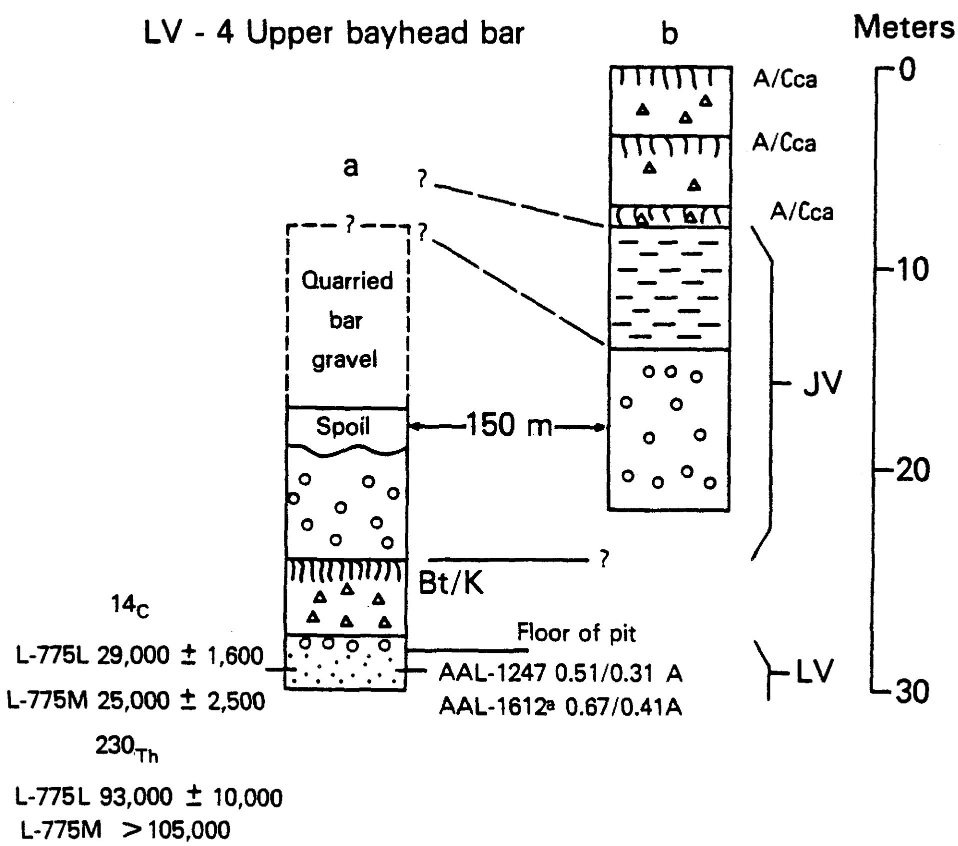


Figure 9.--Two diagrammatic stratigraphic sections at Stop LV-4--upper bayhead bar. The radiometric dates are from Broecker and Kaufman (1965) and Kaufman and Broecker (1965). The dated sand was originally mapped by Morrison (1965c) as deposits of the younger pre-Alpine lake cycle.

STOP 5 — Southeast reentrant

The southeast reentrant is excavated in gravel, sand, and marly silt. The gravel and sand form shoreline embankments and bars; the silts were deposited in lagoons and in deeper offshore environments. Snail shells from several localities in the reentrant have aIle/Ile ratios characteristic of the Jordan Valley lake cycle (McCoy, 1981). No demonstably older lake deposits have been found at this site, but lake deposits, in which we have found no snail shells, that lie below stonelines may be of pre-Jordan Valley age.

STOP 6 — Lava Creekash bed

The Lava Creekash bed (formerly the Pearlette type-O) was erupted from the Yellowstone area about 600,000 yr ago (Izett, and Wilcox, 1982). In this part of the pit, the ash lies near the base of a sequence of alluvium, loess, and buried soils. These subaerial deposits overlie a lake gravel that contains snails that have much higher aIle/Ile ratios than do shells of Little Valley age (fig. 10; tables 3 and 4).

The subaerial deposits are truncated by a stoneline that forms the base of a unit composed of lacustrine sand and minor gravel. To the west the sand unit is found to include an unconformity marked by a stoneline. Amino-acid analyses of shells from the lower part of the sand unit demonstrate a Jordan Valley age for the sand. Therefore, the unconformity at the base of the Jordan Valley deposits represents a loss of considerable record.

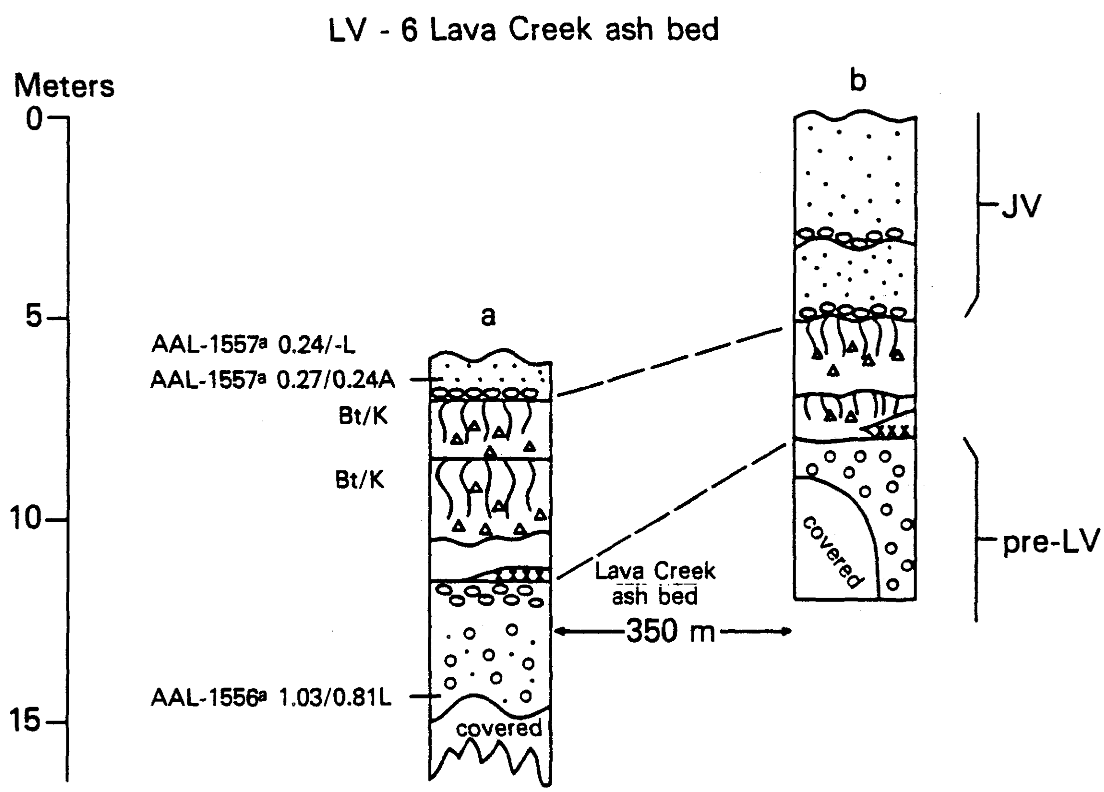


Figure 10.--Two diagrammatic stratigraphic sections along the face at Stop LV-6--Lava Creek ash bed locality. Very little airfall tephra is present; most of the tephra is contained in alluvial or colluvial deposits.

STOP 7 — Ridge south of the upper trestle pit

Exposures on the south side of the ridge that lies on the south side of the upper trestle pit were the type area for a pre-Little Valley lake cycle that McCoy (1981) named Pokes Point. The scraped top of the ridge exposes deposits of the Little Valley lake cycle based on the aIle/Ile ratios of shells of Amnicola that were collected from the base of the upper unit (fig. 11). These deposits rest on a stoneline that cuts interbedded lacustrine sand and silt. Shells from the lower unit have aIle/Ile ratios somewhat higher than those from the upper unit. Near the west end of this face, the two lake units are separated by gravelly alluvium in which a soil is formed. Amino-acid ratios of shells from the two lake units suggest that the deposits are of different ages and the buried soil that separates them demonstrates that the deposits date from two lake cycles that have appreciably different ages.

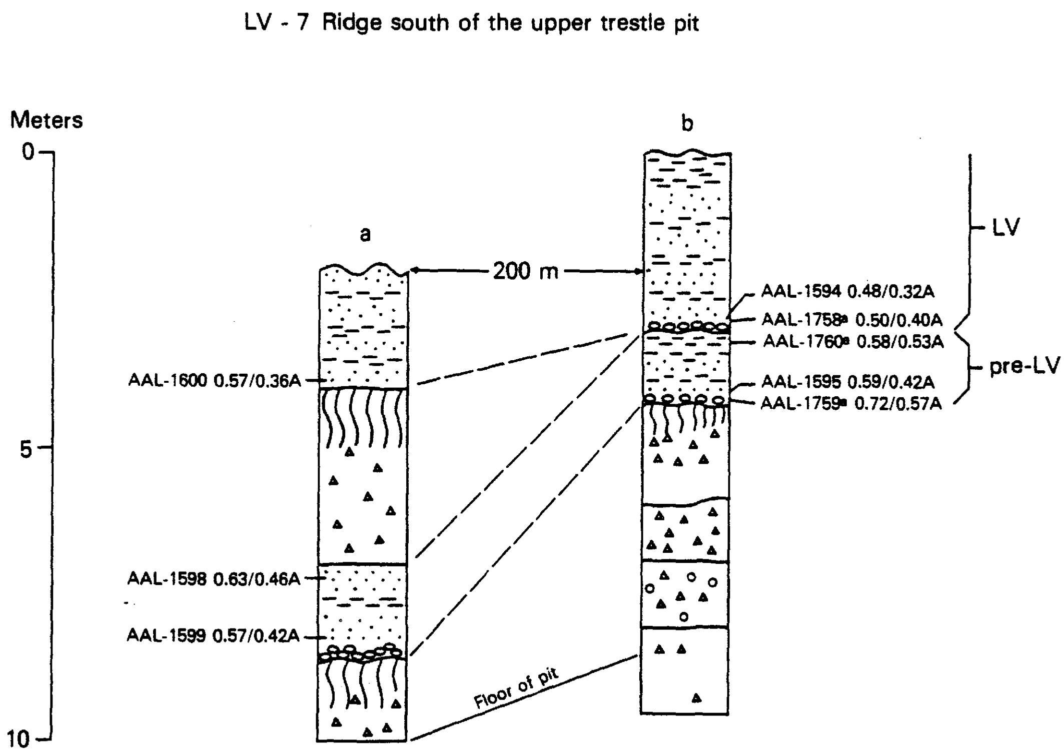


Figure 11.--Two diagrammatic stratigraphic sections at Stop LV-7--south side of the ridge south of the upper trestle pit. Section b is the Pokes Point type locality of deposits of pre-Little Valley age named by McCoy (1981).

STOP 8 — Lower trestle pit

The lower trestle pit exposes deposits of several lake cycles, as well as soils and subaerial deposits (fig. 12). We have not found shells for amino-acid analysis in any of the lake deposits in this pit; however, shells having amino-acid ratios characteristic of deposits of Little Valley age occur in deposits exposed in the low face just south of the concrete pier near the southeast corner of the pit. Therefore, most of the deposits in the pit are of pre-Little Valley age except for deposits of Little Valley age that are exposed in the upper part of the northeast wall and deposits of Jordan Valley(?) age that form the upper part of the northwest wall. The absence of the Lava Creek ash bed in this section suggests, but does not prove, that the deposits are all younger than 600,000 yr.

The lowest lacustrine sediments exposed in the pit were reached by trenching in the southeast corner of the pit. They consist of interbedded silt and sand having a dip of 25° to the northwest that are truncated by fan gravel and loess or reworked loess. The steep dip of these beds may have been caused by faulting or some other process. The marked angular unconformity with the overlying fan gravel suggests that the lacustrine beds may be significantly older than the fan gravel, but there is no way of evaluating their age further without additional work. The loess or reworked loess that lies above the alluvium that buries the lowest lake deposits contains a thin tephra of unknown age and source. Dating of the tephra and paleomagnetic investigations of the loess and lake sediments are needed to define the age of these units low in the pit.

One of the two lacustrine units that are exposed above the tephra may be equivalent in age to the Pokes Point deposits (McCoy, 1981) at Stop LV-7, but the correlation cannot be made without amino-acid data from the deposits in this pit.

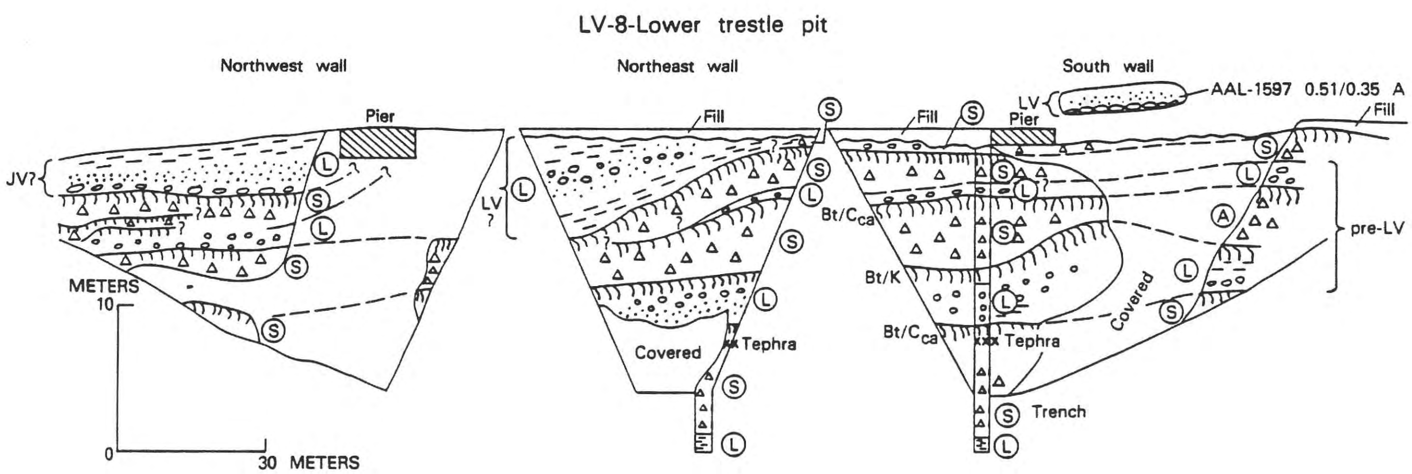
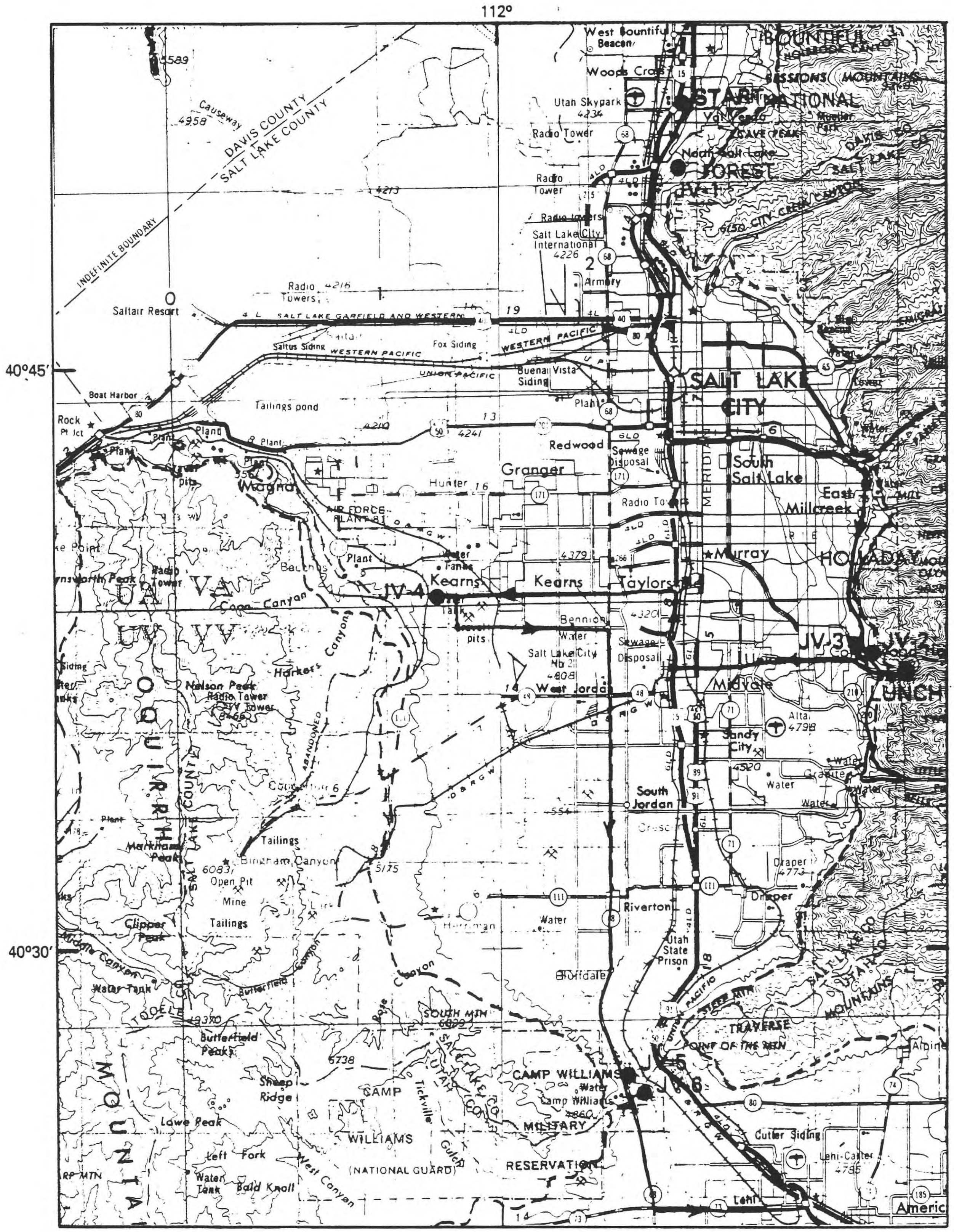


Figure 12.--Sketches of the three faces of the lower trestle pit, Stop LV-8. L = lacustrine deposits; S = subaerial deposits.

Figure 13 (on facing page).--Field-trip route and stops in the Jordan Valley. The Bonneville shoreline is shown by the heavy dashed line. Base is from the Salt Lake City and Tooele 1° x 2° quadrangles, U.S. Geological Survey.


112°
40°45′
40°30′
West Bountiful
Woods Cross
BOUNTIFUL
START
NATIONAL
Utah Skypark
Radio Tower
North Salt Lake
FOREST
JV-1
Salt Lake City International
Armory
DAVIS COUNTY
SALT LAKE COUNTY
INDEFINITE BOUNDARY
Causeway
Saltair Resort
Radio Towers
SALT LAKE GARFIELD AND WESTERN
WESTERN PACIFIC
UNION PACIFIC
Fox Siding
Saltus Siding
Buena Vista Siding
Boat Harbor
Rock Pt Jct
Tailings pond
SALT LAKE CITY
Redwood
Sewage Disposal
Granger
Hunter
Magna
AIR FORCE PLANT 81
South Salt Lake
East Millcreek
MERIDIAN
Radio Tower
Murray
HOLLADAY
Kearns
JV-4
Coon Canyon
Taylorsville
Bennion
Water
Sewage Disposal
Salt Lake City
West Jordan
JV-3
JV-2
LUNCH
Midvale
Harkers Canyon
Nelson Peak
Radio Tower
OQUIRRH
Sandy City
Altai
Water
Granite
Tailings
Bingham Canyon
Open Pit
Mine
Markham Peak
South Jordan
Draper
Riverton
Herriman
Clipper Peak
Water Tank
Butterfield Canyon
Butterfield Peaks
Bluffdale
Utah State Prison
TRAVERSE
POINT OF THE MTN
SOUTH MTN
Rose Canyon
CAMP WILLIAMS
JV-5
JV-6
Camp Williams
MILITARY
RESERVATION
Sheep Ridge
Lowe Peak
CAMP
WILLIAMS
(NATIONAL GUARD)
Tickville Gulch
West Canyon
Left Fork
Bald Knoll
Cutler Siding
Lehi
Lehi-Cutter
Alpine
MOUNTAINS
TOOELE
SALT LAKE CO
UTAH CO

SATURDAY, SEPTEMBER 18 — JORDAN VALLEY AREA (Leaders W. E. Scott, W. D., McCoy, and R. R. Shroba)

Mileage		Observations
Cumul.	Between	
0	0	Trip begins at 7:30 a.m. from the southwest corner of the parking lot of the K-Mart Store at Exit 318 (Woods Cross) off I-15. Head east on road south of parking lot. Figure 13 shows the route and stops.
0.1	0.1	Turn right (southwest) onto U.S. 89 and 91.
1.1	1.0	At 9:00, the MacNeish pit is visible near the Bonneville shoreline. The highest radiocarbon-dated wood sample from transgressive deposits of the Jordan Valley lake cycle was collected from this pit. The date is 16,770 ± 200 yr B.P. (W-4896) on spruce wood (table 2, fig. 3). The lake probably first reached the Bonneville shoreline in areas of low isostatic rebound about 16,000 yr B.P.; and perhaps as much as several centuries later in high rebound areas.
2.1	1.0	Turn left into entrance to a gravel pit operated by the Concrete Products Corp. (CPC).

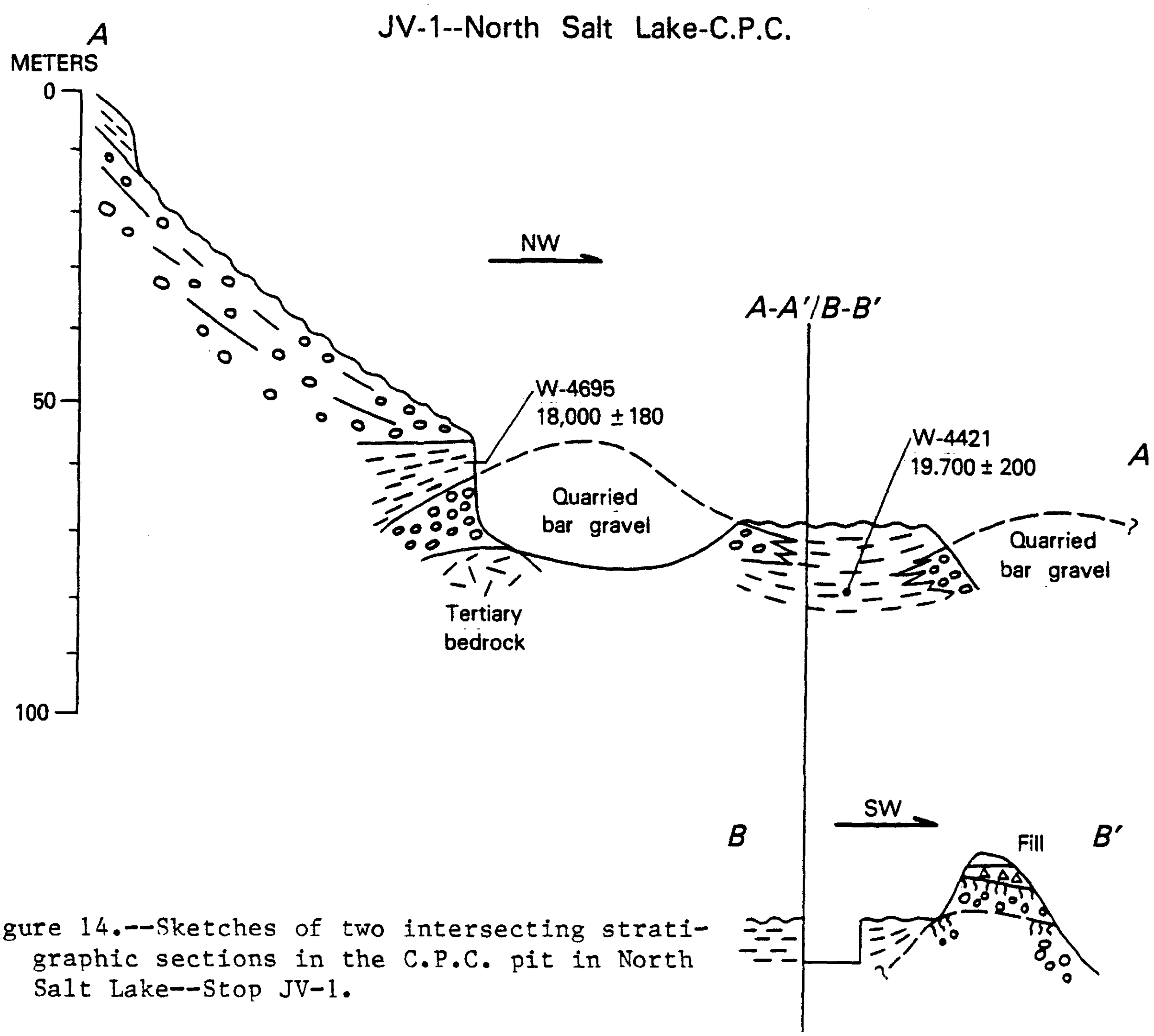


Figure 14.--Sketches of two intersecting stratigraphic sections in the C.P.C. pit in North Salt Lake--Stop JV-1.

STOP JV-1 — NORTH SALT LAKE - CPC

This pit exposes Lake Bonneville deposits from about 4320 ft to almost 5000 ft, which is about 200 ft below the local altitude of the Bonneville shoreline. The exposures low in the pit, which we will not stop to see, consist of sand and interbedded silt that probably were deposited in a nearshore zone. We don't know their age because the exposures are isolated from the upper pit and because we have not found any shells for amino-acid analysis. Our best guess is that they were deposited during the Jordan Valley lake cycle.

Cuts along the road expose light-purplish-gray volcanic breccia and tuffaceous rocks of Tertiary age; correlative beds to the south have yielded fission-track and K-Ar ages of about 35 m.y. (Van Horn, 1981).

Our stop is in the upper part of the pit at the head of the conveyor belt that carries material to the lower pit. The conveyor loading area is at an altitude of about 4780 ft. Gravel of two bars and their related lagoonal deposits that were deposited during the transgressive phase of the Jordan Valley lake cycle are exposed near the head of the conveyor and are shown in two sketched cross sections (fig. 14), whose intersection is in the conveyor trench. The trench is cut in mud and sand that we interpret were deposited in a lagoon that formed behind a gravel bar that stood to the northwest of us, but which has been mostly quarried. Backset (which we use to refer to the landward-dipping beds of a gravel bar; we use foreset beds to refer to the lakeward-dipping beds) gravel beds interfinger with the mud at the down-conveyor end of the trench (A-A', fig. 14). At the up-conveyor end of the trench, the upper beds of the mud and sand sequence interfinger with forest gravel beds of a higher gravel bar that also has been mostly removed by mining, but which once covered the conveyor-loading area. The face near the loading area exposes mud of the lagoon which lay behind the higher bar. Wood from the lower lagoonal mud has a radiocarbon age of 19,700 ± 200 yr (W-4421); wood from mud of the upper lagoon has an age of 18,800 ± 180 ^{14}C yr B.P. (W-4695).

Above the mud exposed in the upper face is northwest-dipping shoreline gravel that was deposited later in the transgression. In the very highest part of the pit, this gravel is overlain by about 4 m of fine sand and silt that were deposited in deeper water than the gravel, probably while the lake stood closer to or at the Bonneville shoreline.

The high remnant of gravel on the southwest side of the trench (B-B', fig. 14) exposes northwest-dipping gravel that overlies a soil that is no longer exposed. The soil dips toward the trench and presumably underlies the mud of the lower lagoon. One year ago, a soil formed in older lake gravel and sand could be seen sloping below the mud of the upper lagoon; at present, the floor of the pit in this area is on red conglomerate of Tertiary age. Apparently, prior to the Jordan Valley lake cycle, there was a valley that transected this area. The rising lake of Jordan Valley age flooded the valley, which was later dammed by a gravel bar. Lagoonal deposits accumulated behind the bar. This scene was then repeated at a higher level.

On the back (southwest) side of the remnant, the west-dipping gravels can be seen overlying a buried soil (Bt/K profile) which is formed in thin subaerial sediments that overlie older lacustrine gravel and sand. The west-dipping gravels of the remnant are truncated by an erosion surface, upon which lies colluvium derived from lacustrine gravel. The erosion surface defines the wall of a gully of post-Jordan Valley age.

The conveyor-loading area lies below the Provo(?) shoreline which consists of a wave-cut cliff and shoreline bench at an altitude of about 4800-4840 ft. If the Provo shoreline represents a stand of long duration (Gilbert, 1890; Currey, 1980), where are the sediments that were deposited while the lake stood at the Provo? The answer is not clear, but deposits of the Provo shoreline are not evident in this pit, as most of the deposits are demonstrably related to the transgressive phase of the last lake cycle and not to the regressive phase, which would include the classic Provo.

3.1	1.0	Leave entrance to CPC pit, turn left (south) onto frontage road on east side of U.S. 89 and 91. The road ahead follows the west end of the Salt Lake salient, a prominent east-west-trending spur of the Wasatch Range.
3.7	0.6	On left, gravel pits operated by Jacobsen Construction Co. expose the smooth, striated fault plane of the Warm Springs fault. The bedrock at the south end of the pit is gray conglomerate of Tertiary age; the fault plane dips westward at 80° (Van Horn, 1981). The deposits of Lake Bonneville exposed in the pit are west-dipping shoreline deposits of gravel and sand with interbeds of silt, fine sand, and clay. Because of the removal of the upper part of the section here, it's not clear if these are transgressive or regressive deposits of the Jordan Valley lake cycle.
5.2	1.5	Frontage road ends at U.S. 89 and 91; turn left (southeast). On the left, behind the Construction Systems concrete plant, the fault plane of the Warm Springs fault is well exposed where it is formed in carbonate rocks of Mississippian age. Most of the Lake Bonneville deposits in the pit have been removed by quarrying.
5.7	0.5	On the left, the remains of the post-Lake Bonneville alluvial fan of Jones Canyon. The white material is lime that was produced by local lime kilns. Gilbert (1890, p. 348, plate XLIV) described a 9-m-high fault scarp that crossed the fan and three alluvial terraces upstream from the scarp. He interpreted the terraces as having been formed by three faulting events.
6.3	0.6	Stay on U.S. 89 and 91; junction of Victory Road on left. The scarp of the Warm Springs fault is just to the left of the highway behind the Children's Museum of Utah, which was formerly a municipal bath facility that used water from the hot springs along the fault. The scarp is formed in gravel and sand of the Jordan Valley lake cycle. South of here, the fault scarp either dies out or has been obliterated by urban development. Further investigations are needed to determine whether or not this active fault extends into the commercial center of Salt Lake City.
7.2	0.9	At the traffic light at the intersection of U.S. 89 and 91 and 6th North (600N), turn right toward I-15. On the right from the overpass ahead, Lake Bonneville shorelines are visible on the west end of the Salt Lake salient. The Bonneville shoreline (5220 ft) is faint and discontinuous; the highest gravel pit on the salient just reaches the Bonneville shoreline. The Provo(?) shoreline is a prominently displayed abrasion platform near the middle of the slope. The lower, prominent abrasion platform is the Stansbury level. These wide abrasion platforms may have been occupied several times in the history of Lake Bonneville, but

because they are erosional features, stratigraphic evidence of multiple occupations is lacking.

7.8 0.6 Turn right onto the ramp to I-15 and Provo.

12.4 4.6 From the left lanes, follow exit 307 onto I-80 toward Cheyenne and Denver.

15.0 2.6 On the right, the Forest Dale Golf Course where Van Horn (1972a, 1972b) mapped and described fault scarps of the East Bench fault that are formed in post-Lake Bonneville alluvium. Scarps that are largely modified by urban development extend south from here for about 8 km. The scarps are formed in deposits of the Jordan Valley lake cycle and younger alluvial deposits. North of I-80 to the University of Utah, the East Bench fault is mapped by Van Horn along a major scarp, which is locally as high as 30 to 40 m. It is not known how much of the scarp's height was formed by faulting in post-Lake Bonneville time, but this is obviously an important topic for earthquake-hazard research.

17.3 2.3 Exit right onto I-215 South, Belt Route. The Bonneville shoreline (altitude about 5200 ft) is visible ahead on the front of the Wasatch Range.

17.5 0.2 View on the right of the valley of Parleys Creek. Scattered outcrops in the valley walls expose fine-grained deposits of the Jordan Valley lake cycle, and possibly the Little Valley lake cycle, which are overlain by deltaic gravel deposited at the Provo shoreline (altitude about 4820 ft) and by alluvial gravel graded to the delta. The alluvial gravel of the topset beds of the delta are exposed in the abandoned gravel pits at 2:00. The soil described later in figure 17 is from the top of this section.

18.4 0.9 Crossing the valley of Parleys Creek on the road fill at the mouth of Parleys Canyon. On the left, the steeply dipping red beds are sandstone and mudstone of the Triassic Ankareh Formation. The prominent, white quartzite unit within the Ankareh is the Gartra Grit Member. Pale-orange, Jurassic(?) and Triassic(?) Nugget Sandstone overlies the Ankareh on the north wall of the canyon (Crittenden, 1965). To the right of I-215, gullies and excavations that are now largely buried by fill from the construction of the building on the rim of the valley exposed in descending order, (1) coarse-grained alluvial gravel graded to the Provo shoreline; (2) lacustrine silt, sand, and gravel of the Jordan Valley lake cycle; (3) a buried soil having Bt and stage III K horizons that is formed in loess(?) and alluvium; (4) lacustrine deposits of the Little Valley(?) lake cycle; (5) gravel alluvium; and (6) shattered bedrock. The buried soil dips to the south into the valley wall; apparently the ancestral valley of Parleys Creek during the last interlacustral lay south of the present valley.

19.0 0.6 On the left, the upper row of houses is just below the Bonneville shoreline, which here is composed of a small gravel embankment and a wave-cut bench.

20.2 1.2 On the left, the Olympus Hills Mall is built on fan gravel derived from Neffs Canyon (10:00). The steep range front ahead is the north face of Mt. Olympus, which exposes quartzites of Cambrian and Precambrian age. No late Quaternary fault scarps have been found in the alluvial and lacustrine deposits between here and Mt. Olympus.

20.9	0.7	On the right, lacustrine sand of the Jordan Valley lake cycle.
21.4	0.5	Temporary end of I-215; merge onto Wasatch Blvd. Wasatch Blvd. follows the Provo shoreline. Above on the left, the Bonneville shoreline is visible on the west end of the Mt. Olympus spur. The lake deposits here, which must have been a high-energy shore, consist mostly of a thin mantle of coarse-grained gravel overlying bedrock.
22.9	1.5	The highest surface ahead is the outwash-fan-and-delta complex that was deposited by Big Cottonwood Creek during Pinedale Glaciation and during the transgression to and the stand at the Bonneville shoreline during the Jordan Valley lake cycle. This fan-delta was incised by streams following the rapid fall of lake level from the Bonneville shoreline to the Provo shoreline during the Bonneville Flood. A strath terrace that was graded to the Provo shoreline is visible below the highest surface. Classic Gilbert deltas, which were deposited where streams entered the lake, are being mined for sand and gravel. The long, steeply dipping forset beds of these deltas are visible in a few of the pits. Much of the sediment that forms the deltas at the Provo shoreline was reworked from the fan and fan-delta deposits at and near the Bonneville shoreline.
23.5	0.6	The steep slope on the right, beyond the line of telephone poles, is a fault scarp formed in sand and gravel of the Jordan Valley lake cycle and overlying fan alluvium of Holocene age. The scarp runs subparallel with Wasatch Blvd. The maximum scarp height is about 24 m.
23.8	0.3	On the left, low road cuts expose fan alluvium of Heughs Canyon. Based on degree of soil formation, this fan surface is considered to be of early Holocene age (R. R. Shroba, unpublished data, 1982). In the oak-covered area to the right, fault scarps as high as 12 m displace the fan surface.
24.3	0.5	Turn left (east) onto the road to the Holladay Gun Club. The active pit south of the road exposes outwash of Pinedale age from Big Cottonwood Creek. Several faults displace the outwash in the northeast corner of the pit.
24.5	0.2	Turn left onto Heughs Canyon Drive and park along Heughs Canyon Drive and in nearby cul-de-sacs.

STOP JV-2 — Big Cottonwood - C.P.C.

At this stop we will examine two gravel pits that are excavated mainly in outwash of Pinedale age from Big Cottonwood Creek, which is veneered with lake deposits of Jordan Valley age. In addition, older outwash and lake gravel are exposed below an unconformity that displays evidence of deep landscape incision along the mountain front and of a long period of soil development that occurred between the two lake cycles.

The road that separates the two pits used to go to the Holladay Gun Club, which is located on the Bonneville shoreline terrace. However, on May 9 of this year, over a period of several hours, a complex failure occurred that removed the road ahead and filled the lower pit on the south side of the road with sediment and water, thereby burying several pieces of expensive equipment. Evidently, saturated gravel and sand with interbeds of silt and clay exposed at the face of the pit began to slump and to flow into the pit. The failure moved headward and formed a scar about 100 m X 60 m X 10 to 15 m deep.

The main part of the pit north of the road (fig. 15A) exposes three units that record outwash deposition, fining of the outwash deposits as the lake level neared this altitude, and the transgression of the lake across this area (Scott, 1981). The lower half of the walls consist of poorly sorted outwash gravel of Pinedale age from Big Cottonwood Creek. Bedding is generally planar, but some beds have low-angle cross-bedding. The outwash contains rock types from the Big Cottonwood drainage, primarily white to tan quartzite and quartz monzonite. A finer grained unit overlies the outwash gravel. It consists of laterally continuous beds and discontinuous lenses of laminated marly silt which contains plant imprints, fine sand, and minor silty clay, which is interbedded with lenses and beds of cross-bedded pebble gravel and sand. We interpret this unit as fine-grained alluvium and deposits of small ponds (in abandoned channels?) that was deposited as the lake margin was approaching. The upper few meters in the northeast corner of the pit consist of lacustrine gravel of Jordan Valley age, which is characterized by a very coarse-grained base, good rounding and sorting, and inclined stratification.

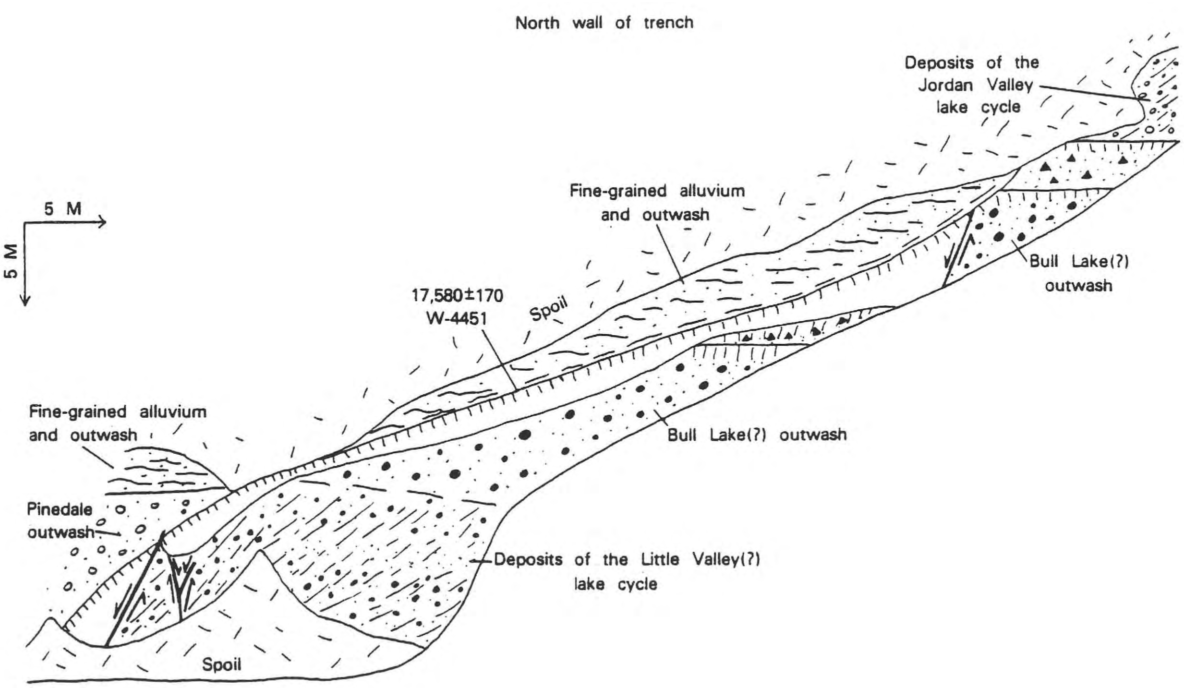


Figure 15.--Sketches showing the stratigraphic relations in Stop JV-2--C.P.C. pits north of the mouth of Big Cottonwood Creek. A. Sketches of the north wall of the trench that enters the southeast corner of the pit north of the road to the Holladay Gun Club. The areas without a pattern expose fault-scarp-derived colluvium. The charcoal of W-4451 was collected about 10 m south of the north wall, in an area that has since been quarried.

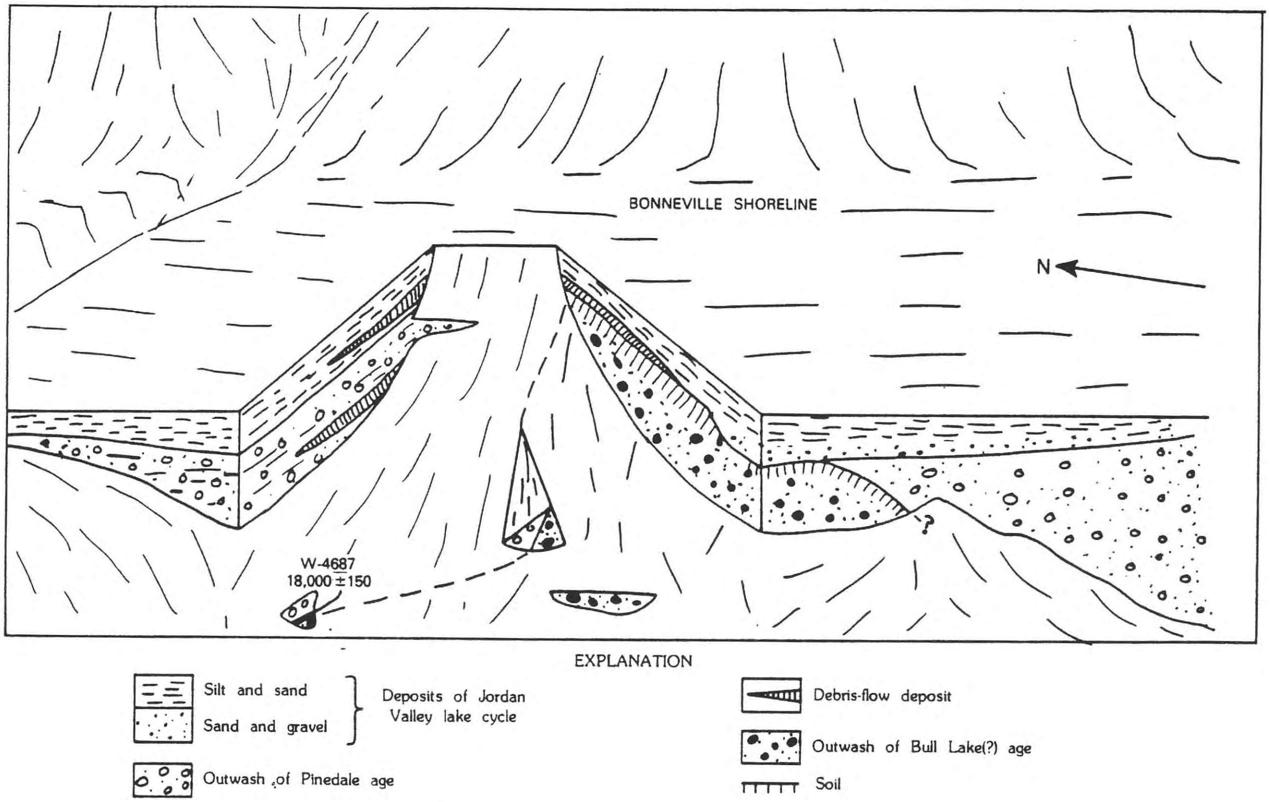


Figure 15.--Sketches showing the stratigraphic relations in Stop JV-2--C.P.C. pits north of the mouth of Big Cottonwood Creek. B. Stratigraphic units exposed in the west-facing wall and trench in the C.P.C. pit south of the road to the Holladay Gun Club. The slope failure of May, 1982, originated on the face near the northwest corner of the pit. The material mapped as outwash of Pinedale age on the north side of the trench and exposed in the recent failure, consists of outwash, alluvium and some pond or lake deposits that filled the paleovalley of Dry Hollow. The valley had been excavated during the Pinedale-Bull Lake interglaciation.

The trench on the southeast corner of the pit exposes the same units as the main pit, but here they bury a fault-bounded sequence of older lake and outwash deposits, subaerial deposits, and buried soils (figs. 15A, 16). The older lake gravel is characterized by parallel inclined beds and well sorted beds. This is the highest lacustrine deposit that we have found that pre-dates the Jordan Valley lake cycle. The top of the lake gravel lies about 220 ft below the local altitude of the Bonneville shoreline. There are no snail shells in the gravel for amino-acid analysis, so we aren't sure of the age of the lake gravel. It's stratigraphic position suggests that it may be a deposit of the Little Valley lake cycle. The lake gravel grades upward to outwash gravel that is similar to, but coarser grained than, the outwash of Pinedale age. A complex of buried soils (fig. 16) are formed in the outwash and in overlying loess, colluvium, and quartzite-rich alluvium of a local basin, Dry Hollow. The buried soils display a much greater degree of development than do soils that have formed in post-Jordan Valley time.

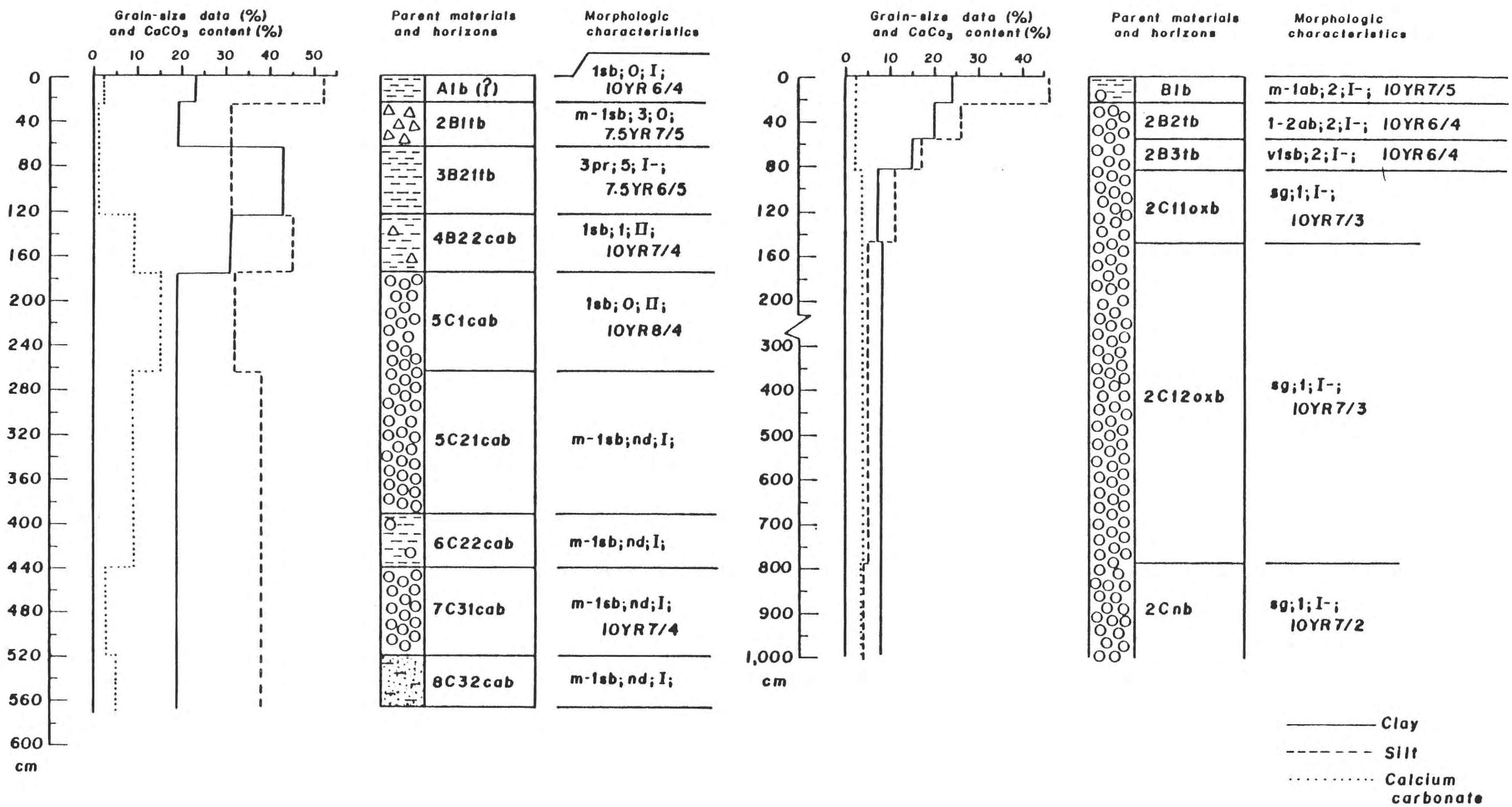


Figure 16.--Morphologic and analytical data for buried soils at Stop JV-2. The soil on the left is directly above and a few meters east of the soil on the right. These soils are exposed in the south wall of a trench (opposite the wall shown in fig. 15A) in the southeast corner of the gravel pit on the north side of the road to the Holladay Gun Club. Parent materials consist of loess (1) over debris-flow(?) colluvium (2) over loess (3) over loessial colluvium (4) over alluvium from Dry Hollow (5-8; 5-pebble gravel, 6-pebbly silt, 7-pebble gravel, 8-silty sand) for the upper buried soil and mixed loess (1) over pebbly outwash gravel (2) from Big Cottonwood Creek for the lower buried soil. Material referred to as mixed loess appears to be loess that is mixed with the underlying gravel.

For comparison, figure 17 presents data for a soil formed in loess and in alluvium of Parleys Creek that is graded to the Provo shoreline. This sequence of lake gravel, outwash, alluvium and soils is offset a total of about 40 m by several faults, and, therefore, the depositional altitude of the lake gravel is not known. The soil that is formed in these deposits and also in colluvium on the fault scarp is buried by the fine-grained unit of the main pit; lake gravel of Jordan Valley age occurs higher in the section. Above the present wall where the trench intersects the main pit, charcoal collected from a 2- to 4-cm thick black bed from near the base of the fine-grained unit yielded a radiocarbon age of 17,580 ± 170 yr B.P. (W-4451). Faulting of the younger outwash and lake deposits has amounted to about 8 m on several faults in the pit.

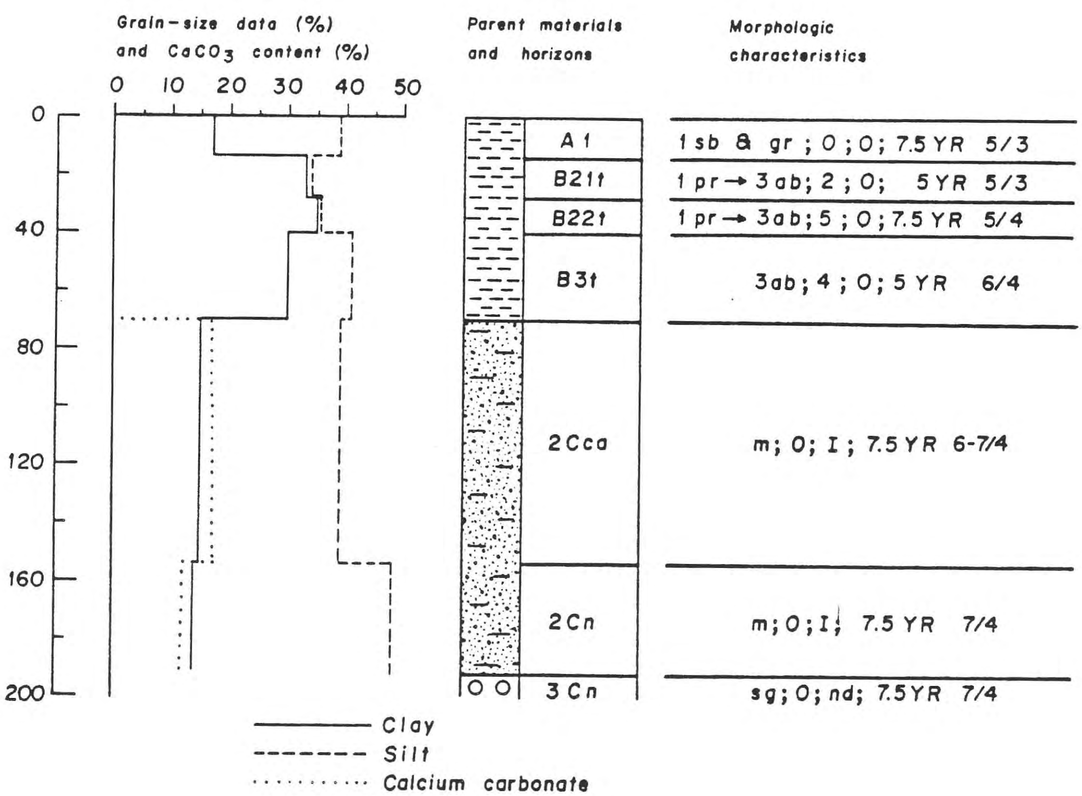


Figure 17.--Morphologic and analytical data for a soil formed in loess and in alluvium of Jordan Valley age along Parleys Creek. The soil is exposed in the south wall of an abandoned gravel pit near the mouth of Parleys Canyon at 2920 South and 3050 East (NE1/4, NW1/4, sec. 26, T. 1 S., R. 1 E.; see road log for mileage 17.5).

The pit south of the road exposes the older outwash gravel, which underlies a paleosurface that has as much as 100 m of relief (fig. 15B). This surface is buried by outwash of Pinedale age, which is overlain by interbedded silt, sand, and fine gravel of Jordan Valley age. Wood from organic-rich mud, which lies below fine-grained deposits that are probably equivalent to the fine-grained deposits in the pit north of the road, has an age of 18,000 ± 150 yr B.P. (W-4687).

The altitude of dated materials from both pits is about the same; however, their altitudes may have been affected by faulting. The dates agree approximately and together suggest that, during Jordan Valley time, the lake did not reach the altitude of the samples, which here lie about 180 ft below the local altitude of the Bonneville shoreline, until sometime after 18,000 to 17,500 yr B.P.

24.7	0.2	Retrace route to Wasatch Blvd. Turn right (north) onto Wasatch Blvd. and immediately turn left onto 6525 South, which is just past the Ski Solitude sign.
25.0	0.3	In the gravel pit on the right, exposures of delta foreset beds.
25.3	0.3	Intersection with Holladay-Cottonwood Road; turn left and park on the right side of the road.

STOP JV-3 (OPTIONAL) Pit operated by Harper Sand and Gravel

The pit is in a Gilbert delta that was deposited by Big Cottonwood Creek, while the lake stood at or just below the Provo shoreline. The east wall exposes thick alluvial topset beds of gravel and sand that overlie northwest-dipping, sandy forset beds.

Continue south on Holladay-Cottonwood Road. Gravel pits on the right are also in a Gilbert delta, and expose foreset beds that dip as steeply as 25 degrees. The road crosses Big Cottonwood Creek and rises onto the top of the delta. The road cuts expose the thick, coarsening-upward, alluvial topset beds of the delta.

26.1	0.8	Intersection with Fort Union Blvd. (7000 South). Turn left (east) onto Fort Union Blvd. The road follows a strath terrace thatime, the lake did not reach the altitude of the samples, which here lie about 180 ft below the local altitude of the Bonneville shoreline, until sometime after 18,000 to 17,500 yr B.P.
27.1	1.0	Traffic light at intersection with Utah-210 (Wasatch Blvd.) at the mouth of Big Cottonwood Canyon; turn right (south). The high scarp just east of Wasatch Blvd. is a fault scarp in alluvial gravel of the terrace that is graded to the Provo shoreline and in fan alluvium that was deposited on the terrace. The road follows the fault scarp and climbs onto the fan-delta that extends to the Bonneville shoreline. Gullies and excavations along the fault scarp expose sand and gravel of the Jordan Valley lake cycle and scarp colluvium derived from these deposits. On the right, the fan-delta surface has been backtilted toward the east by faulting.
28.7	1.6	On the right, a view of the fan-delta of Little Cottonwood Creek and strath terraces that are graded to levels at and below the Provo shoreline.

29.3 0.6 At the La Caille sign, bear right onto Wasatch Blvd. Alluvium and debris flows of Deaf Smith Canyon are displaced by several high fault scarps on the left and by one low scarp to the right.

29.6 0.3 On the right, the Bonneville-shoreline deposits are backtilted by faulting. The Bonneville shoreline trends off to the southwest, away from the road. On the left, the site of a fault-trenching study by Woodward-Clyde Consultants. The fault scarps join to form a single, high scarp at the north end of a graben in till mapped by Richmond (1964) and Morrison (1965b) as late Bull Lake in age. Subsequently, McCoy (1977) and Madsen and Currey (1979) determined that the till is of Pinedale age. Madsen and Currey call this till "Bells Canyon till", an informal name.

30.1 0.5 Wasatch Blvd. crosses Little Cottonwood Creek. 500 m to the northwest on the north side of the creek, gravel and sand of the Jordan Valley lake cycle bury a weak soil formed in Bells Canyon till (fig. 18). Compared with soils of Holocene age in the area and with the surfacce soil formed in Bells Canyon till (fig. 18), Shroba estimates that as much as a few thousand years elapsed between retreat of the glacier from this area and the rise of Lake Bonneville to this level. View ahead to the faulted lateral moraines of Bells Canyon age deposited by the glaciers of Little Cottonwood and Bells Canyons.

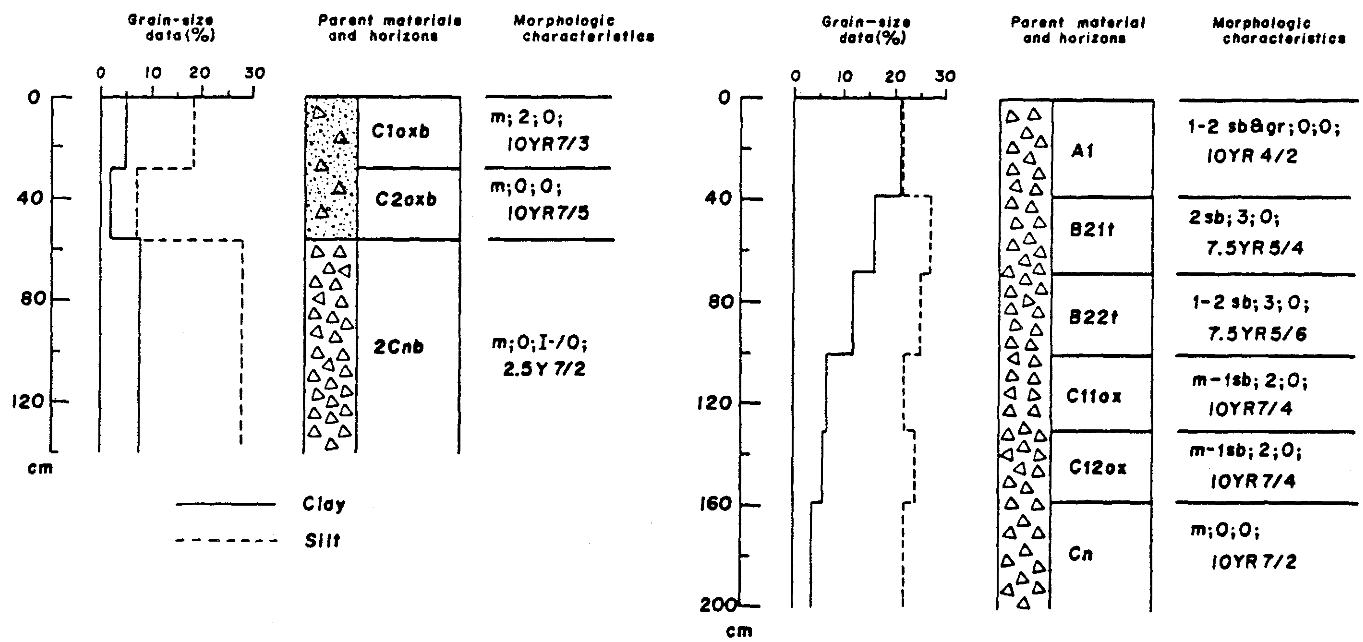


Figure 18.--Morphologic and analytical data for a buried soil and a surface soil formed in Bells Canyon till from Little Cottonwood Canyon. The soil on the left is a buried soil formed in sandy till (1) that overlies more silty till (2). The upper part of the profile has been eroded and is overlain by 2.5 m of sand and gravel of Jordan Valley age. This soil is exposed in a west-facing cut along Little Cottonwood Creek, about 330 m due south of the Murray City Power Plant (SE1/4, SE1/4, sec. 2, T. 3 S., R. 1 E.; Morrison's (1965b, p. 62) stratigraphic section 10). The soil on the right is a surface soil that was exposed in a utility excavation on the crest of a lateral moraine in the Willow Glen Estates subdivision, just northeast of Granite (SW1/4, NE1/4, sec. 11, T. 3 S., R. 1 E.).

30.6 0.5 Wasatch Blvd. ends; turn left toward the mouth of Little Cottonwood Canyon. The road ahead goes through the graben and onto a terrace formed of recessional outwash of the Little Cottonwood glacier.

31.8 1.2 Junction with Utah-210 at the mouth of Little Cottonwood Canyon; turn left. Just northeast of the junction lies the intrusive contact of the quartz monzonitic Little Cottonwood stock of late Oligocene to possibly early Miocene age and quartzite of the Big Cottonwood Formation.

33.0 1.2 Passing the outer limit of till. Ahead, the road descends a fault scarp in fan alluvium of latest Pleistocene to early Holocene age.

35.7 2.7 Traffic light at the junction with Utah-152 at the mouth of Big Cottonwood Canyon; turn right (east).

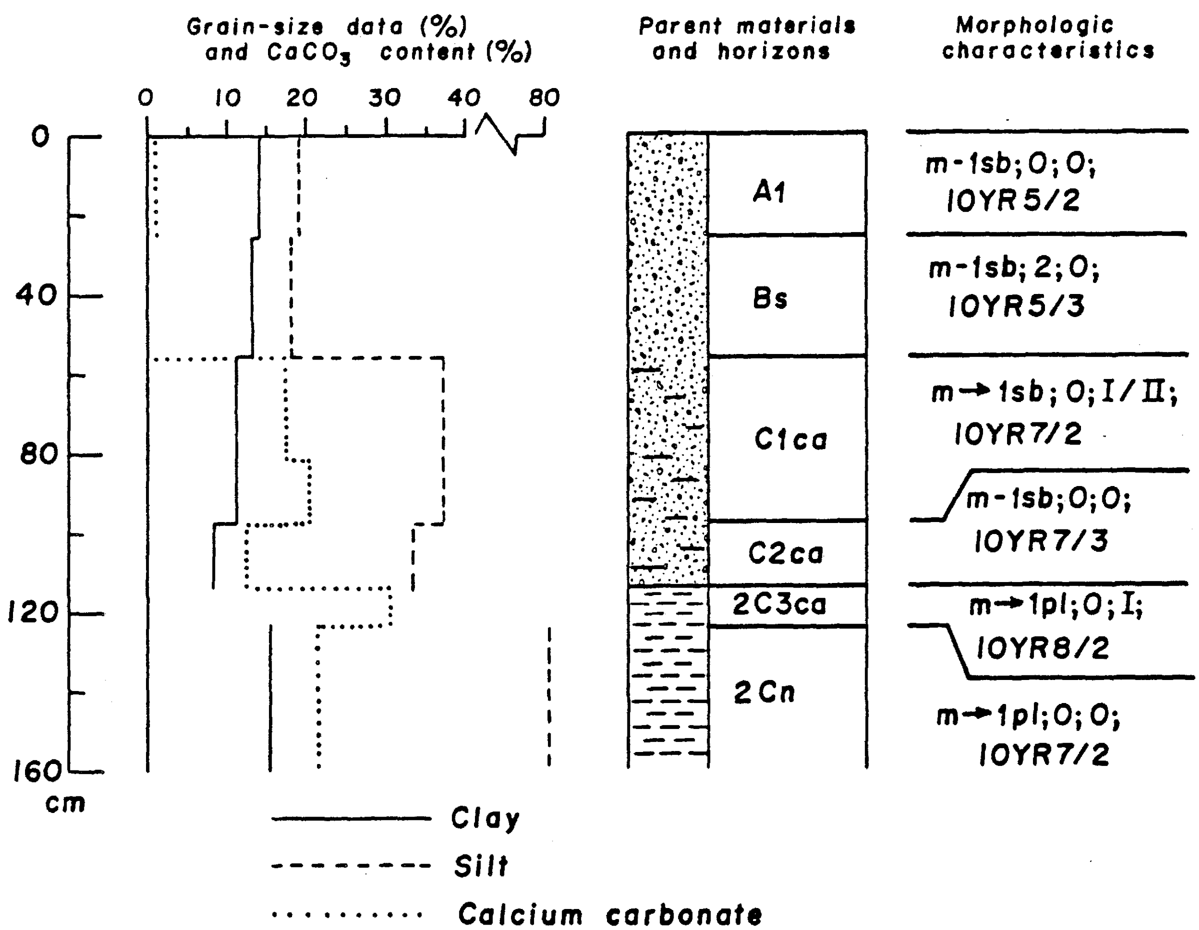


Figure 19.--Morphologic and analytical data for a surface soil formed in lacustrine sand and silt of Jordan Valley age near Taylorsville. Parent materials consist of lacustrine sand (1) over lacustrine silt (2). The upper half of the lacustrine sand is less silty than the lower half and may be partly eolian in origin. The soil was exposed in a utility trench in a new subdivision near 5450 South and 780 West (NE1/4, NE1/4, sec. 14, T. 2 S., R. 1 W.).

36.7	1.0	Turn into Oak Ridge Picnic Area, Wasatch National Forest. Retrace route to the mouth of the canyon.
37.7	1.0	Traffic light at the mouth of the canyon; continue west on Utah-152.
40.6	2.9	On the left, pits expose thin gravel topset beds and steeply dipping sandy foreset beds of the lowest Gilbert delta deposited by Little Cottonwood Creek during the recession of the Jordan Valley lake cycle. The top of this delta is about 75 m lower than the highest Gilbert delta deposited at the Provo shoreline in the Cottonwood area.
43.9	3.3	Junction with I-15; turn right (north) onto I-15.
46.0	2.1	Take Exit 303 to Utah 173 and Murray and Kearns at 5300 South. Turn left (west) toward Kearns on 5300 South (continues west of Jordan River as 5400 South). Figure 19 presents morphologic and analytical data for a soil formed in lacustrine silt and sand of Jordan Valley age near 5450 South. This data will be useful for comparison with data from buried soils of the last interlacustral which we will see at JV-4.
47.3	1.3	Cross Jordan River. Jordan River flows from Utah Lake northward through Jordan Narrows and the Jordan Valley into Great Salt Lake. Small exposures of fine-grained sediments of the Jordan Valley lake cycle occur along the bluffs on both sides of the flood plain of Jordan River. At 8:00 are abandoned clay pits in the bluffs on the east side of the flood plain from which a wood fragment was dated at 26,000 ± 600 yr B.P. (W-4893). The wood was collected from fine-grained, shallow-water deltaic beds that were deposited early in the transgressive phase of the Jordan Valley lake cycle. The wood lay about 100 ft above the present altitude of Great Salt Lake.
48.0	0.7	Junction with Redwood Road (Utah-68); continue west on Utah-173.
49.6	1.6	Intersection with 3200 South. Gravel pits southwest of the intersection that are being subdivided for houses expose gravel and sand that were deposited in bars and shoreline embankments during the Jordan Valley lake cycle. Spruce wood from lagoonal mud near the base of transgressive deposits of the Jordan Valley lake cycle yielded a radiocarbon age of 22,500 ± 300 yr B.P. (W-4898). The pit also exposes deposits of two older lake cycles. The deposits of each lake cycle are separated by buried soils and thin subaerial deposits.
50.6	1.0	Intersection with 4015 West; continue west on Utah-173, which jogs to the left at this intersection.
52.6	2.0	Intersection with 5600 West; continue straight ahead.
52.9	0.3	Crossing the Provo shoreline. To the right, the scarp at the back of the shoreline is cut in thin gravel of Lake Bonneville that unconformably overlies fan alluvium. This alluvium was called the Harkers Alluvium by Tooker and Roberts (1971), who thought it to be of early Pleistocene age. Slentz (1955) first named the unit the Harkers Fanglomerate and suggested it was of Pliocene age. In this area, thin tephra layers are present in the deposit, but they have not been dated.
53.3	0.4	Two gravel pits on either side of the road operated by Pioneer Sand and Gravel. Enter gravel pit on left (south) side of the road.

STOP JV-4 — Kearns — Pioneer Sand and Gravel

In this gravel pit, deposits of two lake cycles are differentiated based on amino-acid ratios of fossil gastropod shells (table 4) and by the presence of a buried soil that lies between the two lake deposits (fig. 20). In this part of the valley, away from major Wasatch Range streams, snails are common in many deposits of Lake Bonneville. We assume that cold, sediment-laden water from meltwater streams on the east side of the valley provided an inhospitable environment for snails.

The deposits of the Little Valley lake cycle form a gravel bar as thick as 12 m, which interfingers with a basal sand unit as thick as 7 m (fig. 20). The sand overlies fan gravels of Pleistocene(?) and Tertiary age, the Harkers Alluvium mentioned at mileage 52.9. Amino-acid analyses are available for three collections of snail shells from the sand at the base of the bar, and are similar to ratios from the type-Little Valley deposits in Little Valley (tables 3 and 4). Except for the faulted older lake gravel of probable Little Valley age at Stop JV-2, the closest deposits to the Bonneville shoreline that are demonstrably of Little Valley age are found here (315 ft below the Bonneville shoreline), in a gravel pit at the Point of the Mountain (230 ft), which we will see from Stop JV-5, and at Stop LV-4 in Little Valley (405 ft).

About 4 m of lacustrine sand at the top of the section was deposited during the Jordan Valley lake cycle. The sand overlies a soil developed in loess(?) and in gravel of Little Valley age. A thin, shell-rich, greenish-gray mud directly overlies the soil and probably in part represents reworking of the A and B horizons of the buried soil.

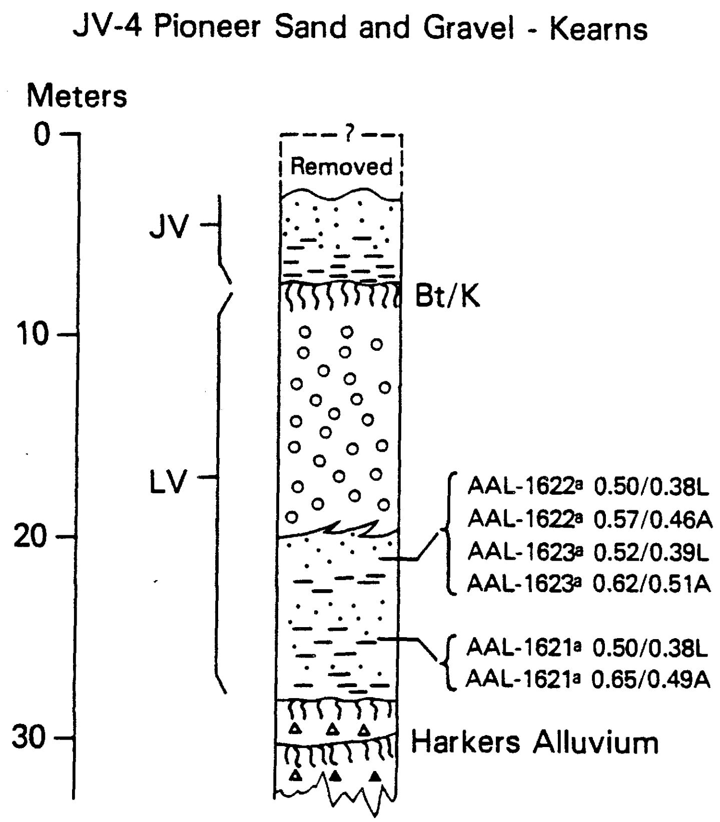


Figure 20.—Diagrammatic stratigraphic section of the west face of the Pioneer Sand and Gravel pit near Kearns—Stop JV-4.

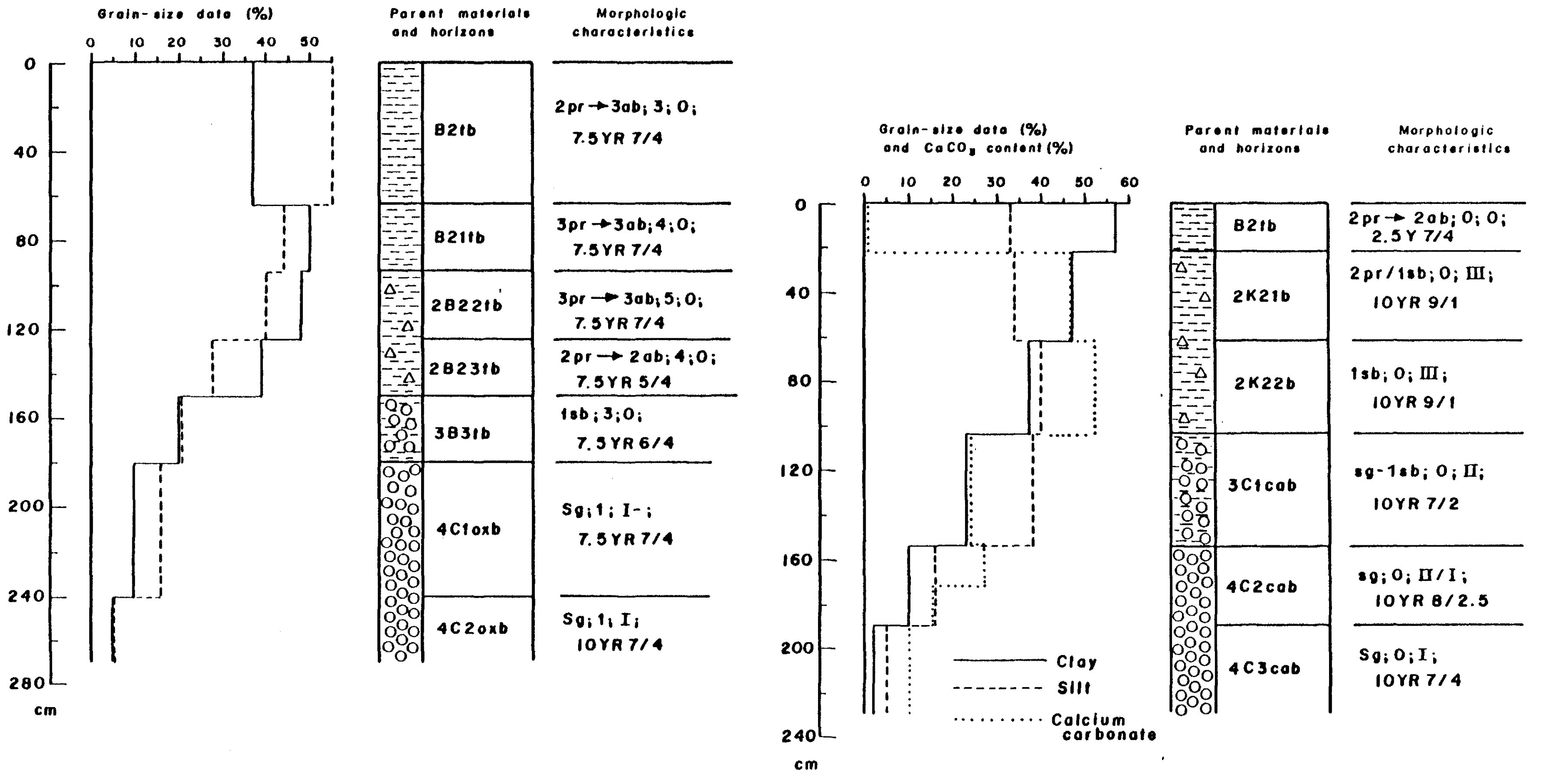


Figure 21.--Morphologic and analytical data for buried soils at Stop JV-4. The soil on the left is exposed in the south wall of the gravel pit, about 110 m east of the southwest corner of the pit. The soil on the right is exposed at the east end of the south wall of a narrow trench in the west wall of the gravel pit, about 90 m north of the southwest corner of the pit. The soil on the left is about 3 m higher and about 145 m southeast of the soil on the right. Soil parent materials consist of loess (1) over loessial colluvium (2) over silty lacustrine(?) gravel (3) over sandy lacustrine gravel (4). The loess parent material for the soil on the left is made up of an older and a younger unit.

The buried soil (fig. 21) consists of a Bt horizon of variable thickness that locally has thick, continuous clay films and moderate to strong prismatic structure. Where the soil has thick calcic horizons, the stage III K horizon and underlying stage I to II Cca horizon contain 47 g of secondary calcium carbonate per cm^2-column of soil. Based on rates of secondary calcium carbonate accumulation in soils in this area in post-Jordan Valley time, this buried soil is estimated to have formed in 94,000 ± 22 yr (table 5; R. R. Shroba, unpublished data, 1982).

53.5	0.2	Leave Pioneer gravel pit and head east on 5400 South.
54.2	0.7	Intersection with 5600 West; turn right (south) on 5600 West. After the turn, the road rises onto the Provo shoreline, which forms a spit that trends to the southeast. The interior of the spit will be visible at mileage 55.5.
55.2	1.0	Intersection with 6200 South; turn left (east) on 6200 South. About 0.6 mi west of this intersection are remnants of a gravel bar that lies at the same altitude as and is probably correlative with the bar of Little Valley age that was exposed in the Pioneer pit at Stop JV-3.
55.5	0.3	On the left, the Monroc-Kearns gravel pit exposes gravel and sand foresets of a spit at the Provo shoreline. A femur of a very large bear, Arctodus?, was found in this pit (Nelson and Madsen, 1980).
58.1	2.6	Intersection with 3200 West; continue east. The road is traversing a series of gravel and sand spits. The surficial deposits are probably related to the recession from the Provo shoreline during the Jordan Valley lake cycle. In addition, from the 22,500-yr date and stratigraphic relations described at mileage 49.6 for a pit 0.5 mi north of this intersection, this level was also the site of deposition of shoreline gravels during the transgressive phase of the Jordan Valley lake cycle and older lake cycles.
59.6	1.5	T-intersection with Redwood Road (Utah-68); turn right (south).
61.1	0.5	Entering West Jordan. The low-relief surface for the next 8 mi is underlain mostly by fine-grained deposits of the Jordan Valley lake cycle.
64.7	3.6	Entering South Jordan. To the east, the moraines at the mouths of Little Cottonwood and Bells Canyons are visible at the Wasatch front. The high peak just south of Bells Canyon is Lone Peak (11,253 ft).
66.2	1.5	Intersection with 10400 South; continue south. LDS Temple to the east is built on a low spit on the flat valley floor.
67.8	1.6	Entering Riverton.
70.6	2.8	Entering Bluffdale.
71.2	0.6	Overlook of the flood plain of Jordan River and the south end of Jordan Valley. The spit at the Point of the Mountain is visible at 11:00 at the west end of the Traverse Mountains. Below Steep Mountain, which is the smooth, steep front of the Traverse Mountains, the Bonneville shoreline forms a prominent embankment. The base of the scarp that fronts the embankment is the Provo shoreline.

The marked vegetation change on the scarp above the Provo is coincident with the contact between lacustrine gravel and sand and highly sheared quartzite bedrock on which the lake cut an abrasion platform. The shrubs are growing on the lake deposits, which grade upward from a basal, bouldery beach gravel to pebble and cobble gravel to fine gravel and sand. The front of Steep Mountain is a 300-m-high wave-cut cliff. As the base of the slope was eroded by waves, the highly sheared bedrock of the range front assumed a uniform 35^{o} slope.

As the road climbs ahead, the view of the spit improves. I-15 follows the Provo shoreline, which is cut into the base of the spit. The pits below I-15 are being excavated in west-dipping sand and gravel at the Provo shoreline and in recessional shorelines below the Provo.

73.2	2.0	Passing under two powerlines. At 11:00, Jordan Narrows is visible.
74.8	1.6	On the right, sign to Jordan Narrows pumping plant; turn left. Stay on paved road.
75.2	0.4	Pull off on the right below the powerlines.

STOP JV-5 — Overlook of Jordan Narrows and Point of the Mountain

To the northeast, the spit at the Bonneville level at the Point of the Mountain was formed by lake currents at this constriction between the Jordan Valley to the north and the Utah Valley to the south. Above the Provo shoreline, on which I-15 is built, several gravel pits, which aren't visible from here, expose the dipping sand and gravel beds in the spit. In one of the pits, a buried soil separates two units of lake gravel and sand. Snail shells from the units have amino-acid ratios characteristic of deposits of the Jordan Valley and Little Valley lake cycles. Wood from a mud at the base of the upper gravel has an age of 18,600 ± 150 yr B.P. (W-4693). As mentioned at Stop JV-4, the highest altitude of the Little Valley deposits in the pit at Point of the Mountain is 4920 ft, which is about 230 ft below the local altitude of the Bonneville shoreline. Relative to the local altitude of the Bonneville shoreline, the Little Valley deposits at the Point of the Mountain are the highest deposits that we have found that are demonstrably of the Little Valley lake cycle.

The pit below the Provo shoreline, which is visible to the north-northeast across the Jordan River, exposes both transgressive deposits of the Jordan Valley lake cycle and deposits of the Provo shoreline, which was occupied during the regressive phase of the Jordan Valley lake cycle. A mud layer midway up the wall in the eastern part of the pit was deposited in lagoon that lay within a transgressive gravel-bar complex. Wood from the mud has a radiocarbon age of 20,900 ± 250 yr B.P. (W-4897). The gravel of the bar complex is truncated and overlain by sand and fine gravel that was deposited while the lake stood at the Provo shoreline. This sediment at the Provo shoreline was probably largely reworked from the Point-of-the-Mountain spit on which the shoreline is cut. With this abundant supply of sediment, the Provo here need not represent a long period of time.

75.4 0.2 Cross canal and turn right onto the road on the outer bank of the canal. CAUTION: If the road is wet, it's going to be very slippery.

75.9 0.5 Gate across road just beyond blue-green stand pipe; park on the road beyond the gate.

STOP JV-6 — Jordan Narrows

This cut was made for a pipeline that carries water from the pumping plant on the Jordan River into the Utah Lake Distributing Canal, which brings irrigation water to the northwestern Utah Valley.

Deposits of at least three lake cycles and intervening unconformities are exposed in the cut (fig. 22); all the units have been identified on the amino-acid ratios of fossil gastropod shells (table 4).

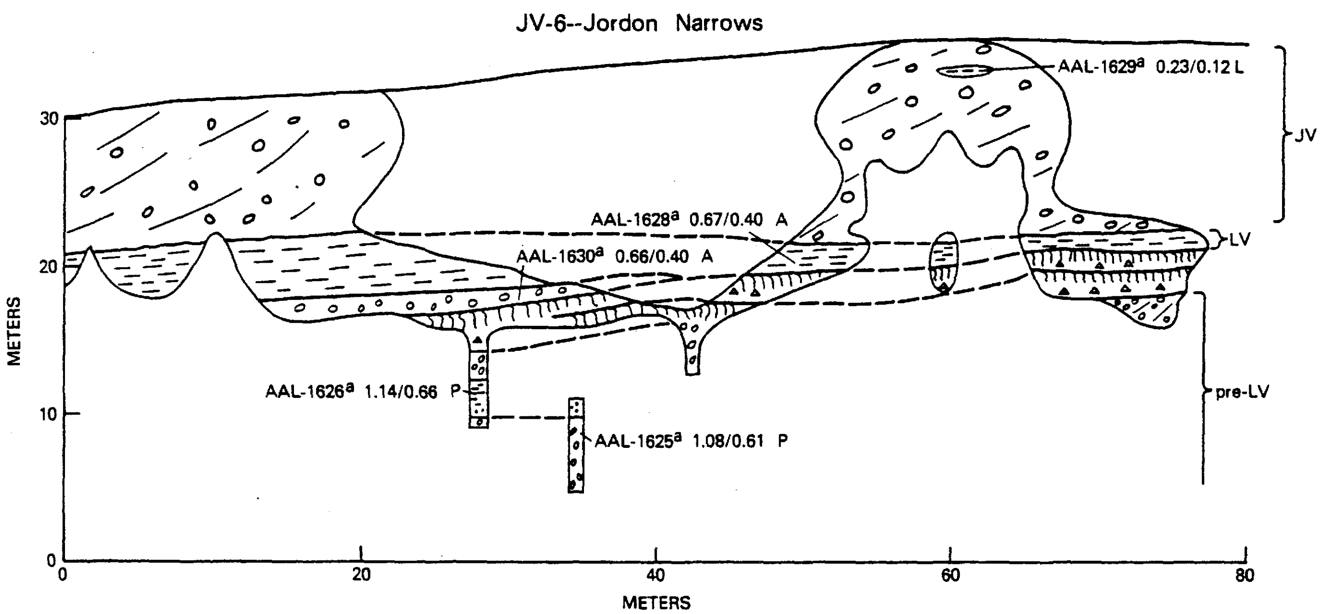


Figure 22.--Sketch of the section exposed above the buried pipeline south of the blue-green standpipe above the Jordan Narrows Pumping Plant.

The upper gravel and underlying silt and fine sand demonstrate the problems in interpreting unconformities in the Lake Bonneville sequence and the value of the amino-acid technique in differentiating stratigraphic units. A silt and sand lense near the top of the east- to southeast-dipping gravels at the top of the section contains Lymnaea shells having ratios characteristic of the Jordan Valley lake cycle. The gravel overlies light brown silt and fine sand with a sharply defined erosion surface having relief of tens of centimeters. Amnicola shells in the silt and sand have ratios characteristic of the Little Valley lake cycle. Without the amino-acid measurements we would have no way to evaluate the time significance of the erosion surface, as similar surfaces occur within the deposits of a single lake cycle. The lost record at the unconformity probably includes additional lake sediments and subaerial deposits and soils of the last interlacustral episode.

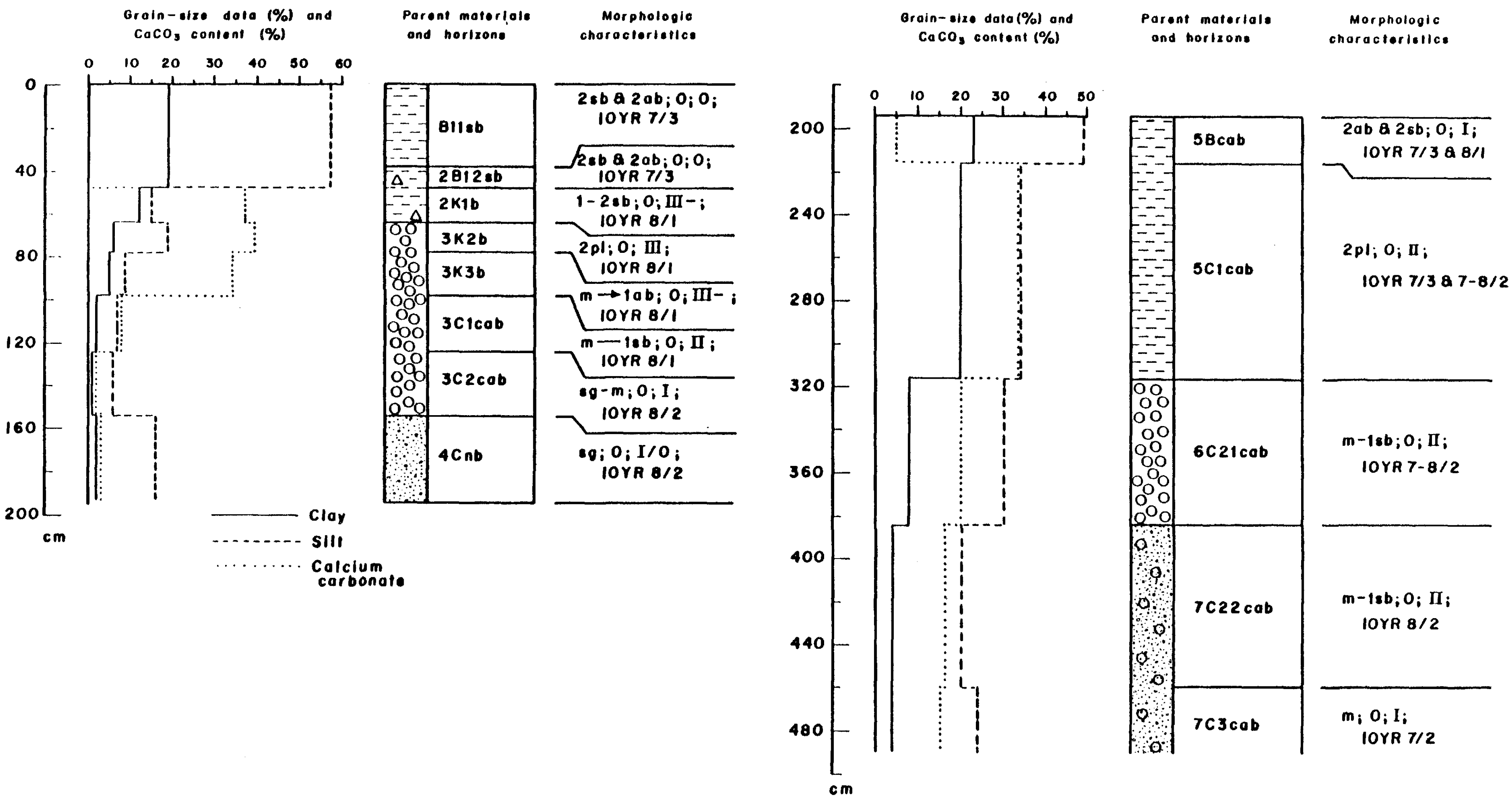


Figure 23.--Morphologic and analytical data for buried soils at Stop JV-6. The soil on the left is directly above the one on the right. Parent materials consist of loess (1) over loessial colluvium (2) over pebbly alluvium (3) over eolian sand (4) for the upper buried soil and loess (5) over sandy pebble gravel (colluvium?, 6) over pebbly sand (colluvium?, 7) for the lower buried soil.

A buried-soil complex (fig. 23) underlies the silt and sand unit. On the west end of the exposure, two soils having a Bs/K and a Bca/Cca profile are formed in loess, eolian sand, alluvium, and colluvium, and underlying lacustrine sand and gravel. These profiles merge to form a single soil in the area that is largely covered, to the east of the scar at the west end of the exposure.

Lacustrine gravel and sand below the soil complex has yielded <u>Physa</u> shells for amino-acid analysis (table 4). Based on amino-acid ratios, McCoy (1981) suggests that these deposits are of equivalent age, or somewhat younger than lacustrine gravels in Little Valley that lie immediately below the 600,000 Lava Creek Ash bed from the Yellowstone area.

		This is the last stop for today. Retrace route to Utah-68. Driving time from Jordan Narrows to Beaver is about 3 hr.
76.9	1.0	Junction with Utah-68; turn left (south).
77.5	0.6	Entering Utah County and Utah Valley; Utah Lake straight ahead. On the left, view along the south side of the Traverse Mountains toward the town of Alpine at the foot of the Wasatch Range. Hunt and others (1953) named the Alpine Formation for fine-grained sediments that form low hills around Alpine. They inferred that the Alpine Formation was deposited in a lake cycle that preceded the last. We find no evidence of a marked unconformity between deposits mapped by them as Bonneville and Alpine Formations, and we believe that both are facies of deposits of the last (Jordan Valley) lake cycle. The Bonneville Formation of Hunt and others was deposited in nearshore environments; the Alpine was deposited in offshore environments.
80.7	3.2	Intersection with Utah-73; turn left (east) on 73 toward Lehi and I-15.
81.2	0.5	Cross Jordan River. Fine-grained lake deposits are exposed in the cut bank on the west side of the river.
84.0	2.8	In Lehi at intersection of several roads; stay on Utah-73, which turns slightly to the left and continues east.
85.1	1.1	Intersection with I-15; turn right onto I-15 South toward Provo. Traveling south of I-15, the slope on the left is formed by the fronts of the deltas of Dry Creek and American Fork that were deposited at and below the Provo shoreline. Both drainages contained large glaciers in Pinedale time.
92.0	6.9	Exit 273 to Geneva and Lindon; continue on I-15. The scarp immediately east of I-15 is the front of the very large delta of Provo River that was deposited at and below the Provo shoreline. Pits, largely abandoned or reclaimed, along the delta front expose sandy foreset and gravelly topset beds. Recessional shorelines are visible locally along the delta front.
93.7	1.7	On the right, between I-15 and the Geneva Steel Plant and just south of the Intermountain Farms elevator is the site of a hole that was drilled by U.S. Geological Survey. Deposits of Jordan Valley age are probably about 30-35 m thick. They consist mostly of sand and interbedded sand and mud.
95.8	2.1	Exit 270 to Utah-265, North Provo and South Orem. If you wish to eat dinner or to obtain supplies before heading on to Beaver, restaurants and stores are in abundance 2 mi to the east on Utah-265.

98.4	2.6	Just north of the Center St. exit to Provo. The slope at the front of the delta is terminated where it has been incised by Provo River. Most of the city of Provo is built on a post-Lake Bonneville fan of Provo River that is inset below the delta at the Provo shoreline. Part of Brigham Young University is built on a remnant of the delta.
102.9	4.5	On the right, Provo Bay of Utah Lake. On the left, the mountain front turns eastward toward Springville. Beyond Springville, Spanish Fork Peak displays well developed faceted spurs. The Bonneville shoreline is clearly visible at the base of the mountain front above a 30- to 40-m-high fault scarp formed in deposits of the Jordan Valley lake cycle and in post-Lake Bonneville alluvium. South of Springville to the town of Spanish Fork, the slope to the east of I-15 is the front of the deltas of Hobble Creek and Spanish Fork.
107.1	4.2	Exit to U.S.-6, Price and Manti. At 10:00, the low point in the range is Spanish Fork Canyon, which lies between Spanish Fork Peak on the north and Loafer Ridge to the south. The slope east of I-15 is the front of the delta of Spanish Fork.
111.4	4.3	Exit to Benjamin and Salem. At 10:00, a broad piedmont area extends above the Bonneville shoreline. This is one of the few areas along the Wasatch front where the Bonneville shoreline is not on the range front itself. Scarps of the Wasatch fault are present along the base of the range front at the head of the piedmont. Several alluvial-fan surfaces that pre-date the Bonneville shoreline are mappable on the piedmont. They occur in both the grassy and oak-covered areas above the Bonneville shoreline, which here is both cut into the alluvial-fan deposits and forms a series of bars deposited on the alluvial-fan deposits. At the far corner of the piedmont, close to where Payson Canyon cuts through the range, Bishop ash (Izett and others, 1970) occurs in a sequence of fan alluvium, loess, and buried soils.
114.1	2.7	Exit to Payson and Utah-115. The range to the west is West Mountain. At 1:00, near the south end of West Mountain, the Payson Dump exposed bar gravels and fine-grained deposits of the Jordan Valley lake cycle. About 1 mi south of the dump, excavations behind a warehouse expose deposits of two lake cycles that are separated by a buried soil. This is the only place in the Utah Valley where we have found lake deposits that are demonstrably of a pre-Jordan Valley lake cycle. East of I-15, a spit extends 2 mi south of Payson at and below the Provo shoreline.
119.5	5.4	Sign "U.S.-6, Santaquin, Eureka; Exit 1 mi." Pits at 10:00 expose faulted, west-dipping sand and gravel at the Bonneville shoreline.
120.7	1.2	Crossing U.S.-6 in Santaquin. At 9:00, a high fault scarp crosses the mouth of a small canyon above the Bonneville shoreline. To the south, fault scarps in alluvium follow the base of the range.
121.7	1.0	Crossing the road that goes up Santaquin Canyon. The abandoned gravel pits expose alluvial gravel of Summit Creek overlying lacustrine gravel and sand of the Bonneville shoreline. A low gravel bar lies northeast of these pits.

122.6	0.9	At 3:00, a small pit exposes gravel of a bar that was deposited during the transgressive phase of the Jordan Valley lake cycle. Graded pits on the left are in gravel deposited at the Bonneville shoreline.
124.1	1.5	Entering Juab County. From here on, many of the observations are taken from an unpublished field-trip guide by R. E. Anderson, R. C. Bucknam, and W. K. Hamblin for the 1978 meeting of the Rocky Mountain section of the Geological Society of America. Long Ridge is the low range to the west. The pits on the right are in gravel and sand of a spit that was deposited at the Bonneville shoreline. Its position between two valleys is similar to that of the spit at the Point of the Mountain between Jordan and Utah Valleys. The Juab Valley contains little morphologic evidence of having been flooded by Lake Bonneville. The floor of Juab Valley is at about 4880 ft, which means that the maximum depth of the arm of Lake Bonneville that occupied the basin was about 220 ft. In addition, the lake was at a high enough altitude to flood the basin for only about 4000 yr. The alluvial fans that are crossed by I-15 are largely of late Pleistocene age, based on degree of soil development, but do not have shorelines formed on them, probably because the fan surfaces were regraded by streams after the lake dropped to the Provo shoreline, which lies below the altitude of Juab Valley.
125.2	1.1	On the left, a debris flow in red and yellow rocks of the Upper Cretaceous and Paleocene North Horn Formation.
129.4	4.2	Mona Reservoir (alt. 4882 ft) on the right. The reservoir is impounded by a low dam on Currant Creek, which flows westward through a canyon in Long Ridge to Goshen Valley, which drains to Utah Lake. A delta of silt and sand at the Provo shoreline was deposited by Currant Creek in the Goshen Valley. At 9:00, the mouth of the canyon of North Creek, which is marked by a grove of cottonwoods, is crossed by fault scarps formed in alluvium of Holocene age. A remnant of an older alluvial surface is preserved on the north side of the canyon mouth. Conspicuous fault scarps continue south of North Creek along the base of the range.
131.5	2.1	At 9:00, a large graben lies just east of the dissected alluvial surface at the mouth of Pole Canyon. The high peak whose northern flank is drained by Pole Canyon is Mt. Nebo (11,877 ft). Three steep cirques are present on the west side of the peak.
132.3	0.8	Exit to Utah-54, Mona.
132.9	0.6	On the left, just north of Willow Creek canyon is a large landslide.
133.9	1.0	At 9:00, a fault scarp crosses the alluvium at the mouth of Willow Creek canyon.
134.2	0.3	Sign "Freeway ends 1 mi." At 9:00, a fault scarp with a very sharp crest lies at the mouth of a small canyon.
135.1	0.9	Freeway ends, begin 2-lane road. South from here, young fault scarps are formed near the base of the range in steeply sloping colluvium. The fault scarps appear as scars in the colluvium. The fault plane in bedrock is exposed in gravel pits at the mouth of Little Birch Creek.

137.2	2.1	On the left, high fault scarps are formed in fan alluvium of late Pleistocene and older ages at the mouth of Gardiner Creek canyon. Young fault scarps die out just south of Gardiner Creek. Note the marked decrease in the steepness and height of the range front to the south, where young fault scarps are absent.
138.1	0.7	Entering Nephi, which is built on the alluvial fan of Salt Creek. The margin of Lake Bonneville at its highest level would have been just west of town. South of Nephi, the eastern bounding range is the San Pitch Mountains, a part of the High Plateaus.
141.6	3.5	Crossing the I-15 overpass that is under construction south of Nephi. Low point in the road is about at the altitude of the highest level of Lake Bonneville. The gravel pit ahead on the left is in fan alluvium of late Pleistocene age. The red color of the sediments is inherited from rocks of Tertiary age in the San Pitch Mountains.
150.4	8.8	Enter Levan.
155.6	5.2	On the right, Juab siding on the railroad. The highest level reached by Lake Bonneville is at about the altitude of the siding. Ahead on the right, low scarps and discontinuous deposits of silt are probably related to Lake Bonneville.
157.2	1.6	On the left, Chicken Creek Reservoir (alt. 5050 ft), which is only about 35 to 50 ft below the maximum altitude of Lake Bonneville in this area. Roadcuts on the hill ahead are in middle Eocene Green River Formation.
161.1	3.9	Passing below the upper limit of Lake Bonneville.
165.6	4.5	Crossing the Sevier River. The Sevier River deposited a large delta in the southern part of Lake Bonneville that occupied the basin of the Sevier Desert. The divide between the Sevier basin and the basin of Great Salt Lake is at an altitude of about 4,600 ft. Evidence from the Old River Bed (Gilbert, 1890) demonstrates that the lake in the Sevier basin was still overflowing while the lake in the basin of Great Salt Lake was at a low level. Ahead, the light-gray and light-brown sediments probably were deposited in Lake Bonneville. The red and yellow sediments, which locally have discernible dips, are probably of Tertiary age.
170.8	5.2	Paleocene and Eocene Flagstaff Limestone and Upper Cretaceous and Paleocene North Horn Formation crop out on both sides of the road.
171.6	0.8	Entering Millard County and the Scipio Valley. Lake Bonneville did not occupy the Scipio Valley.
174.4	2.8	On the right at the margin of the valley bottom, young fault scarps are formed in alluvium. R. E. Anderson and others (unpub. data) noted that the youngest faulting event appears to be of Holocene age based on scarp morphology.
176.6	2.2	Junction with Utah-26. At 8:00, the Valley Mountains, an uplifted block of the High Plateaus, are composed of sedimentary rocks of Late Cretaceous to early Tertiary age. At 10:00, the Pavant Range consists of Paleozoic rocks thrust over Paleozoic and Mesozoic rocks that are unconformably overlain by Upper Cretaceous and Tertiary sedimentary rocks. On the right, the Canyon Mountains are composed of Precambrian rocks thrust over Paleozoic rocks.

178.8	2.2	Four-lane section of I-15 begins as road climbs to Scipio Pass.
182.3	3.5	Scipio Pass (alt. 5969 ft).
187.6	5.3	Exit 179 to Holden and U.S.-50. Entering the basin of the Sevier Desert. Road crosses fans from the Pavant Range.
192.5	4.9	Exit 174 to Holden. The Bonneville shoreline runs through the town of Holden.
193.8	1.3	At 3:00, Pavant Butte, a basalt cone, has a K-Ar age of 30,000 to 70,000 yr (Hoover, 1974). Basalt flows near it and south of it are dated at 30,000 to 22,000 yr by Condie and Barsky (1972) and Hoover (1974). Pavant Butte is near the north edge of an extensive province of bimodal basalt-rhyolite of late Cenozoic age.
198.3	4.5	Sign on the right, "Fillmore Exit, 1 mi." The road crosses alluvial-fan deposits that pre-date the Jordan Valley lake cycle in which a soil having a stage III K-horizon is formed. By the sign, "Fillmore 24 hr Restaurants, Motels, and Gas", the soil is exposed in a low roadcut on the right. Beyond the sign, the gravel pits are being excavated in deposits of the Bonneville shoreline, which is cut into the older fan gravels.
199.3	1.0	Exit to Fillmore.
200.9	1.6	The southern part of the Sevier Desert between 12:00 and 4:00 includes the northern part of an extensive area of bimodal basalt-rhyolite volcanism of Quaternary age. The lavas erupted from northerly trending fault-controlled fissures. Several of the faults are visible from the highway. Successively older eruptive products record progressively greater amounts of fault displacement. Hoover (1974) reported displacements ranging from 67 m in 1-m.y.-old lavas to about 6 m in lavas that are inferred to be a few thousand years old. The youngest basalts in the area lie just west of Fillmore. Hoover (1974) estimates that their age is between 1000 and 4000 yr based on their stratigraphic position and degree of preservation.
210.2	9.3	Overpass.
210.6	0.4	At 3:00, basaltic cone of Tabernacle field. Early eruptions in the Tabernacle field were subaqueous into Lake Bonneville and are estimated to be 12,000 to 24,000 yr old (Hoover, 1974).
213.0	2.4	At 3:00, low white ridge consists of tufa mounds of Meadow Hot Springs and Hatton Hot Springs, which were formerly the sites of baths.
214.2	1.2	At exit to view area. To the southeast, Black Rock volcano has the Bonneville shoreline cut on its north flank. The lavas have a K-Ar age of 670,000 yr (Hoover, 1974).
215.9	1.7	At 9:00, lavas of Black Rock volcano.
220.0	4.1	Exit 145 to Kanosh. On the left, highly deformed lower Paleozoic rocks are part of the upper plate of a thrust of the Sevier orogeny. At 2:00, two white rhyolite cones; the southern cone has an age of 2 m.y. (H.H. Mehnert, unpub. data, 1975). Basalts having ages of about 1 m.y. (Condie and Barsky, 1972) surround all the rhyolite flows and plugs on the west, south, and east. Basalts at 4:00 have K-Ar ages of 540,000 and 920,000 yr (Hoover, 1974).
222.7	2.7	On the right, conspicuous shorelines at 3:00. Road climbs above the maximum level of Lake Bonneville.

225.7	3.0	Discontinuous roadcuts on both sides of the road for the next 1.5 mi are in shattered Paleozoic carbonate rocks of the upper part of a thrust plate that moved eastward over Mesozoic and upper Paleozoic rocks during the Sevier orogeny.
227.3	1.6	Pass, entering small closed basin called Dog Valley.
231.9	4.6	Exit to Cove Fort, a civilian outpost constructed in 1868. At 1:00, a large basaltic cinder cone in the Cove Fort field. Ahead on the left, the Tushar Mountains are composed of Oligocene to Pliocene volcanic rocks of the Marysvale center.
232.9	1.0	On the right, northeasterly trending fault scarps cut lavas of the Cove Fort field. The rocks are coextensive with those of the southern Sevier Desert viewed earlier. Clark (1977) calculated an extension rate of 7.5 m/km within the last 1 m.y. from offsets on more than 300 northerly trending normal faults in the field.
233.3	0.4	Borrow pit on the left exposes tuffaceous conglomerates and sandstones of Miocene(?) age, which underlie some of the 8- to 9-m.y.-old rhyolites and basalts of the Cove Fort and Beaver areas.
233.8	0.5	Fault scarps in basalt on both sides of road.
235.1	1.3	Exit to I-70, Denver. On the left, 3/4 mile to the east, the borrow pit just south of I-70 exposes 2 rhyolitic tephras interstratified with alluvium. Glen Izett (U.S. Geological Survey, Reston) has identified the lower ash as 0.7-m.y.-old Bishop ash. The upper tephra is named the tephra of Ranch Canyon and was erupted 0.53 m.y. ago from the Mineral Mountains, about 20 mi southwest of here.
235.3	0.2	Enter Beaver County. Low pass about 7 mi ahead divides westward-flowing streams of the Tushar Mountains into the Cove Fort basin on the north and the Beaver basin on the south.
235.8	0.5	On the left at the base of the mountains is Sulphurdale, where sulphur is being mined from mid-Tertiary rocks.
236.9	1.1	At 9:00, the Tushar Mountains rise to about 12,000 ft.
238.7	1.8	On the right across the cultivated field, a 4.3-m-high fault scarp cuts fan alluvium.
240.9	2.2	Climbing a gentle grade, the steep-flanked hills to the west are Woodtick Hill at 2:00 and Gillies Hill at 1:00, which are composed of locally derived rhyolite flows and altered rhyolite ash-flow tuffs (Machette and others, 1981; Steven and Morris, 1981). K-Ar ages are 8 to 9 m.y. (Evans and Steven, 1982).
242.3	1.4	Top of pass, ranch road exit. Entering Beaver basin. Views of the Tushar Mountains at 8-11:00, the Black Mountains from 11-1:00, and the Mineral Range from 1-4:00.
243.6	1.3	Road cuts expose rhyolites and vitric tuffs? of Gillies Hill. On the left is the faulted front of an elongate, north-south ridge named Cedar Knoll; the exhumed fault plane on rhyolite has striations that dip 70°W, but have no apparent oblique slip. Basin-fill deposits are in fault contact with and unconformably overlie these rhyolites. To the south of Cedar Knoll these same faults have recurrently displaced middle to upper(?) Quaternary alluvium.
247.0	3.4	Manderfield Exit (junction with Utah-91). Entering an area known as Wildcat Field, which is the floodplain of three convergent streams. Two fluvial terraces of Fortuna Canyon are at 3:00.

The lower (120-135 ft above stream level) and upper (200-215 ft) terraces are formed of deposits correlative with alluvium of Bull Lake age (140,000 yr old; unit Qtm of Machette, 1982) and with alluvium of pre-Bull Lake age (240,000 yr old; unit Qto of Machette, 1982), respectively, in the Beaver basin. The higher ridge about 2 mi to the west is a south-trending horst formed by conglomerates of Maple Flats, an upper Miocene to lower(?) Pliocene, coarse-grained member of the basin-fill deposits of the Beaver basin (Machette, 1982; Machette and Steven, 1982).

248.2 1.2 Highway ascends ridge capped by middle Quaternary piedmont-slope deposits named the gravels of Last Chance Bench (Machette, 1982; Machette and Steven, 1982). For the next 2 mi the highway descends into the broad valley of Indian Creek and crosses piedmont-slope and terrace deposits of middle Pleistocene to Holocene age. South- and south-southeast-trending ridges and swales are formed by fault scarps and by fault-controlled drainages.

250.3 2.1 Indian Creek. Slope ahead is the north edge of the Last Chance Bench, which here is a southwest-trending, highly deformed alluvial surface about 0.5 m.y. old.

250.8 0.5 Crest of hill. Low hills to the left are fault scarps formed in the gravels of Last Chance Bench. To the right, note the aligned south- and south-southwest-trending, fault-controlled drainages between tilted fault blocks of the the Last Chance Bench.

252.2 1.4 Descend from Last Chance Bench onto the flood plains of North Creek and the Beaver River. Beaver, Utah (pop. 2,000) is located about 2.5 mi ahead.

253.4 1.2 Exit to Beaver. Exit and pass to the east under I-15. Proceed to Beaver on the highway access road which turns south into Main Street.

255.3 1.9 Turn left (east) just north of the high school onto Utah-153, which is marked by sign to Puffer Lake and Mt. Holley Ski Area. There presently are only two food stores in Beaver -- one is one block north of the high school and the other is about three blocks to the south of Utah-153 on Main Street. Proceed east on Hwy 153 to the outskirts of town.

256.7 1.4 Beaver Canyon Campground is on the left. Pull in and register for campground space. End of road log for day 2.

Appendix.--Locations of radiocarbon samples (table 2). Street addresses are from Salt Lake City grid.

Locality number	Name	Location
1	Little Valley	Large abandoned gravel pit 0.8 km north of Promontory Point, Ut.; SE1/4,SE1/4, sec. 2 and S1/2, sec. 1, T. 6 N., R. 6 W., and west-central sec. 6, T. 6 N., R. 5 W.
2	MacNeish pit	Gravel pit 2.5 km southeast of North Salt Lake, Ut.; NW1/4, SW1/4, sec. 7, T. 1 N., R. 1 E.
3	Concrete Products Corp., North Salt Lake	Gravel pit 1.5 km south of North Salt Lake, Ut.; SW1/4, sec. 12, T. 1 N., R. 1 W.
4	CPC pit, Big Cottonwood	Gravel pits on north and south sides of road to Holladay Gun Club, 7 km east of Murray, Ut.; SW 1/4, sec. 24, T. 2 S., R. 1 E.
5	5750 S Bullion St.	Abandoned clay pit and slag dump 3 km southwest of Murray, Ut.; center sec. 14, T. 2 S., R. 1 W.
6	Moffat Bros. pit	Gravel pit that is being subdivided for houses at 5700S/3500W, about 2 km east of Kearns, Ut.; SW1/4, NE1/4, sec. 17, T. 2 S., R. 1 W.
7	Geneva Rock Products pit at Point of the Mountain	Gravel pit on east side of I-15, 3 km northeast of Jordan Narrows; SW1/4, SW1/4, sec. 13, T. 4 S., R. 1 W.
8	Salt Lake Valley Sand pit at Point of the Mountain	Sand and gravel pit 1.5 km north of Jordan Narrows; center sec. 23, T. 4 S., R. 1 W.

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PART II: BEAVER BASIN, SOUTH-CENTRAL UTAH

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

The Beaver basin of south-central Utah, a site of prolonged closed-basin deposition during the late Tertiary, has exposures of upper Cenozoic deposits not usually seen in the Basin and Range province. Stream erosion has exposed a nearly continuous section of upper? Miocene to lower? Pleistocene sediments that contain the only Blancan fossils collected in Utah and an assemblage of Pliocene to middle Quaternary volcanic ashes from local and distant sources. Surficial deposits are widespread in the basin and record a sequence of middle Quaternary to Holocene erosional and depositional events that probably are climatically controlled. Both Quaternary and Pliocene sediments are intensely deformed into a broad north-trending antiform resulting from intrusion of a thick, deep diapir of remobilized Jurassic? sediment. These same sediments are displaced by basin-margin faults related to the structural extension of the Basin and Range province and coincident uplift of the adjacent Colorado Plateau. K-Ar age determinations on volcanic ashes and basalt, quantitative analyses of soil development, and uranium-trend soil ages provide time control for Quaternary stratigraphic divisions and for estimates of recency and recurrence intervals of faulting in the basin. Additionally, the physical stratigraphy of the basin-fill sediment, the development of subsurface structure, the concentration of radon gas, and the chemistry of uranium-saturated ground water indicate that uranium mineralization is present in the basin-fill sediments.

Much of the stratigraphy, structural interpretations, and geologic history presented here are the results of recent mapping by M. N. Machette and his colleagues at the U.S. Geological Survey. This mapping is part of a larger effort to understand the development of the Marysvale Volcanic Field and the regional geology of the Richfield $1^{o} \times 2^{o}$ quadrangle. Those interested in the details of the Miocene and older geologic history of the area should consult the recent publications by Cunningham, Rowley, Steven, and others (see reference list).

LATE CENOZOIC GEOLOGY OF THE BEAVER BASIN

The Beaver basin, a sharply defined structural and topographical basin, has been the site of extensive sedimentation, deformation, and potential uranium mineralization since at least late Miocene time. The basin is 25 km long north-to-south and 16 to 22 km wide east-to-west; it is bordered on the east by upper Oligocene to lower Miocene volcanic rocks of the Tushar Mountains (Cunningham and others, 1982a, b) and on the west by the Tertiary? granite-cored Mineral Mountains, Utah's largest exposed pluton (fig. 1). The low hills at the north end of the basin are formed by 8- to 9-m.y.-old rhyolite domes and flows (rhyolite of Gillies Hill, Evans and Steven, 1982) that rest on a platform of volcanic rocks which are distal equivalents to those of the Tushar Mountains (Steven and Morris, 1981; Machette and Steven, 1982). The east and west margins of the basin are fairly abrupt and linear and are controlled by border faults that have been recurrently active during the late Cenozoic.

Sediments exposed in the topographically low parts of the basin are entirely late Miocene or younger with the exception of a southward-projecting horst in the north-central part of the basin. Directly south of this horst, a wildcat oil-and-gas well penetrated 1,400 m of Miocene and younger basin-fill sediment. Unpublished seismic-reflection data along an east-west line through the drilling site show that post-volcanic age sediment (<19 m.y. B.P.) fills

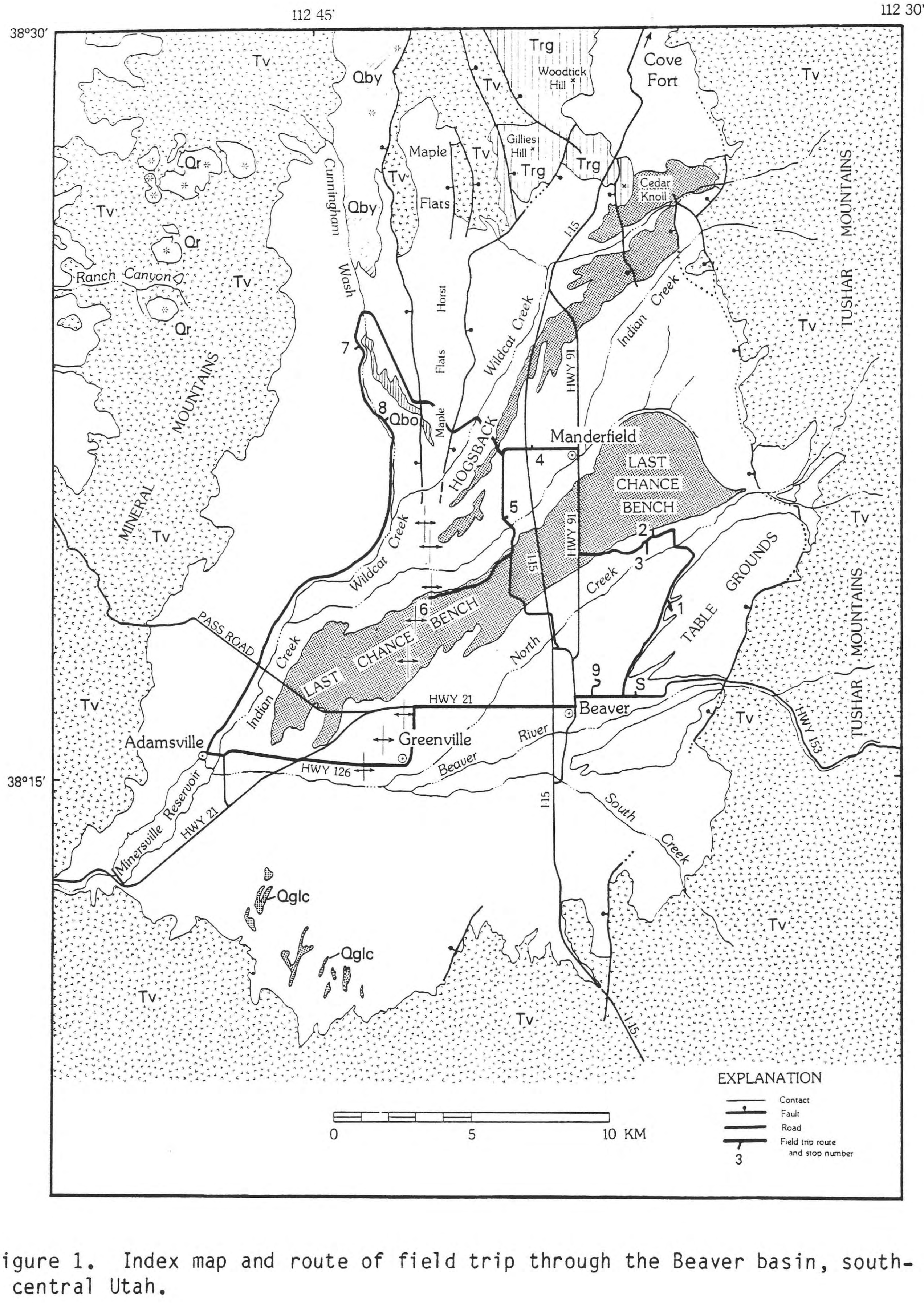


Figure 1. Index map and route of field trip through the Beaver basin, south-central Utah.

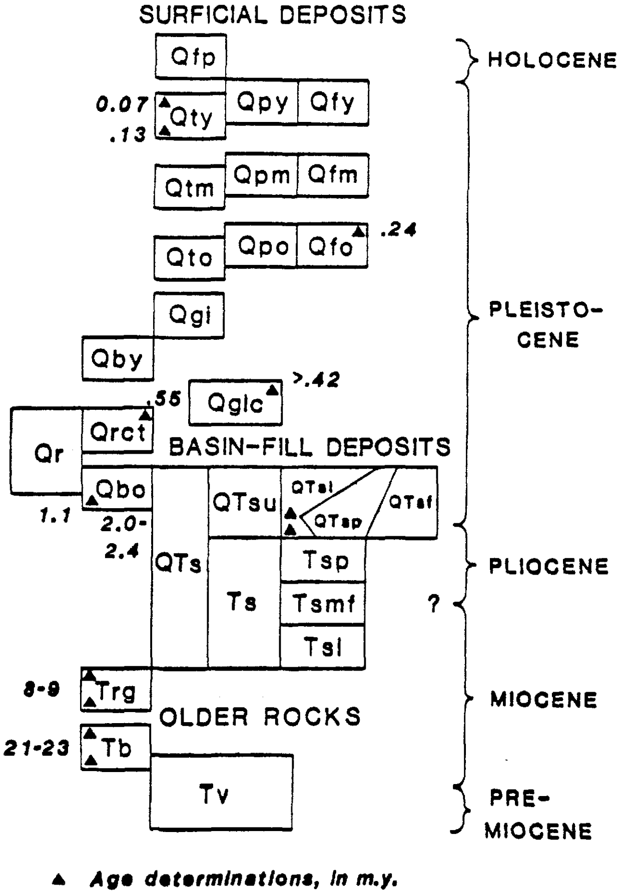
a relatively deep structural trough which is shallower in the center than along the mountain fronts, especially along the east margin of the basin. The east and south-central parts of the Beaver basin probably have the thickest fill; more than 2,000 m may be present in these areas. Because Pliocene and Quaternary deformation probably follows that of the Miocene, mapping of the young basin fill and surficial deposits provides an analog for subsurface exploration of oil and gas and uranium in the Beaver basin (see latter discussion of uranium potential in the basin).

Lower basin-fill deposits and volcanic rocks

The history of early-basin development is obscure because generally only the youngest basin-fill deposits are exposed. Near Cove Fort, about 35 km north of Beaver, a depositional basin of some sort existed in middle Miocene time. In that area and north of Woodtick Hill, poorly exposed gravelly silt and sand underlie the rhyolite of Gillies Hill (figs. 1 and 2, Trg), but exposures of these sediments are sparse and small and provide no information about the thickness of the early basin-fill deposits or the configuration of the basin in which they were deposited. Although the divide area between the Cove Fort and Beaver basins is presently structurally and topographically high, there little evidence that this barrier existed before the eruption of the rhyolite of Gillies Hill, 8-9 m.y. B.P. Upper Miocene and older volcanic rocks, which provide the platform on which the rhyolite rests, were derived from sources to the east, in the Tushar Mountains; this evidence suggests that the present divide area was topographically low in early Miocene time. Therefore, most of the present structural relief in the divide area results from uplift of the Maple Flats horst, whereas the topographic relief is formed by the eruptive pile of upper Miocene rhyolites. The Beaver and Cove Fort basins, and their connecting trough, form a 45-km-long, north-south structural depression named the Cove Fort-Beaver Graben (Cook and others, 1980).

Near the southwest corner of the Beaver basin, pumice-bearing conglomerate and a 7.6-m.y.-old basalt flow (Best and others, 1980) fill a narrow west-flowing channel that drained at least the Beaver basin part of the graben. The pumice fragments and overlying basalt indicate that the conglomerate accumulated during a 9-m.y.-old episode of rhyolitic volcanism documented along the north, east, and south margins of the Beaver basin (Steven and others, 1981; Evans and Steven, 1982). This channel was later closed by uplift along the southwest flank of the Mineral Mountains and the north flank of the Black Mountains (fig. 1) as evidenced by up to 20^{o} of post-depositional rotation of the 7.6-m.y.-old basalt exposed near Minersville Reservior.

The sediments of the Beaver basin form two basic packages, which I refer to as upper and lower basin-fill (see fig. 2, correlation of map units). The lower basin fill has three members; the oldest and most poorly exposed (Tsl) consists of moderately oxidized, slightly gypsiferous, fine-grained bolson deposits of unknown thickness. These rocks crop out only locally at the south end of Maple Flats and, although their relation to the rhyolite of Gillies Hill can not be proven, the exposed part must be younger than the rhyolite. The upper Miocene conglomerates near Minersville Reservior are considered as a coarse-grained facies of the lower member (Tsl). Preliminary interpretation of subsurface drill data suggests that much of this member is coarse grained and could be as much as 1,000 m thick.



SURFICIAL DEPOSITS

Qfp FLOOD-PLAIN ALLUVIUM (HOLOCENE)

YOUNG ALLUVIUM (CA. 12,000-15,000 YR B.P.)

Qfy Alluvial-fan deposits

Qpy Piedmont-slope alluvium

Qty Terrace alluvium

MIDDLE ALLUVIUM (CA. 120,000-140,000 YR B.P.)

Qfm Alluvial-fan deposits

Qpm Piedmont-slope alluvium

Qtm Terrace alluvium

OLD ALLUVIUM (CA. 250,000 YR B.P.)

Qfo Alluvial-fan deposits

Qpo Piedmont-slope alluvium

Qto Terrace alluvium

Qgi GRAVEL OF ANCESTRIAL INDIAN CREEK (CA. 350,000-400,000 YR B.P.)

Qby BASALTS OF RED KNOLL AND CRATER KNOLL (MIDDLE? PLEISTOCENE)

Qglc GRAVEL OF LAST CHANCE BENCH (CA. 500,000 YR B.P.)

Qrct TEPHRA OF RANCH CANYON (550,000 YR B.P.)

Qr RHYOLITE DOMES AND FLOWS (MIDDLE TO LOWER PLEISTOCENE)

BASIN-FILL DEPOSITS

Qbo BASALT OF CUNNINGHAM HILL (CA. 1.1 M.Y. B.P.)

QTs SEDIMENTARY BASIN-FILL DEPOSITS (LOWER? PLEISTOCENE TO UPPER? MIOCENE)--Includes informal units of poorly to moderately consolidated fluvial and lacustrine deposits that comprise two major sedimentary packages

QTsu The upper part consists of a gradational sequence of lacustrine (QTsl), piedmont-slope and fluvial (QTsp), and fanglomeratic (QTsf) basin-fill sediments. The upper basin-fill deposits, early(?) Pleistocene and late Pliocene in age, contain the 1.9-m.y.-old Huckleberry Ridge Ash bed

Ts The lower part is moderately oxidized (in surface exposure), calcalareous and indurated. The upper and lower members (Tsp and Tsl) are relatively fine-grained and are separated by a basinward-thinning(?) coarse-grained conglomeratic member, the conglomerate of Maple Flats (Tsmf). The exposed part of the lower basin fill is Pliocene to late(?) Miocene in age

Trg RHYOLITE AND RHYOLITE TUFF OF GILLIES HILL (UPPER MIOCENE, 8-9 M.Y. B.P.)

OLDER ROCKS

Tb POTASSIUM-RICH MAFIC LAVA FLOWS (MIOCENE)--K-Ar ages are 21.7±0.8 m.y., 22.1±0.8 m.y. (H. H. Mehnert, written commun., 1980), and 23.2±0.2 m.y. (Best and others, 1980)

Tv VOLCANIC ROCKS OF THE TUSHAR MOUNTAINS (EARLY MIOCENE AND LATE OLIGOCENE) AND SEDIMENTARY AND INTRUSIVE ROCKS (MIOCENE TO PALEOZOIC)

Figure 2. Correlation and brief description of major map units in the Beaver basin (see also expanded version in Machette and others, 1981).

Tsl is overlain by a coarse-grained member that consists of interbedded silt, sand, and gravel; these deposits are informally named the conglomerate of Maple Flats (Tsmf). This conglomerate is late Miocene and (or) early Pliocene in age and clearly overlies 9-m.y.-old rhyolite. Boulders in the conglomerate are as much as 2 m in diameter and reflect the vigorous upheaval of the Mineral Range and possibly the Tushar Mountains along the bordering faults of the Beaver-Cove Fort Graben. Because there are no marker beds in the conglomerate member, it is not possible to determine its thickness. However, at least 250 m of these strata are exposed and 500 m or more may be present in the subsurface to the south of Maple Flats. The conglomerate of Maple Flats is exposed mainly in the horst of Maple Flats (fig. 1; Machette and Steven, 1982), in the north-central part of the Beaver basin.

The youngest member of the lower basin fill (Tsp) is a piedmont facies consisting of interbedded fluvial-channel and deltaic(?) sands, calcareous marls, and pebble to cobble gravels. The piedmont facies is moderately oxidized and indurated and contains calcium-carbonate-cemented sandstone lenses and calcium-carbonate nodules. This member is differentiated from younger and older deposits by its moderate amount of oxidation, calcareous marls, and tephra assemblage. Several tephra are present in the upper part of this member, but their sources and ages have not been identified. In the subsurface, the piedmont facies probably intertongues with a playa or lacustrine sequence towards the center of the basin.

Upper basin-fill deposits

Unlike the lower basin fill, which is characterized by discontinously exposed members that form a vertical assemblage, the upper basin fill is exposed over most of the basin and consists of a complex lateral assemblage. This assemblage contains intertonguing lacustrine (QTsl), fluvial and piedmont-slope (QTsp), and alluvial-fan (QTsf) deposits (fig. 2). The lacustrine deposits consist of light- to medium-green silty clay and silt interbedded with well-bedded, light-gray to light-brown fine sand grading laterally into pebbly sand. The lacustrine sediments are the most widespread and best exposed of the basin-fill deposits in the Beaver basin.

The upper basin fill accumulated in and adjacent to a large perennial-lake basin that persisted through Pliocene and early Pleistocene time. The lake that occupied this basin is here informally called Lake Beaver. At least four and as many as six volcanic ashes (tephra) fell into Lake Beaver during the Pliocene and early Pleistocene; some ashes were erupted locally whereas others were derived from sources thousands of kilometers away.

Blancan fossils collected by G. A. Izett and J. G. Honey from the basal part of intertonguing lacustrine and piedmont-slope deposits include the zebra *Dolichohippus*, the muscrat *Ondatra* cf. *O. idahoensis*, and the microtine rodent *Mimomys meadensis*. The small-mammal taxa suggest a Blancan-5 age of 2.0 to 2.5 m.y. (C. A. Reppening, written commun. to G. A. Izett, 1980). The fossils are from sediments 25 to 50 m below the thickest and most persistent ash in the basin, the Huckleberry Ridge ash bed (previously known as the "Pearlette type B ash"; Izett, 1981; Izett and Wilcox, 1982). This ash is the distal airfall component of a rhyolitic tuff erupted at Yellowstone Park, Wyoming, 2.0 m.y. B.P. Water-laid Huckleberry Ridge ash is found in the western one-half and southern two-thirds of the basin, indicating the minimum extent of Lake Beaver during the late Pliocene and early Pleistocene. About 200-250 m of the lacustrine facies is exposed in the north-center of the basin, but drill-hole data shows that lacustrine deposits must be thicker and have older equivalents in the subsurface, especially near Greenville (fig. 1).

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Two other ashes are widely preserved in the 30 m of sediment underlying the Huckleberry Ridge ash bed; they are informally named the "middle ash bed" and the "Indian Creek ash bed." The middle ash bed is correlated, on the basis of its stratigraphic position and mineralogic and chemical properties, with the 2.1-m.y.-old Taylor Canyon-C ash bed of the Long Valley-Glass Mountain area in eastern California (Izett, 1981, 1982). The Indian Creek ash bed, 30 m below the Huckleberry Ridge ash bed, is composed of glassy, gray to black obsidian pellets in a matrix of medium-grained sand. It has chemical and mineralogical affinities with 2.3- to 2.4-m.y.-old rhyolites near the Cudahey Mine and at South Twin Peak (Lipman and others, 1978, table 3; Izett, 1981), both of which are located about 55 km northeast of Beaver. The coarse-grained texture of the Indian Creek ash, indicative of a nearby source area, strengthens its correlation with the local rhyolites.

Another ash, here informally named the Hogsback ash bed, is locally preserved below the Indian Creek ash bed in exposures along the north side of the Hogsback. It is interbedded with varigated light-green silty clays and slightly oxidized, orangish-brown sands. This ash lies about 20 m below the Indian Creek ash and about 50 m below the Huckleberry Ridge ash bed. The Hogsback ash also has chemical and mineralogical affinites that suggest a correlation with the rhyolites of Cudahey Mine and South Twin Peak, although it is much finer grained than the Indian Creek ash.

There are at least 100 m of lacustrine and fluvial sediment overlying the Huckleberry Ridge ash bed. A fifth, locally preserved, thin fine-grained ash (the Last Chance Bench ash bed; Izett, 1981) is found in this part of the Pleistocene section about 40 m above the Huckleberry Ridge. This ash has not been correlated with a source area, but is considered to be about 1.8 m.y. old on the basis of its position relative to the underlying 2.0-m.y.-old Huckleberry Ridge ash bed (Izett, 1981).

Ostracodes and diatoms were collected by R. M. Forester and J. Platt Bradbury from a 35-m-thick interval of sediment underlying the Huckleberry Ridge ash bed and from a 12-m-thick interval containing the Last Chance Bench ash bed; spot collections also were made from sediments of the lower basin fill. Forester and Bradbury's study (1981) suggests that the Beaver basin contained at least four distinctive lacustrine systems and various marginal environments during the Pliocene and the early Pleistocene. These lacustrine systems include an early freshwater lake (Pliocene?), a late Pliocene saline lake (basal QTsl), a late Pliocene to early Pleistocene slightly saline to freshwater lake (middle? QTsl), and an early Pleistocene freshwater lake-pond-stream network (upper? QTsl) similar to some of the modern day environments of the basin. This interpretation of Lake Beaver's water chemistry is supported by the general lack of carbonate mineralization in much of the lacustrine sediment.

The late Pliocene sediments (basal QTsl) contain an ostracode assemblage that is dominated by Limnocythere sappaensis according to R. M. Forester (written commun., 1982). L. sappaensis occurs abundantly in lakes whose hydrochemistry is dominated by $(Na^+ + K^+)$-HCO_3^--CO_3^{2-} and is depleted in Ca^{2+}. The quantities of Mg^{2+}, SO_4^{2-}, and Cl^- are variable, but usually are common and occasionally comprise the dominant cation or anion. These hyrochemistries and the presense of L. sappaensis are typical for closed lake basins in volcanic terrains. The salinity tolerance of L. sappaensis is broad in waters with the above composition, however, the presence of Candona rawsoni in low numbers throughout the section suggests that the salinity of Lake Beaver was usually within the range of 1,000 ppm to 10,000 ppm. C. rawsoni can not tolerate elevated salinities in lakes with large quantites of HCO_3 -CO_3^{2-}. The pH of waters containing large quantities of HCO_3^--CO_3^{2-} is usually greater than 9.0. Such alkaline waters may explain the absence of diatoms from all but one sample in this unit, because opaline silica is highly soluable in high pH waters.

The sediments of the late Pliocene and early Pleistocene Lake Beaver (QTsl) contain an ostracode assemblage that is dominated by Limnocythere robusta, but contains several other species including L. sappaensis. The presence of this assemblage suggests that the solute composition of the late Lake Beaver was similar to the one discussed above except that this phase had a higher quantity of Ca^{2+}. The greater quantities of Ca^{2+} are probably due to a higher stream inflow into the lake and (or) less evaporation caused by transition to the cooler/wetter climates of the Quaternary; both of the factors would produce a fresher and less alkaline lake. The ostracodes and the diatoms suggest that this lake had a salinity that was ussually in the ragne of 500 ppm to about 5,000 ppm. The pH would also have been lower or at least more variable, which may explain the greater frequency of diatom occurences.

The paleolimnologic interpretations given above for both phases of Lake Beaver are further supported by the general absence of carbonate minerals in the samples collected from the two detailed sections. Scirpus, Chara, and snails are present in much of the lacustine sequence along with ripple-bedded sands and mudcracks. This data, and the sedimentary structures and stratigraphy of the lacustrine deposits, suggest that Lake Beaver was a shallow, but permanent feature.

The youngest dated unit contained within the basin fill is the basalt of Cunningham Hill (fig. 2, Qbo), a dark-gray, scoriaceous to massive basaltic lava flow (Machette and others, 1981). This basalt was erupted 1.1±0.3 m.y. B.P. (Best and others, 1980) while the Beaver basin was still closed. The vent for the basalt may lie beneath younger basalt flows (Qby) in the northwest part of the basin, between the horst of Maple Flats and the Mineral Mountains (fig. 1). The basalt of Cunningham Hill has a weakly reversed natural-remanent magnetic direction with a strong normal (chemical?) overprint (Machette and Steven, 1981); this data shows that the basalt must be older than 0.7 m.y. The basalt flowed south and southeast in an old channel of Cunningham Wash and, because of topographic reversal, it now forms a ridge about 100 m above the level of adjacent, eroded upper basin-fill deposits.

The basalt of Cunningham Hill is displaced by a series of north-trending, down-to-the-east normal faults that give the basalt flow a segmented, westward tilt. These faults have a net Quaternary throw of at least 100 m, down towards the basin center, and indicate post-1.1 m.y. uplift along the Maple Flats Horst. This structural interpretation is also supported by discordant relations between the upper and lower basin fill that document sedimentation and contemporaneous growth of an north-trending antiform within the central part of the basin during Pliocene and Pleistocene time.

Unpublished seismic-reflection data and the pattern of faulting along the east margin of the basin show that the youngest basin fill probably underlies the Table Grounds surface (fig. 1, stop 1). Table Grounds is a broad fan-shaped constructional surface that projects to a level of about 45 to 75 m above North Creek and 75 to 100 m above the Beaver River. The southernmost remnant of the Table Grounds surface is preserved as an elogate, west-sloping to flat ridge south of the Beaver River.

Table Grounds is underlain by oxidized sandy pebble to cobble gravels and sparse interbeds of sand (QTsf) Near the Beaver River this sediment buries early Miocene lava flows (Tb; Tmpl of Machette and others, 1981), small remnants of which rise 5-10 m above Table Grounds. The Table Grounds surface is here considered to be about 0.75 m.y. old; this age is based on sedimentation rates of the upper basin fill, the 1.1 m.y. age of the basalt of Cunningham Hill, a 0.55 m.y. age on the post-basin-fill tephra of Ranch Canyon, and an assessment of the relic soil developed in alluvium that forms the Table Grounds surface (see discussion of soil development). Throughout most of the Beaver basin, sediment of 0.75-1.5 m.y. age is either buried by surficial deposits or has been eroded.

Surficial deposits

The time at which the Beaver basin was breached and Lake Beaver drained into the Escalante Desert via Minersville Canyon is evidenced by the fluvial deposition of a locally derived rhyolitic obsidian-lapilli and pumice deposit--the tephra of Ranch Canyon (Lipman and others, 1978; Qrct of Machette and others, 1981). This tephra was erupted from rhyolitic domes in the central Mineral Mountains 0.55±0.01 m.y. B.P. (G. A. Izett, written commun., 1981) and then redeposited in alluvial channels cut in basin-fill sediment. In the Beaver basin, the tephra of Ranch Canyon is exposed mainly along Cunningham Wash (field trip stop 7) and along the southern part of Indian Creek where it is unconformably overlain by surficial deposits. About 3.1 miles north of Manderfield, in the large west-facing road cut of Utah Highway 91, the tephra is interbedded with the basal part of the oldest surficial deposit of the Beaver basin, the gravel of Last Chance Bench. Thus, by about 0.55 m.y. B.P., Lake Beaver had emptied through an outlet at Minersville Canyon, the drainage in the Beaver basin was integrated and had eroded a broad pediment across basin-fill sediment, and the extensive gravel cover of Last Chance Bench was being deposited.

The gravel of Last Chance Bench was deposited and its constructional surface was stablized by about 0.5 m.y. B.P. This estimate is constrained by two ages: 1) the underlying tephra of Ranch Canyon (0.55 m.y. B.P.) and 2) a preliminary uranium-trend soil age of 420,000±40,000 yr B.P. (H. M. Steer, 1980; J. N. Rosholt, personal commun., 1981). The later date is from a soil formed in fault scarp colluvium and gravel of Last Chance Bench, and was determined by method described by Rosholt (1980); it is here considered to be a minimum age for the gravel (see discussion at field trip stop 2). Thus, for the purposes of this report, I use an age of 0.5 m.y. B.P. for the Last Chance Bench surface and its underlying gravel. This gravel consists of light-brown to reddish-brown pebbly sand to sandy gravel that generally is coarser grained than the basin-fill sediment on which it lies disconformably near the mountains and unconformably in the center of the basin. Although the gravel is only 2-5 m thick, it forms a protective mantle over the fine-grained basin-fill.

Last Chance Bench is the most extensive geomorphic surface in the Beaver basin; it extends from the east front of the Tushar Mountains, between Indian Creek and North Creek, westward 20 km to near Adamsville (about 5 km northeast of Minersville Reservior). Outliers of this same gravel are preserved as the "Hogsback" between Wildcat Creek and Indian Creek, as high surfaces south and east of Cedar Knoll, and as surfaces mantled by basalt boulders on the north flank of the Black Mountains, south of the Beaver River. Because the gravel of Last Chance Bench is extensively faulted, it occupies a wide range of topographic positions: less than 30 m to more than 100 m above stream level. Most commonly it occurs at levels of about 75 m above stream level. The surface of Last Chance Bench projects 20-50 m above North Creek, a level that is about 25 m below Table Grounds.

Since deposition of the gravel of Last Chance Bench about 0.5 m.y. ago, the history of the basin has been one of periodic downcutting and subsequent deposition of surficial materials related to climatic and tectonic control. These surficial deposits are contained within three major and several minor groups, all of which form widespread gravelly piedmont-slopes, alluvial fans, and terraces (fig. 2). The oldest of these sediments, the ancestral gravel of Indian Creek (Qgi; Machette, 1982a), is inset 5-12 m below the gravel of Last Chance Bench at the south end of the Hogsback and forms a ridge 30-38 m above Indian Creek; a level well above the next younger alluvial unit southwest of the Hogsback. Although the course of ancestral Indian Creek was controlled by fault-induced topography, deposition of the alluvium probably resulted from fluctuations in the climate. Soils data and age control are not available for unit Qgi, but constraints from younger and older surficial deposits suggest an age of 350,000-400,000 yr B.P.

The three major groups of surficial deposits in the Beaver basin are informally designated as "old", "middle", and "young." All three groups consist of locally derived alluvial-fan (Qf), piedmont-slope (Qp), and terrace (Qt) deposits (see fig. 2; Machette and others, 1981; Machette, 1982a; Machette and Steven, 1982). For example, the soils at field trip stops 2 and 4 are formed in old alluvial-fan (Qfo) and piedmont-slope (Qpo) deposits, respectively. The field relations for all three groups of surficial deposits indicate that most fan and piedmont-slope alluvium are slightly younger than the associated terrace alluvium. This same relation has been recognized for alluvial units in central New Mexico (Machette, 1978) and suggests that the slight time-lag between main-stem deposition and local-tributary deposition may be a widespread phenomena in the desert environments of the southwestern United States.

Old alluvium is poorly preserved in small terrace remnants 16-18 m above the Beaver River (near Greenville) and 5-15 m above North Creek, and in small islands of piedmont-slope that are graded to levels 20-25 m above Indian Creek (stop 4). These same terrace deposits are much higher in the northeastern part of the basin; they lie about 60-65 m above Fortuna Canyon west of Wildcat Fields, near the Manderfield exit on I-15. I estimate that the bulk of old aluvium was deposited about 250,000 yr B.P. on the basis of soil development (such as total $CaCO_3$ content, Bt horizon thickness, and clay content) and the correlation of old alluvium with deposits of the last major pre-Bull Lake glaciation in the Rocky Mountains (terminalogy of Colman and Pierce, 1981). An age of 240,000$\pm$40,000 yr B.P. (H. M. Steer, 1980; J. N. Rosholt, personal commun., 1981) was determined from the soil developed in Qfo at stop 2 by the uranium-trend method (Rosholt, 1980).

The middle group of surficial deposits forms terraces along most of the major streams in the Beaver basin and forms extensive piedmont-slopes in and around the basin. Middle alluvial terraces are 2-13 m above the Beaver River near Greenville and 10-13 m above Indian Creek near Manderfield. Most middle alluvium was deposited 120,00-140,000 yr ago. This age range is based on soil development and the correlation of middle alluvium with deposits of the Bull Lake glaciation in the Rocky Mountains (Colman and Pierce, 1981).

Uranium-trend ages between 75,000 and 130,000 yr B.P. (H. M. Steer, 1980; J. N. Rosholt, personal commun., 1981) were determined from soils developed on several faulted middle terraces along South Creek, about 3 km south of Beaver. Soils on the lowest of these "middle terraces" are similar but less developed that those on middle alluvium to the north, and suggests that the group of three South Creek "middle terraces" have a longer age range and their alluvium is slightly younger than most other middle alluvium. The South Creek terraces were formed due to periodic faulting and subsequent downcutting along South Creek, and thus, are considered as a young phase of middle alluvium.

The young group of surficial deposits forms low-level terraces, elevated floodplains, and small alluvial fans throughout most of the Beaver basin. Partly because of their lack of erosion, young deposits have the largest areal distribution and volume of the three groups. Young alluvium forms broad, slightly elevated and coalesced surfaces 3-6 m above the modern floodplain of the Beaver River, between Greenville and Adamsville (13 km west of Beaver), and 3-5 m above Indian Creek, near Manderfield. On the basis of their B and Cca horizon development, young alluvium is correlated with deposits of the most recent major glaciation, the Pinedale, which probably ended about 12,000 to 15,000 yr B.P.

Holocene deposits in the Beaver basin have similar facies as the three alluvial groups, but are restricted mainly to incised and inset channels and small alluvial fans. The Holocene alluvium is generally light-brown to light-gray, medium- to coarse-grained sand and pebbly to bouldery gravel that forms broad, slightly dissected surfaces along the Beaver River and North Creek and, towards the Tushar Mountains, form narrow channels inset into older deposits. Along the lower parts of Wildcat and Indian Creek and their tributaries, the Holocene alluvium includes massive silt and fine sand and abundant organic matter and calcium carbonate deposited in a marsh-like environment. Numerous seeps and springs indicate ground water is near the surface of this unit along the Beaver River and has prevented $CaCO_3$ from accumulating in many of the Holocene soils.

SOIL DEVELOPMENT

The degree of development of soils formed in surficial deposits is used for mapping and correlating these deposits over the basin, and for making estimates of soil age. The discussion of soil development presented here is based on descriptions of about 25 soil profiles and on selected laboratory data for soil characteristics such as texture, $CaCO_3$ content, bulk density, and saturated pH. The laboratory methods used for these analyses are basically the same as those reported in Machette and others (1976) and include clay content by the pipette method (using chemical dispersion) and $CaCO_3$ content by the Chittick gasometric method. Although not reported completely here, these analytical data are the primary basis on which I compare and contrast soil development.

The soils on surficial deposits in the Beaver basin are formed in an alluvial chronosequence that spans the last 0.75 m.y. Because these soils are formed in parent materials of similar lithologies and textures, in similar landscape positions, and in similar biotic, vegetative, and climatic environments, I ascribe their main differences in development to the influence of time, that is, the duration of soil formation. The parent materials consist mainly of pebbly to sandy gravels derived from Tertiary mafic and silicic volcanic rocks. Loess and fine-grained eolian sand, which mantle some of the alluvial deposits in the basin, contribute to the apparent development of B horizons.

Because the soils of the Beaver basin have noncalcareous to very weakly calcareous (<2 percent $CaCO_3$) parent materials, and because there is no evidence of deposition of $CaCO_3$ by shallow ground water, most or all of the $CaCO_3$ in the soils are derived from aerosolic sources such as calcareous eolian sand and dust and from Ca^{++}-enriched rainfall (Bachman and Machette, 1977). Alternately, some soils may have periodically lost $CaCO_3$ from their soil profiles during climatic periods of relatively high-leaching capacity with respect to the rate at which Ca^{++} is supplied to the land surface (Machette, unpublished data, 1982).

The continental climate of the Beaver basin ranges from semiarid with 20-25 cm of rainfall in the low parts of the basin, to dry-subhumid with 25-30 cm of rainfall along the margins of the basin at elevations below 2,100 (6,900 ft) (Stott and Olsen, 1976). The bulk of the annual precipitation occurs during the winter and spring months with about 30 percent falling as rain during the summer months. The mean-annual air temperature ranges from 45^{o} to 49^{o} C at elevations of 1,585 to 2,100 m (5,200 to 6,900 ft) in the basin and the average-monthly maximum (30^{o} C) and average-monthly minimum (-10^{o} C) temperatures occur in January and July, respectively. Under the climatic conditions of the Holocene, calcium carbonate probably accumulates at depths of 50-100 cm and is not leached from the soil because the distribution and amount of annual precipitation is balanced with respect to the airborne influx of Ca^{++} ions to the soil surface (Machette, unpub. data, 1982).

Soils are an important tool in this study because deformation during the Quaternary has left alluvial deposits of many ages at different topographic levels in the basin. I have summarized data for some soil properties of the Beaver chronosequence in table 1, and although this list is not a comprehensive analysis, it shows some time-related soil properties that have proven useful for mapping and differentiating Quaternary alluvial deposits in the Beaver basin. The soil description and laboratory data in this report is presented in tablular form and uses abbreviations for much of the standard soil terminalogy. Readers unfamilar with this terminalogy should consult Soil

Taxonomy (Soil Survey Staff, 1977) or references that deal with soils and geology such as Birkeland (1974).

The two oldest geomorphic surfaces of the basin, Last Chance Bench and Table Grounds (table 1), are significantly different in age, yet have soils that appear similarly developed. One might consider this similarity to indicate a stable or steady state of soil development, but it is an artifact of several factors. Because the Table Grounds surface is only preserved at relatively high altitudes along the moist, eastern side of the basin, its soils have lost more $CaCO_3$ due to periodic leaching than those from Last Chance Bench, which are topographically lower and have formed under a relatively drier environment. This is the reason soils on Table Grounds contain less total $CaCO_3$ (55-70 g/cm^2) than soils on the younger, Last Chance Bench (average of 74 g/cm^2). Compounding this climatic factor is the problem of adequate sampling. The soils of Table Grounds are more eroded than those of Last Chance Bench and my soil pits on Table Grounds did not extend to the base of the Cca horizon; therefore the calculated total $CaCO_3$ contents of Table Grounds soils are minimum values (see table 1).

Combined, these factors result in soils on Table Grounds that appear less developed than those on Last Chance Bench. This is not so. The differentiating criteria lies in the development and the strength of K horizon development (Gile and others, 1965, 1966; Bachman and Machette, 1977). The Last Chance Bench soils have K horizons with advanced forms of stage III $CaCO_3$ morphology, but lack a laminar layer which is typical of the stage IV pedogenic calcretes (indurated calcic soils, Bachman and Machette, 1977) that are developed on Table Grounds. This criteria alone is not compelling evidence for greater soil ages because soil texture can greatly influence the stage of $CaCO_3$ development (Gile and other, 1966). More compelling evidence for greater age is the higher concentration of $CaCO_3$, greater thickness of the zone in which $CaCO_3$ accumulates, and the presence of argillic horizons that have been engulfed by $CaCO_3$. Together, these data suggest that the soils of Table Grounds (0.75 m.y. B.P.) are about 1 1/2 times as old as the soils of Last Chance Bench (0.5 m.y. B.P.).

The next younger group of soils are formed on old alluvium. These soils are markedly less developed than old soils as evidenced by their thinner and less calcareous K horizons, slightly less developed $CaCO_3$ morphology (stage III), and less total $CaCO_3$ content (table 1). The total $CaCO_3$ content of "old soils" ranges from >9 g/cm^2 (a partially leached soil) to a maximum of 38 g/cm^2 (soil profile 8/18/78-1, table 1; field trip stop 3). Although I need more data for these soils, a total $CaCO_3$ content of 35-40 g/cm^2 is probably representative of their maximum calcic development. If one uses this range of values and assumes that the average rate of $CaCO_3$ accumulation during past 0.5 m.y. (0.15 g/cm^2/kyr; Machette, 1982a) is valid, the calcic horizons of old soils could have formed in about 230,000-270,000 yr. This soil-age estimate and the uranium-trend age of 240,000$\pm$40,000 yr strongly suggest that the old alluvium is about 250,000 yr old. It is interesting to note that soils of $\geq$250,000 yr age seem to reach a maximum B-horizon development in terms of clay content, thickness, and color. This observation must be tempered with the probability that B horizons become engulfed by underlying, upwardly migrating calcic horizons and that B horizons are subject to progressive surface erosion with increasing age.

The soils on middle alluvium are much less developed than those on old alluvium, yet show moderately well-developed profile characteristics. Middle soils are differentiated from old soils by Bt horizons that are 1) less red, typically with a maximum color of 7.5YR5/4d, 2) thinner, usually about 30 cm

Table 1. Comparison of some properties of soils formed in Quaternary surficial deposits of the Beaver basin, south-central Utah.

(The abbreviated headings are as follows: d, thickness: B horizon values in parentheses are thickness of the clay bulge; *Clay is the difference in clay content between the maximum and the A(↓) or the C (↑) horizon; *$CaCO_3$ is the maximum percent calcium carbonate in the less than 2 mm fraction and the value in parentheses are the maximum percent calcium carbonate in the whole-soil fraction. Tabular abbreviations are as follows: t, thickness; m, moist; d, dry; n.d., no data; -, weak; +, strong.)

Number and location	Deposit	B horizon t, in cm	B horizon Max. color (Munsell)	B horizon *Clay	Cca/K horizon t, in cm	Cca/K horizon Max. Stage	Cca/K horizon *$CaCO_3$	Total $CaCO_3$, in g/cm^2	Remarks
8/8/78-1 Stop 9	Qty	30	5YR 5/3 to 5/4d	3(↓)	100	I	0.4 (0.1)	n.d.	High water table
8/13/78-1 Country Inn	Qty	35	7.5YR 4/4d to 5/4d	3(↓)	20 to 120	II-	0.7 (0.1)	n.d.	High water table
5/14/80-2 Manderfield Church	Qpy	25	7.5YR 4/4m	4(↓)	110	I+	1.9 (0.2)	0.3	
COMMON VALUES, YOUNG ALLUVIUM		30	7.5YR 5/4d	3(↓)	100	I+	<2.0 (0.1)	0-0.3	Age: 12-15 kyr
8/9/78-2 Stop 5	Qtm	17	5YR 5/3d to 5/4d	8(↓) 20(↑)	56	III	32 (30)	11	
5/11/80-2 Greenville dump	Qtm	31	7.5YR 5/4m	18(↓) 29(↑)	53	III-	27 (26)	>8	Thin profile, $CaCO_3$ lost
5/14/80-1 LDS farm	Qpm	45	7.5YR 5/5m	11(↓) 16(↑)	52	III-	16 (10)	>6	Leached, high water table
COMMON VALUES, MIDDLE ALLUVIUM		30	7.5YR 5/4d	12(↓) 22(↑)	54	III-	25 (22)	10-12	Age: 120-140 kyr
8/9/78-1 Stop 4	Qpo	60(85)	5YR 5/6d	7(↓) 25(↑)	118	III	47 (24)	25	Loess over gravel
8/11/78-1 Greenvl. cemetary	Qto	35(68)	5YR 5/6d	25(↓) 32(↑)	85+	III	15 (11)	9	Thin on QTs, $CaCO_3$ lost
8/18/78-1 Stop 3	Qfo	47(88)	5YR 6/6d	18(↓) 25(↑)	115	III	40 (32)	38	Thick, U-trend age: 240kyr
COMMON VALUES, OLD ALLUVIUM		51(80)	5YR 5/6d	17(↓) 27(↑)	106	III	44 (28)	31	Age: 250 kyr
8/8/78-2 Hwy 91 pit	Qglc	35(107)	7.5YR 4/3d	8(↓) 28(↑)	127	III+	59 (59)	78	Max clay in IIK1 horizon
9/27/78-1 Stop 2	Coll/ Qglc	67(132)	5YR 5/6d	23(↓) 32(↑)	133+	III+	53 (38)	49	Base covered
5/10/80-2 Upper BLM pit	Qglc	18(100)	5YR 4/4m	10(↓) 24(↑)	132	III+	68 (67)	70	U-trend age: 420 kyr
COMMON VALUES, GRAVELS OF LAST CHANCE BENCH		40(100)	5YR 5/5d	14(↓) 28(↑)	130	III+	60 (55)	74	Age: 450-500 kyr
9/28/78-1 Stop 1	QTsf	none	n.d.	n.d.	110+	IV	50 (46)	>51	Eroded, cov'd base, min $CaCO_3$
5/10/80-1 BLM pit	QTsf	27	7.5YR 5/4m	n.d.	150+	IV	~65 (~62)	66	High altitude, $CaCO_3$ lost
COMMON VALUES, TABLE GROUNDS SURFACE		strip, consumed	7.5YR 5/4m	n.d.	150?	IV	65 (62)	55-70	Age: 750 kyr, $CaCO_3$ lost

thick, and 3) less clayey, with 12 to 22 percent more clay than the minimum amounts above and below, respectively. Where calcareous, middle soils have K horizons that are 4) thinner and 5) less calcareous, and 6) have less-developed $CaCO_3$ morphology (stage III-) than those of old soils. Middle soils have a maximum calcic development of 10-12 g of $CaCO_3/cm^2$ of soil column. These values require 67,000-80,000 yr to accumulate at a rate of 0.15 g of $CaCO_3/cm^2/kyr$; a period slightly less than the 70,000-130,000 yr age suggested by uranium-trend soil ages on middle alluvium.

My studies of calcic soils in the southwestern United States (Bachman and Machette, 1977; Machette, 1982a, Machette, unpubl. data, 1982) show that soils formed during the last major glacial-interglacial cycle (10,000 to 140,000? yr B.P.) probably yield inaccurate soil-ages when estimated from total-$CaCO_3$ values. This may be explained by climatically induced changes in the rate of accumulation of soil carbonate. During the Holocene, calcic soils in New Mexico have accumulated $CaCO_3$ at rates 2-3 times higher than rates during late Pleistocene time (Machette, 1982a). Climatically induced, cyclic changes in the rate of $CaCO_3$ accumulation have the greatest influence on calcic soils of post-Bull Lake age (that is 100,000-130,000 yr), because $CaCO_3$ may form in these soils during a long pluvial episode (120,000 yr?) marked by a low accumulation rate and a short interpluvial episode (10,000 yr) marked by a higher accumulation rate. Measurements to total $CaCO_3$ content in relict soils of pre-Bull Lake age deposits yield similar average accumulation rates (Bachman and Machette, 1977; Machette, unpub data, 1982) because these soils have formed under multiple cycles which tend to attenuate rate changes. If the $CaCO_3$ in the Beaver soils accumulated at such cyclically variable rates, then the total $CaCO_3$ contents of soils formed over the last 50,000 to 130,000 yr would yield soil-age estimates that are too young. I suggest an age of 120,000-140,000 yr for the middle group of alluvium on the basis of these arguments, the uranium-trend soil ages, strength of soil development, and their probable correlation with deposits of the last major pre-Pinedale glaciation (the Bull Lake glaciation).

The youngest major group of soils in the Beaver chronosequence are weakly developed on latest Pleistocene alluvium. Young soils are characterized by 30-cm-thick, weak argillic B horizons and thick, very weak Cca horizons (table 1). The B horizons are commonly 7.5YR in color, but some of this reddening is caused by ground-water oxidation. Where the water table has remained low, the young soils have weak accumulations of $CaCO_3$, mainly as thin coatings on clasts (stage I), over a thickness of 100 cm. Because most of these soils are developed in fining-upwards stratified deposits, it is difficult to evaluate the amount of secondary clay in their B horizons. For example, the B horizon of soil profile 8/8/78-1 (tables 1 and 7) has 3 percent more clay than its A horizon (18 percent), but has 12-17 percent more than the underlying gravel (a second parent material) Nevertheless, the weak argillic B horizons and lack of substantial accumulations of $CaCO_3$ are the main criteria for differentiating young and middle soils.

Holocene soils in the Beaver area are weakly developed because of the young age and the high level of the water table during the Holocene. Although no detailed soil descriptions were made for Holocene soils of the Beaver basin during this study, these soils are characterized by incipient Bt horizons (usually a cambic or structural B) and oxidized C horizons.

In summary, the soils of the Beaver chronosequence show systematic changes in the developement of argillic and calcic horizons that are related to time. Characteristics of these horizons provide valuable criteria for recognizing and differentiating the surficial and youngest basin-fill deposits of the Beaver basin.

LATE CENOZOIC STRUCTURAL DEVELOPMENT OF THE BEAVER BASIN

The earliest deformation recorded by basin-fill deposits in the Beaver basin involves the north-trending Maple Flats horst which is formed by the conglomerate of Maple Flat and underlying basin-fill deposits and, in the north-central part of the basin, by volcanic rocks. The timing of the horst's uplift is problematical, but the coincidence of its east side with the west margin of the rhyolite of Gillies Hill suggests that the horst existed at least 9 m.y. B.P.

The horst continued to be a positive structural and topographic feature through the subsequent history of basin-fill deposition. Conglomerate along the east side of the Maple Flats horst has been uplifted and is in fault contact with the stratigraphically higher upper-piedmont member (Tsp). The horst has been an uplifted pennisula since Pliocene time as shown by the areal distribution of 2.0-m.y.-old ash found in lacustrine sediment (QTsl) northwest and northeast of the horst, but not on the horst itself. Uplift of the horst continued during the Pleistocene as shown by displacement of the basalt of Cunningham Hill (1.1 m.y.) and by subsidary faults that offset the gravel of Last Chance Bench (0.5 m.y) on the Hogsback.

The Maple Flats horst extends southward as a topographically high block as far as Wildcat Creek and probably extends further southward in the subsurface beneath Last Chance Bench where upper basin-fill sediment is deformed into a broad antiform. This antiform, here named the Last Chance Bench antiform, is cut by as many as 100 closely spaced normal faults trending N. to N. 20° E., and by fewer and more subtle, but clearly contemporaneous, northeast-trending normal faults with down-to-the-northwest displacement.

The axial trace of the Last Chance Bench antiform (fig. 1; Machette and others, 1981) steps 2.4 km east of due north through a series of right-lateral shifts over a distance of 10 km between the Beaver River and Wildcat Creek. Upper basin-fill sediments have attitudes of as much as 20° near the axis of the antiform and horst, but dip less than 5° several kilometers to the east and west of the axis. The 2.0-m.y.-ash is present at roughly concordent elevations, throughout the basin and shows that, although extensively faulted, there has been little net structural displacement across the Last Chance Bench antiform during the Quaternary. However, basin-margin faults east of the Beaver-Manderfield road (Hwy 91) have displaced 0.5-m.y.-old gravels as much as 100 m, down-to-the-west, indicating that extension? and uplift are still active processes in the Beaver basin.

Although north-trending faults are predominant in the basin, east- to northeast-trending faults also are present, probably to a greater degree than shown on recent geologic maps (Machette and others, 1981; Machette, 1982a; Machette and Steven, 1982). For example, northeast-trending down-to-the-north faults form lineaments and small scarps in middle and old alluvium north of Indian Creek. The main southwest-trending valley of Indian Creek probably is controlled by a major fault of this same system which would explain the 30-100 m of elevational difference between the levels of Last Chance Bench and the Hogsback.

Many of the faults scarps on Last Chance Bench are 10 to 25 m in height and clearly have a history of recurrent movement. Data on fault scarp morphology and stratigraphic evidence show that many of the faults in the east part of the Beaver basin had late Pleistocene movement (Anderson and Bucknam, 1979; H. M. Steer, 1980). Two major faults displace young alluvium (12,000-15,000 old) in the Beaver area (Machette and others, 1981). The western of the two faults form an arcuate, west-curving, 0.5- to 3-m-high scarp that extends from the Beaver River to North Creek (Anderson and Bucknam, 1979).

Data of R. E. Anderson (written commun., 1982) and H. M. Steer (1980) show that this scarp is slightly less degraded than wave-cut shorelines (data of R. C. Bucknam, written commun., 1979) associated with the 15,000-yr-old shoreline of Lake Bonneville (W. E. Scott, written commun., 1980). These data and the stratigraphic control indicate that the youngest faults in the Beaver area are probably less than 12,000-15,000 yr old.

There are clearly two deformational systems active in the Beaver basin, one related to the progressive growth of the Last Chance Bench antiform that is probably nontectonic, and a second that may be related to recurrent tectonic faulting along the active boundary of the Basin and Range Province and the Colorado Plateau.

POTENTIAL URANIUM MINERALIZATION IN THE BEAVER BASIN

The following discussion of uranium mineralization in upper Cenozoic deposits of the Beaver basin may seem peripheral to the purpose of this report, but is included here to show the potential economic and scientific importance of studying Quaternary stratigraphic and structural problems. Steven and others (1981) argue that the Beaver basin had long been a structural sump for waters draining uranium source areas in the Tushar and Mineral Mountains. The evidence for secondarily deposited uranium in the thick, closed-basin fill of the Beaver basin is largely circumstantial, but apparently convincing enough to promote recent exploration by several companies.

Several stratigraphic, structural, and geomorphic factors are important in a consideration of the potential for uranium concentration in this basin: 1) the basin contains a thick sequence of bolson and lacustrine deposits that date back to the Miocene, and buried parts of this section may contain significant carbonaceous material, 2) rapid lateral-facies changes may provide both chemical and lithological discontinuites favorable for uranium precipitation, 3) the faulted antiform and horst undoubtedly influenced the flow of ground water, and the recurrent nature of the faulting may have caused the flow pattern to change many times; and 4) the basin had a high ground-water table and possibly reducing environment at depth until an outlet was established shortly before 0.5 m.y.

Recent geochemical surveys by Miller and others (1980), a helium survey by Reimer (1979), and radon surveys by McHugh and Miller (1982) and industry (S. M. Hansen, in Steven and others, 1981) strongly suggest that uranium is concentrated in the Pliocene and Miocene basin-fill deposits (see also Miller and McHugh, 1981). Texaco, Phillips, Canyon Resources, and other companies recently have spent considerable time and effort exploring for uranium in the basin. These efforts have concentrated on drilling 150- to 450-m-deep wells in the upper and lower basin-fill deposits between Wildcat Creek, Manderfield, and the Beaver River. The results of these drilling activities is unknown to U.S. Geological Survey personnel at the present time.

ROAD LOG OF THE BEAVER BASIN

Mileage		Observations
Cumul-ative	Between observations	
0.0	0.0	Start of Road Log. Beaver Canyon Campground is located on the north side of Utah State Highway 153 about 1.4 miles east of the juction with Utah Hwy 90 (see fig. 1, field trip route). The campground is built on young (Qfy) and middle (Qfm) alluvial fans of Bone Hollow; these deposits interfinger with and overlap young (Qty) and middle (Qtm) terrace alluvium of the Beaver River that is associated with outwash of the Pinedale and Bull Lake glaciations, respectively. (See fig. 2 for correlation of deposits in the Beaver area.) A soil pit excavated in young fan alluvium on the east side of Beaver Canyon Campground has a profile with A (11 cm), Bt? (33 cm, 10YR5/3d), and weak stage II Cca (50 cm) horizons. A soil pit excavated in middle fan alluvium on the north side of the campground has a much stronger profile consisting of a thin A and thick calcic Bt (stage II) and K/Cca (stage III) horizons. The Bt horizon has 7.5YR 5/4d to 4/4m colors. Turn right (W) onto Hwy 153.
0.2	0.2	Turn right (N) onto North Creek Road, just past the sign for Hi County Estates subdivision. Road climbs up onto small west-sloping remnant of terrace and fan deposits of middle age (correlative with deposits of the Bull Lake glaciation).
0.5	0.3	Broad low surface to the left (W) is the late Pleistocene and Holocene flood plain of North Creek, a major drainage of the Tushar Mountains. Note the west-facing, north-trending fault scarp marked by a line of cottonwood trees about 250 m west of the road.
2.2	1.7	Gravels underlying the Table Grounds surface are displaced by a west-dipping normal fault that is exposed in east face of the gravel pit.
3.4	1.2	Turn left onto access road to De Armitt property. Park at base of hill and walk to top of Table Grounds.

STOP 1. **Table Grounds surface and overview of the Beaver basin**

Overview of the Beaver basin (12:00 is due north):

8-11 Mineral Mountains: Tertiary(?) intrusives, metamorphosed Paleozoic rocks, and Quaternary rhyolites (at the north end).

10-11 Maple Flats horst: Pliocene to Miocene fanglomerate at the south end and Miocene and Oligocene rhyolitic to intermediate volcanic and intrusive rocks at the north end. Middle? Pleistocene cinder cones along the northwest escarpment of the Maple Flats horst.

11:30 8- to 9-m.y.-old rhyolites of Gillies Hill (area of antennas) and Woodtick Hill.

12-4 Tushar Mountains: Intermediate to silic volcanic rocks of 19-27 m.y. age. (For details see Cunningham and others, 1982a.)

4-5 Flat-topped ridges north and south of Beaver Canyon are 22-to 23-m.y.-old potassium-rich mafic lava flows (Machette and others, 1981).

6:00 Ridge south of Beaver River: a remnant of Table Grounds; numerous breaks in slope are scarps formed by middle to late Pleistocene down-to-the-west faults.

6-7:30 Black Mountains: composed of volcanics of the Tushar Mountains, distal ash-flow tuffs from southern Utah, and local rhyolites and basalts.

7:30 Minersville Reservior and Canyon: drainage outlet of the Beaver River and its tributaries.

This stop is on the west edge of the Table Grounds surface, the depositional top and youngest part of the basin-fill. Table Grounds is the highest of the geomorphic surfaces of the Baver basin and is preserved as (1) a narrow remnant of coalesced alluvial fans between North Creek and the Beaver River and (2) as an elongate west-sloping ridge of alluvial-fan and piedmont-slope alluvium just south of the Beaver River. This ridge is cut by north to northeast-trending faults that form scarps 3-15 m high. The eastern end of the ridge is terminated by a down-to-the-west normal fault; the downdropped part of the surface is visible as an $1/2^{\circ}$ to 1° east-tilted surface at the southern I-15 exit to Beaver. This fault has an estimated throw of 70 m (Anderson and others, 1978) based on the elevations of displaced surfaces.

To the east of us, the frontal fault of the Tushar Mountains places lower Miocene volcanic rocks against lower? Plesitocene fanglomerates (QTsf). The mafic lavas that form high ridges to the east and southeast of here are downdropped about 150 m across this fault zone as evidenced by small outliers of lava which rise slightly above the Table Grounds surface, directly north of the Beaver golf course. Additional, larger-displacement faults, which are basinward of the mountain front, may have a total of several thousands of meters of stratigraphic throw since the early Miocene. These faults form a several-kilometer-wide zone that marks the transition between the Colorado Plateau to the east and the Basin and Range to the west.

Although the soil is not well exposed, fragments of laminated, stage IV calcrete crop out along the margins of Table Grounds. A 1.25-m-deep excavation for the swimming pool on the south side of the DeArmitt home revealed a very strongly developed, thick K horizon, overlain by a Aca and Cca horizons (soil profile 9/28/79-1, table 1 and 2). The maximum clay content of this soil occurs in the K2m horizon, and indicates that the K horizon may have grown upward and engulfed a earlier, deep Bt horizon.

I dug a soil pit on a stable part of Table Grounds, about 1 km to the east of here, that exposed a 27-cm-thick Bt horizon and a stage IV K horizon more than 150 cm thick (table 2, soil profile 5/10/80-1). The thickness of the Bt and K horizons, the advanced stage of $CaCO_3$ morphology in the K horizon, and the surfaces' topographic position above Last Chance Bench, indicate that the Table Grounds surface must date be significantly older than 0.5 m.y. On the basis of this evidence, and stratigraphic and sedimentologic considerations, I estimate that the Table Grounds surface is about 0.75 m.y. old.

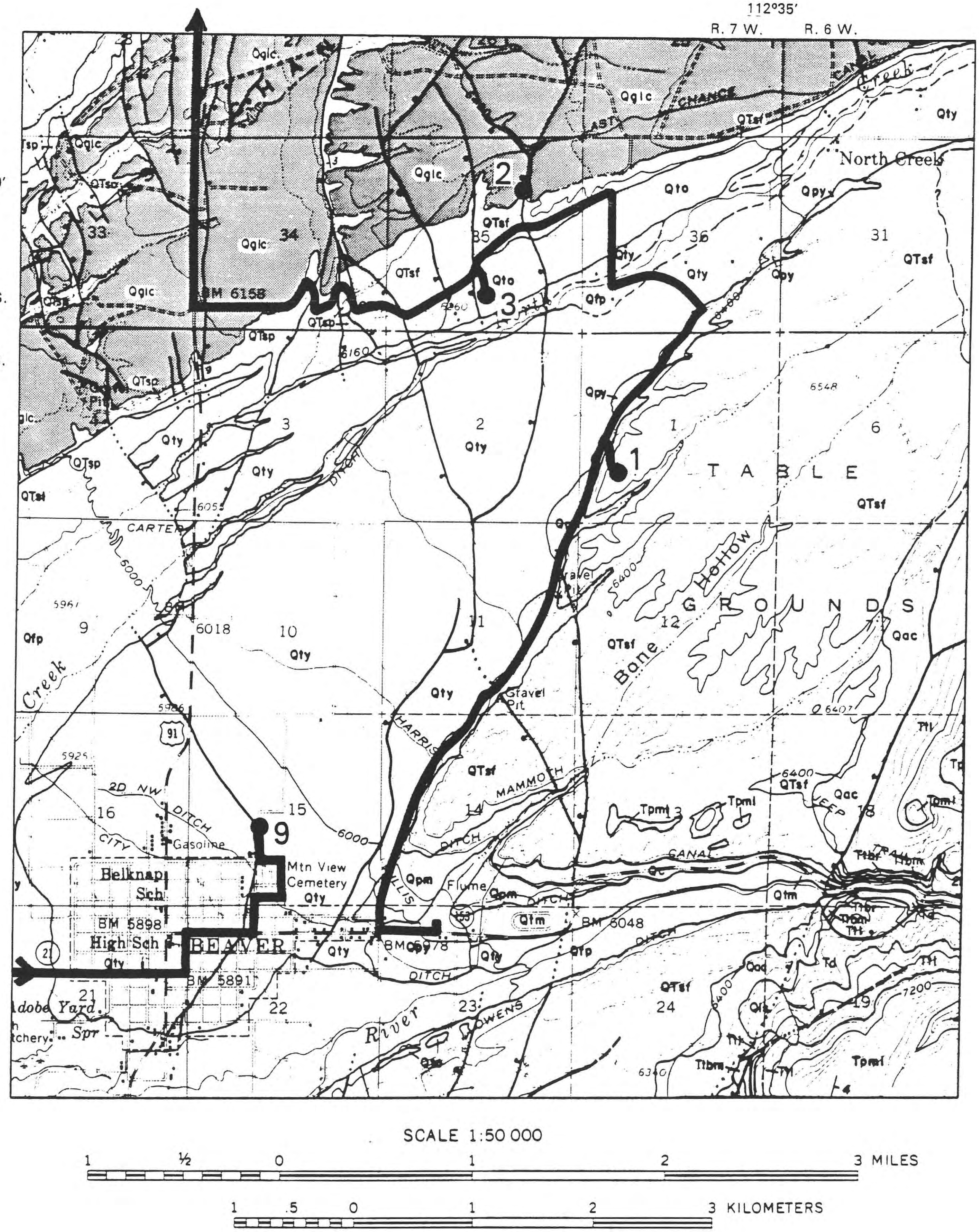

Figure 3. Geologic map of deposits near stops 1, 2, and 3 (from Machette and others, 1981). Map symbols and units are the same as on figures 1 and 2.

Table 2. Soil description and selected laboratory data for soil 9/28/79-1, relict soil on fanglomerate facies of upper basin fill, Table Grounds surface (about 0.75 m.y. old)

Horizon depth, in cm	Color m, moist d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
Aca	10YR4/4m	gL to	1f-vf	ss,ps	I	26.8	16.9	
0-15	10YR5/3d	gSiL	gr	loose		17.5	11.1	34.6
Cca	10YR5/3m	gSiL	2cgr to	ss,ps	I and IV	16.8	38.9	
15-25	10YR7/2d		2fsbk	firm	(frags)	10.2	23.7	39.0
K22m	n.d.(m)	SiL?	3cpl	s,ps	IV to	10.7	49.7	
25-55	white(d)			v hard	III+	10.0	46.2	7.0
K23m	10YR5/5m	SL- to	mass	s,ps	III+	9.5	41.6	
55-85	white(d)	LS+		v hard		9.0	39.5	5.0
K3	10YR7/3m	vgSL+	mass		III-	2.0	25.6?	
55-85	10YR8/2d			hard	to II	0.4	5.0	80.6
C2ca	10YR6/6m	vgSL-	mass	ss,ps	II to	4.2	21.1	
85-125+	10YR7/4d		to sg	friable	I+	1.6	8.3	60.9
Base covered								

3.4	0.0	Turn right (N) onto North Creek Road.
4.1	0.7	Turn left (NW) onto narrow paved road. Route crosses flood plain of North Creek which is formed by young alluvium (Qty), minor Holocene floodplain alluvium (Qfp), and sparse remnants of middle terrace alluvium (Qtm). Road parallels North Creek for about 1/4 mile.
4.6	0.5	North Creek. After bridge, road crosses narrow Holocene floodplain, a 50-m-wide remnant of middle terrace alluvium, and levels out on a wide terrace of old alluvium (Qto). About 2.5 km to the west (down grade), a fault displaces Qto and forms an 11-m-high scarp. The upthrown fault block is marked by junipers and the downthrown block is cultivated. Good view of scarp from stop 2, 1 mile ahead.
5.0	0.4	Turn left (W). High surface to the right (N) is the eroded south edge of the Last Chance Bench (LCB) surface.
5.6	0.6	After cattle guard, the road swings to the right (N) as it descends fault scarp. The road then turns to the left (W); park on the right side of road near the irrigation flume. Parking space is limited here, so park close together.

STOP 2. **Buried soil on fault scarp colluvium and gravel of Last Chance Bench.**

Well-developed soils formed on fault scarp colluvium (upper parent material) and gravel of Last Chance Bench (second and third parent materials) are exposed in the arroyo that cuts along the base of this fault scarp (fig. 3). The Bt horizon of this soil is aggradational, having developed while colluvium was washed down the fault scarp. Samples collected by Horst Steer from this soil profile (table 3) yielded a minimum uranium-trend soil age of 420,000±40,000 yr B.P. for the combination of parent materials (J. N. Rosholt, written commun., 1981).

This soil is well developed, but atypical of the Last Chance Bench in that it has a thick, well preserved Bt horizon. The Bt horizon has 23 and 32 percent more clay than the upper and lower soil horizons (table 1), respectively, and has a strong yellowish-red color (5YR 5/6d). The underlying K horizon contains a maximum of 53 percent $CaCO_3$ (<2 mm fraction, stage III+); the $CaCO_3$ in this horizon may be overly concentrated by the change in texture at the horizons's base.

Table 3. Soil description and selected laboratory data for soil 9/27/79-1, buried soil developed in scarp colluvium and gravel of Last Chance Bench (0.5 m.y. B.P.).

Horizon depth, in cm	Color m, moist d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
A1 0-10	10YR3/2m 10YR4/3d	gSL to gL	1f-vf gr	ss,ps firm	none	12.2 7.3	0.3 .2	29.9
B1t 10-20	7.5YR4/3m 7.5YR5/4d	CL	1msb to 1m-fgr	s,p firm	none	31.1 26.0	.3 .3	16.5
B21t 20-38	5YR5/4m 5YR5/5d	gCL	2c-m abk	s,p firm	none	35.0 25.3	.5 .4	27.7
B22tca 38-77	5YR4/6m 5YR5/6d	vgCL	3m-fabk to 3mpr	s,p firm	I to II-	34.5 13.8	2.5 1.0	60.1
K1 77-100	7.5YR7/5m 7.5YR8/2d	gCL	3m-fpl	s,ps hard	III-	33.4 20.3	31.9 19.4	39.1
K2 100-142	7.5YR8/3m white (d)	gCL-	3m-fpl	ss,ps hard	III	27.6 20.2	52.8 38.4	27.3
2K3 142-180	10YR8/3m white (d)	vgSL	mass	ss,ps hard	III-	13.2 5.0	44.4 16.8	62.2
3Cca 180-210+ Base covered	7.5YR7/4m 7.5YR8/2d	LS-	mass to sg	ss,po loose	II- discon- tinous	2.4 2.2	10.3 9.5	7.9

A soil pit dug about 2 km north of here exposed an 18-cm-thick, 5YR Bt horizon, but the laboratory data indicate a clay bulge extends to a depth of about 125 cm, well within the K horizon (table 1). The morphology of $CaCO_3$ in this and other soils on stable sites of Last Chance Bench is an advanced form of stage III (Gile and others, 1966; Bachman and Machette, 1977). The total secondary $CaCO_3$ content of uneroded, relict soils on Last Chance Bench ranges between 70 and 78 g/cm^2 of soil column. Using an age of 0.5 m.y. B.P. for these soils, I calculated an average $CaCO_3$ accumulation rate of 0.15±0.02 g of $CaCO_3$/cm^2/kyr for the Beaver basin (Machette, 1982b).

This long-term accumulation rate is substantially lower than those determined from calcic soils of New Mexico (0.22-0.51 g/cm^2), but is similar to that estimated for the Vidal Junction area of southeast California (Machette, unpubl. data, 1982). Rates determined by R. R. Shroba (in Scott, 1982) for late Pleistocene and Holocene soils in the Salt Lake City area are much higher--0.50 g/cm^2/kyr--than in the Beaver area. It appears that the Salt Lake region has a substantially higher $CaCO_3$ flux rate than Beaver due to the wide exposures of calcareous lake beds and these soils may not have periodically lost $CaCO_3$ due to excessive leaching, as is suspected for many of the soils developed in the relatively wetter climate along the eastern margin of the Beaver basin.

		Continue west on road.
5.9	0.3	Turn left through gate onto private property. Park cars close to road to minimize damage to the field. Walk south about 250 m to the northeast corner of the unfinished house.

STOP 3. **Soil developed on old fan (Qfo) alluvium near North Creek**

Although I initally mapped this alluvial-fan deposit as middle alluvium, the basement excavation for this home revealed a soil far more developed than any I had seen before on middle alluvium. As it turns out, the alluvial fan and terrace are formed by old alluvium that lies at a low topographic position due to offset by down-to-the-west faults. One such fault forms an 11-m-high scarp about 1/2 km to the east of this site (fig. 3)

The soil exposed in the northwest corner of the basement excavation is thick, well developed and contains a full assembleage of subhorizons; it is the most complete and best preserved soil that I have found on old alluvium in the Beaver basin. The argillic B horizon is 35 cm thick and, based on laboratory data, appears to have a clay bulge that extends down into the K horizon (table 4). The maximum clay content in the soil is about 34 percent (<2 mm, B22t horizon), whereas overlying and underlying horizons contain a minimum of 16 and 8 percent clay, respectively. Subhorizons of the B, including the calcareous B3tca, are commonly 5YR6/6d, a strong reddish-yellow color.

The morphologic development of calcic horizons in this soil range from a stage II B3tca (8 percent $CaCO_3$) to a stage III K22 horizon (about 40 percent $CaCO_3$). The calcareous part of the soil is about 75 cm thick (K21-K32 horizons) and represents a significant portion of the soils total $CaCO_3$ content of about 38 g/cm^2. As previously discussed, the time necessary to form this amount of soil carbonate is 230,000-270,000 yr, based on 35-40 g $CaCO_3$ and an average accumulation rate of 0.15 g/cm^2/kyr. This soil-age estimate agrees with the uranium-trend soil age of 240,000±40,000 yr B.P. determined from samples collected at this site.

Table 4. Soil description and selected laboratory data for soil 8/18/78-1, relict soil on old fan alluvium (Qfo) overlying old terrace alluvium (Qto) of North Creek (250,000 yr B.P.).

Horizon depth, in cm	Color m, moist d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
A 0-8	7.5YR5/4 to 5/3d	SL	1cpl to 1fsbk	ss,ps	none	16.2 14.5	0.5 .5	10.8
B1 8-20	7.5YR5/4 to 4/4d	SL	2m-f sbk	ss,ps	none	17.5 15.9	1.0 .9	9.0
B22t 20-36	n.d.(m) 5YR5/6d	CL	2c-m sbk	ms,ps	none	33.7 28.7	.7 .6	14.8
B23t 36-49	n.d.(m) 5YR6/6d	L	1m-f sbk	ms,ps	none	18.6 15.8	.7 .6	15.0
B3tca 49-55	n.d.(m) 5YR6/6d	gL	3m-2f sbk	ms,ps	II	20.3 14.4	8.0 5.7	29.2
K21 55-70	n.d.(m) 7.5YR7/4d	L	2msbk-2mabk	ms,ps hard	II+ to II-	18.9 15.6	32.4 26.8	17.4
K22 70-80	n.d.(m) white(d)	L-	2c-f abk	ms,ps hard	III	13.3 10.8	39.5 32.3	18.3
K31 90-110	n.d.(m) 5YR8/2-3d	L	2m-fpl	ss,po hard	III-	13.9 13.7	34.3 33.7	1.7
K32 110-130	n.d.(m) 5YR8/2d	L	2f-1mpl	ss,po firm	III- to II	23.8? 22.5?	26.7 25.2	5.6
C1ca 130-160	n.d.(m) 7.5YR7-6/4d	SL?	1fsbk	so,po loose	II- to I	n.d.	8.2 6.8	16.9
C2ca 160+ Base covered	n.d.(m) 5YR5/6d	gSL	sg	so,po loose	II- to I	8.3 5.4	5.8 3.8	34.9

Turn left (W) onto paved road. Road ascends Last Chance Bench and crosses several down-to-the-west fault scarps.

6.6 0.7 Road descends hill (fault scarp) and turns left (W) along arroyo. Exposures in this arroyo show a soil with a well-developed Bt and calcic horizons (formed in gravels of LCB) in fault contact with piedmont facies (QTsp) of the upper basin-fill that underlie LCB. This site has a geomorphic and structural setting similar to that of stop 2.

7.0	0.4	Gravel pit on right (N) is excavated along the largest fault scarp of LCB, here about 25 m high; this scarp continues to the south, where it intersects a fault that extends south of Beaver. Note the small graben at the base of the main fault scarp.
7.6	0.6	T-intersection with Hwy 91 (Manderfield Road). Turn right (N). Road traverses faulted LCB surface for the next 1.5 miles. Note the numerous 1- to 4-m-high north-trending fault scarps at the north end of Last Chance Bench. Hills to the left (W) are formed by a 1-km-wide northwest-trending horst.
8.0	0.4	Sileage pit on right (E) exposes a well-developed calcic soil typical of LCB.
9.3	0.7	Gravel pit on right (E), field trip stop for Anderson and others (1978, p. 18, mileage 171.0), contains a well developed, stage III calcic soil formed in gravels and a moderately developed Bt horizon formed in a mixture of gravel and loess? (see table 1, soil profile 8/8/78-2). The total $CaCO_3$ content of this soil is 78 g/cm^2, 10 percent greater than the 70 g/cm^2 determined at a wetter site, 80 m higher and 3 km to the east.
9.4	0.1	Cross Indian Creek. Road climbs up onto slightly higher surfaces underlain by young to middle terrace and piedmont alluvium.
10.0	0.6	Manderfield. Turn left (W) at abandoned gas station. Proceed west on dirt 1/4-section-line road. Road descends low swales underlain by thin Qpy and ascends broad interfluves of Qpm and Qpo alluvium. These surficial units overlie sandy piedmont-facies (QTsp) of the upper basin-fill.
10.8	0.8	Road climbs up onto the northern edge of an island of Qpo. Directly past the green cattle-feeder trough, the road drops over a 2- to 3-m-high fault scarp formed in Qpo; the road continues west on dissected surfaces of Qpy and Qpm.
11.2	0.4	Abandoned on-ramp to Interstate Hwy I-15.

STOP 4 (OPTIONAL). **Soil developed in old piedmont-slope alluvium (Qpo) overlying sandy piedmont facies of the basin-fill deposits (QTsp)**

The man-made exposure directly east of the underpass is an uncompleted on-ramp to I-15. These cuts are in an elongate, low south-trending hill that is a isolated remnant of a once-more-extensive piedmont-slope deposit. They expose a well-developed soil formed in loess?, old piedmont-slope alluvium, and sandy piedmont-facies of the upper basin-fill. The east and west edges of this hill are buried by middle and young alluvium, and to the south of here, the old alluvium is displaced by a series of down-to-southeast faults. The detailed division of surficial deposits near here and stop 5 (fig. 4) reveal faulted old and middle age alluvium, but rarely faulted young alluvium (see fig. 4).

The soil at this stop (table 5) is representative of old alluvium, although it is not as well developed as at stop 3. The Bt horizon is 60 cm thick, but the zone of clay accumulation is 85 cm thick; the Bt also has 5YR5/6d colors and weak to moderate subangular blocky structure. A maximum of 29 percent clay (<2 mm; 27 percent, whole soil basis) occurs in the B22t horizon compared to 13 percent in the B3ca and 4 percent in the basal part of the alluvium (3Cn horizon).

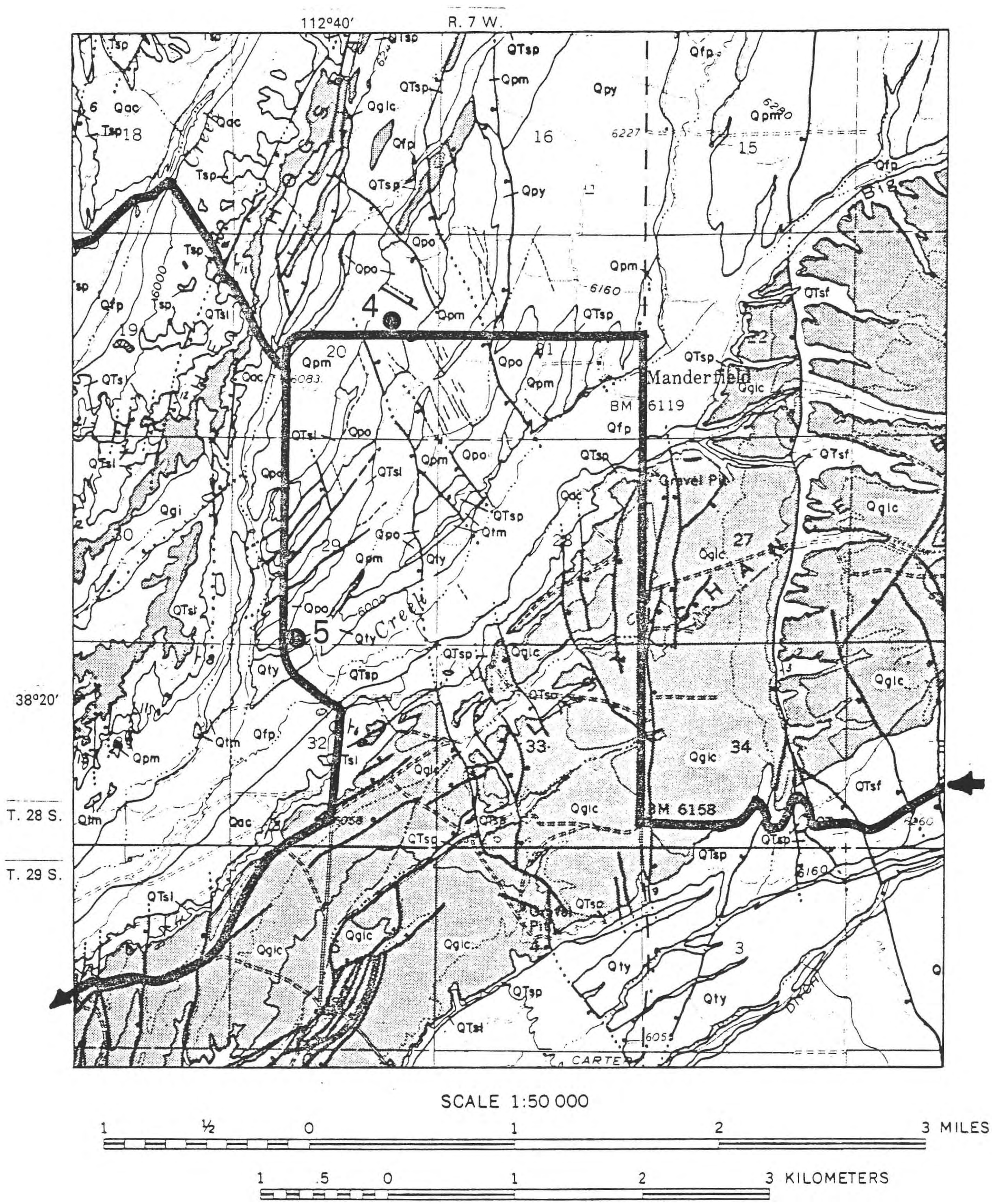

Figure 4. Geologic map of deposits near stops 4 and 5 (from Machette and others, 1981). Map symbols and units are the same as on figures 1 and 2.

Because the B horizon is relatively stone-free (less than 10 percent) and is enriched in silt content (30-40 percent, <2 mm fraction), I think that the parent material for the upper part of this soil may be a sandy loess, partially mixed with the underlying alluvium.

The K horizon, formed mainly in gravelly to very gravelly sands, is thinner (70 cm versus 125 cm) and has $CaCO_3$ more concentrated in thin horizons (47 percent maximum, <2 mm) than at stop 3. $CaCO_3$ is distributed over a total thickness of 118 cm if the calcareous part of the Bt is included. Although the total $CaCO_3$ content for this soil is only 31 g/cm^2, compared to a maximum value of about 38 g (stop 3), the amount is well in the range for old alluvium (table 1).

Table 5. Soil description and selected laboratory data for soil 8/9/78-1, soil on old piedmont alluvium (Qpo, 250,000 yr B.P.), abandoned on-on-ramp to I-15.

Horizon depth, in cm	Color m, moist d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
A/B 0-10	7.5YR3/5m 7.5YR4/4d	L	2fpl	ms,ps	none	21.4 20.0	0.2 .2	6.4
B22t 10-38	7.5YR4/4m 5YR4/5d	CL-	2fsbk	s,pm	none	28.5 27.4	.2 .2	3.9
B23tca 38-52	7.5YR4/5m 5YR5/6d	SCL-	1msbk	ms,ps	I	21.5 19.5	1.7 1.6	9.5
B3ca 52-70	7.5YR6/4m 7.5YR7/4d	SCL	2msbk	ms,ps	II+	13.3 12.8	28.2 27.2	3.7
K22 70-95	n.d.(m) 5YR8/3-2d	gSL+	2mpl	ss,po	III	15.7 8.1	47.3 24.4	48.4
K23 95-115	n.d.(m) 5YR8/3d	vgSL-	1mpl to mass	so,po firm	III	7.7 2.5	36.6 12.0	67.2
C1ca 115-170	n.d.(m) 7.5YR8/2d	vgLS-	mass to sg	so,po loose	III-	3.7 .8	11.0 2.4	77.8
2C2ca 170-230	n.d.(m) 7.5YR7/3d	vgS	sg	so,po loose	I+	4.0 .6	3.8 .6	85.4
3Cn(QTsp) 230+ Base covered	n.d.(m) 10YR5/4d	SiL+	mass	ss,po firm	I vienlets	19.2 19.2	.4 .4	.0

11.5	0.1	I-15 underpass. Proceed west; high juniper-covered surface, named the "Hogsback," is a northern extension of LCB. The gravel that forms the Hogback is 2-5 m thick and contains the same calcic soil as seen on LCB.
11.6	0.5	Turn left on south fork of road.
12.2	0.6	Small patented claim at 3:00 (W) is in the Huckleberry Ridge ash bed (2.0 m.y. B.P.). Although the airfall component is only 5-10 cm thick, the ash is as much as 1.5 m thick in the lacustrine facies due to reworking from adjacent terrain.
12.4	0.2	Road crosses intermittent drainage and climbs up on Qpo. This alluvium is displaced by a series of NE-trending faults that are part of a large, but poorly preserved fault system which controls the course of the ancestral and the modern Indian Creek.
13.1	0.7	Road descends onto terraces along north bank of Indian Creek. Notice small fluvial scarps as we drop from Qpo to Qtm and to Qty. Turn left into parking area, west (upwind we hope) of pig feeding lot.

STOP 5. **Soils developed on middle and young terrace alluvium of Indian Creek**

The parking area for this stop is located on the lower of two rather continuous alluvial terraces that are preserved mainly along the north side of Indian Creek. The lower terrace is 5-6 m above stream level and is underlain by about 3 m of sandy gravel that lies on light-green silty clays of the upper basin fill (QTsl). The upper of the two terraces is 10-13 m above stream level and here is formed by interfingering middle terrace alluvium of Indian Creek and middle piedmont-slope alluvium derived from basin-fill and older surficial deposits to the north. The middle alluvium is displaced by a series of parallel north- to northeast-trending, down-to-the-southwest faults (fig. 4).

The gravel pit in middle terrace alluvium exposes an eroded, yet representative profile of a middle-age soil. The soil has a partially eroded 17-cm-thick Bt horizon with a maximum of 22 percent clay, 8 percent and 20 percent more than the minimum contents of the respective overlying and underlying horizons (table 6). Laboratory data show 15-20 percent clay in the K horizons, indicating the possibility of a deep, engulfed Bt horizon. The Bt has a maximum color of 5YR5/3d, slightly less chroma than old soils.

$CaCO_3$ is concentrated at a shallow depth in this soil, with a maximum content of 32 percent in the K3 horizon (44-60 cm). $CaCO_3$ forms a continuous medium within the soil (stage III), coating and engulfing all clasts and giving the soil matrix a white color. The total $CaCO_3$ content for this soil is 11.6 g/cm^2, about one-third that of old soils and one-sixth that of soils formed in gravels of Last Chance Bench (table 1).

In contrast to the moderately well-developed soil on middle alluvium, the young alluvium exposed near the road, contains a weakly developed stage I calcic horizon and 7.5YR colors in the B and Cox horizons. Data for several other young soils are summarized in table 1 and we will see a noncalareous soil in young alluvium at stop 9.

Table 6. Soil description and selected laboratory data for soil 8/9/78-2, relict soil on middle terrace alluvium of Indian Creek (120,000-140,000 yr B.P.)

Horizon depth, in cm	Color d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
A 0-7	10YR5/2 to 6/2d	L-	2f-1f sbk	ss,ps	none	12.1 11.4	0.2 .2	5.4
B2t 7-13	7.5YR5/3 to 6/3d	L+	1f-wf sbk	ms,pm	none	22.8 19.0	.2 .2	16.5
B3 13-24	5YR5/4 to 7.5YR5/2d	gL	2msbk	ms,ps	none	20.0 15.1	.6 .5	24.6
K2 24-44	white to 7.5YR8/3d	gL	1mpl	ss,ps	III	15.6 10.9	18.9 13.2	30.2
K3 44-60	white to 7.5YR8/2d	SiL	2msbk	n.d.	III	19.1 18.4	31.6 30.4	3.9
2Cca 60-80	7.5YR8/3d	vgSL-	1fsbk to sg	n.d. loose	II to I	5.0 1.5	9.0 2.6	70.6
2Cn 80-100+ Base covered	n.d.	vgS	sg	so,po loose	I-	2.2 .4	3.3 .5	83.3

Continue south across Indian Creek.

14.0 0.9 Road climbs steep, short grade cut on interfingering piedmont and lacustrine facies of the upper basin fill.

14.2 0.2 Crest of hill, turn right (W). Road parallels north edge of LCB from here to our next stop (6), a distance of about 1.8 miles. Most of the surface south of this road junction consists of faulted sections of LCB with scarps of 2-10 m height. Note that most of these surfaces are back-tilted to the southeast, whereas the predominant fault trend is N. to N. 10° E. with down-to-the-west movement. The spacing between faults decreases westward, towards the axis of the LCB antiform.

15.1 0.9 Continue straight (W), past ranch road. This road is one of the few good accesses into the cental part of Indian Creek.

15.7 0.6 Intersection with road to the left (S); continue straight (W) through unlocked gate in section-line fence.

16.4 0.7 Pull off of the road and park among the juniper tress. We should now be at the highest elevation on the central part of Last Chance Bench, on the surface axis of the antiform.

STOP 6. **Last Chance Bench, overview of upper Cenozoic deposits and structure**

This stop provides a convenient point to view and discuss some of the stratigraphic and sedimentary aspects of the upper Cenozoic basin-fill deposits. Stop 6 is located on the surface axis of the Last Chance Bench antiform and we can see both east- and west-tilted beds below the gravel mantle (fig. 5). Near the axis, these beds dip as much as 20°, but several kilometers away these beds become nearly conformably with the overlying gravels, indicating a narrow, but intensive, zone of deformation.

The numerous scarps we crossed in route from stop 5 to 6 are produced by the episodic? or continual growth of the antiform. These scarps range from 1- to 2-m-high gentle slopes to 10- to 20-m-high steep escarpments. Drainage from the bench is through a system of ephemeral streams and arroyos which are almost entirely structurally controlled by a combination of west- and east-tilted surfaces, and subparallel fault scarps; these structures tend to concentrate runoff into the south-central part of the bench.

Faulted gravels are exposed along the north rim of Last Chance Bench. In several places, the gravels are downdropped in fault contact with much older basin-fill sediment: the presence of well-developed soils in the gravel indicates that displacement must be fairly recent (post-soil formation). Along the Beaver River, these same faults offset middle alluvium, indicating late Pleistocene movement.

The axis of the antiform was mapped from the pattern of east- and west-tilted surfaces, from the dip of underlying sediments, and from the orientation of the fault scarps (Machette, 1982a). From its southernmost exposure, directly north of the Beaver River, to Wildcat Creek on the north, the axis of the antiform trends about 15° E. of N., and steps to the east, en echelon through a series of northeast-trending faults (figs. 1 and 5). To the north of stop 6, the axis is located at the west end of the Hogsback and projects northward to the low ridge formed by conglomerate of Maple Flats. This ridge is a the southern extension of the Maple Flats horst.

The upper Cenozoic sediments exposed below the gravel here, and in exposures on the south side of the Hogsback, provide a nearly continuous record of more than 1 m.y. of lacustrine silts, clays, and finely bedded sands deposited in a shallow, but permanent lake. Sandstones with ripple marks and mudcracked claystones also show the lake was shallow during deposition of the upper basin fill.

Five discrete volcanic ashes are preserved in the lacustrine facies of the upper basin fill. The uppermost ash, named the Last Chance Bench ash (Izett, 1981), is white, fine-grained, and about 5 cm thick. The Last Chance Bench ash bed is estimated to be 1.8 m.y. old (Izett, 1982, p. 21) on the basis of its stratigraphic position with respect to other dated units and its chemical and mineralogic similarities with Bishop-type ashes from the Glass Mountain-Long Valley area of California (Izett, 1981). This ash is well exposed about 10-20 m below the gravel of Last Chance Bench on west of the limb of the antiform (fig. 6).

A medium- to coarse-grained, ripple-bedded sandstone crops out 20-25? m below the Last Chance Bench ash, and this sandstone lies about 12-15 m above a second ash in the section, the 2.0-m.y.-old Huckleberry Ridge ash bed (Izett, 1981, 1982; Izett and Wilcox, 1982). The basal Huckleberry Ridge is composed of 5-10 cm of coarse, water-laid airfall ash; it is overlain by 0.8-1.5 m of reworked, finer grained ash with abundant sedimentary and deformational load structures. The Huckleberry Ridge ash bed, interbedded in lacustrine sediment, has been found in 40-50 outcrops in the southern and western parts of the Beaver basin.

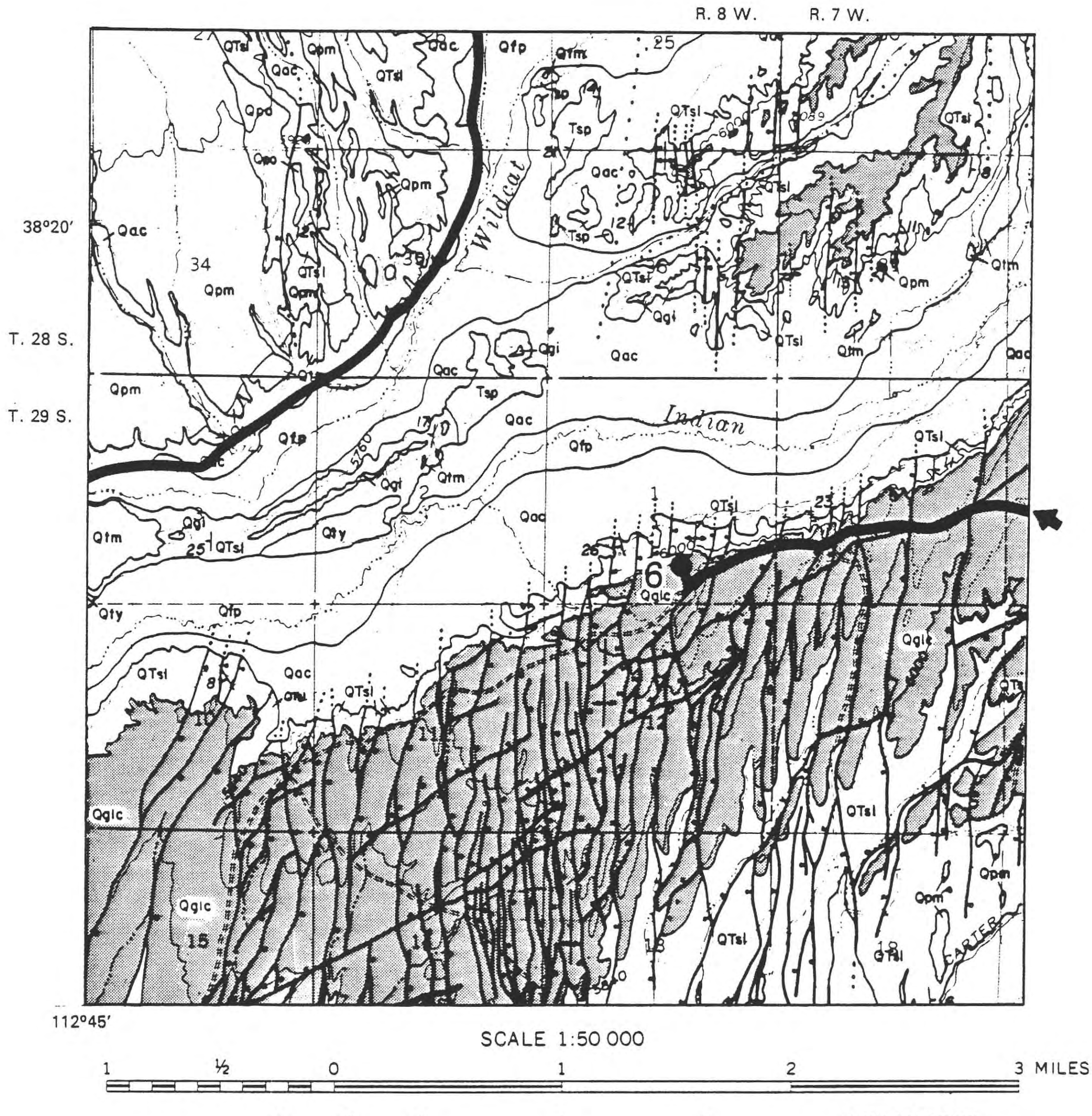

Figure 5. Geologic map of the central part of Last Chance Bench near the antiform crest, stop 6 (from Machette and others, 1981). Map symbols and units are the same as on figures 1 and 2.

An outcrop area known informally as the "triple ash locality", located about 1 km north of Indian Creek (N. 25° E of stop 6), is one of the most important localities in the Beaver basin in that it permits the physical correlation of beds south and north of Indian Creek. In this area, the Huckleberry Ridge ash bed caps a 30-m-thick section that contains a very fine-grained white ash informally named the middle ash bed and, 4 m lower at the base of the section, a coarse-grained obsidian-rich lapilli bed informally named the Indian Creek ash bed (Izett, 1981). These ashes are correlated with the tuff of Taylor Canyon (type-C, 2.1 m.y. B.P., Glass Mountain-Long Valley area; Izett, 1981) and with tephra from the rhyolite of Cudahey Mine? (2.3-2.4 m.y., near Black Rock, Utah; Izett, 1981), respectively.

Another ash, here informally named the Hogsback ash bed, is locally preserved below the Indian Creek ash bed in exposures along the north side of the Hogsback. It is interbedded with varigated light-green silty clays and slightly oxidized, orangish-brown sands. This ash lies about 20 m below the Indian Creek ash and about 50 m below the Huckleberry Ridge ash bed. The Hogsback ash also has chemical and mineralogical affinites that suggest a correlation with the rhyolites of Cudahey Mine and South Twin Peak, although it is much finer grained than the Indian Creek ash. Although the correlation of these ashes are tentative, the suggested ages agree well with other stratigraphic and sedimentalogic evidence.

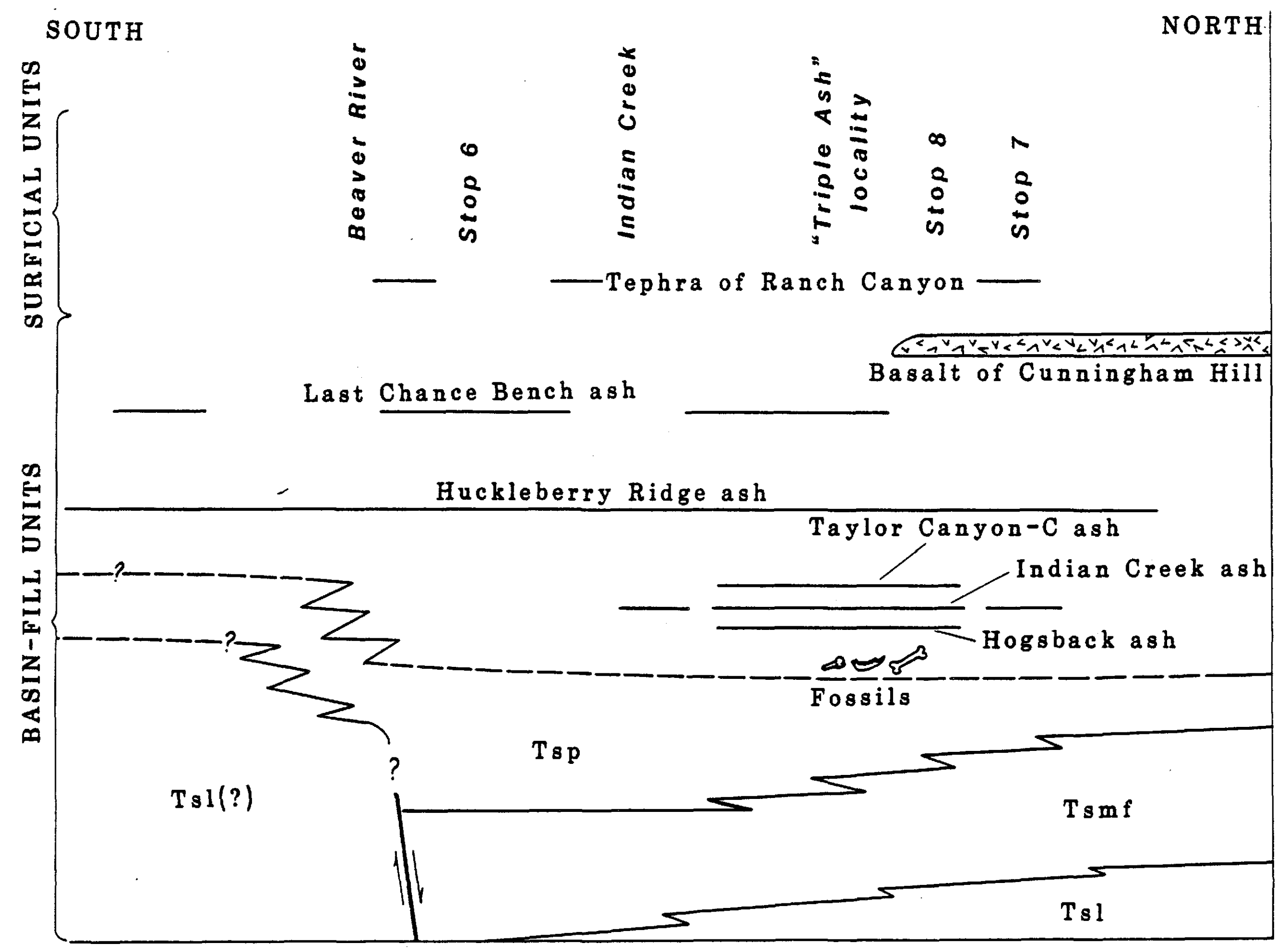

Figure 6. Schematic cross section of sedimentary deposits of the Beaver basin showing position of volcanic ashes. Map symbols and units are the same as on figures 1 and 2.

Fossils collected below the Huckleberry Ridge ash bed, and probably below the Hogsback ash, indicate a late Pliocene age for the enclosing sediments. These fossils, the first Blancan mammalian assembleage collected in Utah, provide more evidence of the Pliocene and Pleistocene history of basin sedimentation. Additional data, in the form of subsurface information, may allow a more complete analysis of Miocene sedimentation and deformation in the basin. For example, the Beaver Lulu Federal No. 1--a 11,400-ft-deep wildcat oil-and-gas test--was drilled at a site 1 1/2 km northeast of stop 6. This well was spudded in Pliocene sediments, about 20 m below the Huckleberry Ridge ash bed, and penetrated about 1,400 m (4,600 ft) of unconsolidated bolson deposits, including thick sections of coarse-grained conglomerates and alternating beds of oxidized and reduced playa? sediments.

To the south of Last Chance Bench, Texaco Minerals has recently completed a uranium exploration program: they had anticipated drilling about 300 wells, 150-500 m deep, to evaluate the potential for in-situ recovery of uranium. Geophysical logs of these drill holes contain a wealth of information from which one could interpretate the subsurface configuration, structure, and facies relations of Pliocene and Miocene sediment in the Beaver basin.

21.1	4.7	Retrace route along north edge of LCB, across Indian Creek and north to Y in road. This route provides a better view of the patented claim in the Huckleberry Ridge ash bed. Take left fork (NW) at Y intersection.
21.4	0.3	Crest of the "Hogsback." Road cuts expose gravel of Last Chance Bench unconformably overlying ostracode and gastropod bearing light-green siltly-clays and light-brown to orangish-brown sands of the lacrustrine facies of the upper basin-fill (QTsl).
21.8	0.4	Road descends the Hogsback. Small knob directly to the left (W) has Huckleberry Ridge ash in fault contact with uplifted older piedmont facies of the upper basin fill (Tsp). The piedmont facies is characterized by reddish-brown, thin-bedded conglomerates and sands, white to very light-brown calcareous marls, and light-brown silty clays.
22.1	0.3	Road makes a sharp left turn and crosses Wildcat Creek. Hills to the west are formed by the basalt of Cunningham Hill (1.1 m.y.) and QTsl and Tsp facies of the upper basin fill. Maple Flats, the high ridge to the north, is a horst formed by conglomerates and the underlying oxidized bolson sediment that comprise the two lowest exposed members of the lower basin fill. The east and west margins of Maple Flats are fault controlled.
23.0	0.9	Continue on road as it turns to the right (NW). Road ascends valley cut in lower basin-fill deposits. Graded dirt road to the left (S) goes around the south end of the southern extension of Maple Flats and affords a good view of deformed sediment between here and the south end of the Hogsback.
24.0	1.0	Road cuts to the right are in west-dipping conglomerate of Maple Flats that is in fault contact with lacustrine (QTsl) and piedmont (QTsp) sediments. The fault extends from south of the basalt of Cunningham Hill (at 9:00) to the drainage divide between the Cove Fort and Beaver basins, 10 km to the north.

24.4	0.4	Road climbs out of arroyo and crests hill. Proceeds northwest to first graded road to the left. Middle? Pleistocene basalt of Crater Knoll (cinder cone at 1:00) is preserved on the eastern flank of this valley. The vents for Crater Knoll and Red Knoll are coincident with the major west-bounding fault of the Maple Flats horst.
26.6	1.8	Turn left (W) and cross Cunningham Wash. The 1.1-m.y.-basalt of Cunningham Hill is poorly exposed in this arroyo. The source vent for the basalt has not been found.
27.0	0.4	Most of the piedmont slope along this portion of the road is formed by a thin mantle of middle alluvium that overlies fluvially deposited tephra of Ranch Canyon.
27.5	0.5	Pull off road at top of hill. As the road turns to the left it will descend into a tributary canyon of Cunningham Wash.

STOP 7. **Cunningham Hill area: Relation between the basalt of Cunningham Hill (1.1 m.y.) and the tephra (pumice) of Ranch Canyon (0.55 m.y.)**

This road cut and exposures to the northwest in a tributary to Cunningham Wash show the relations between middle piedmont alluvium (Qpm), the tephra of Ranch Canyon (Qrct), and the basalt of Cunningham Hill (fig. 7).

The tephra of Ranch Canyon, here a water-laid obsidian pellet and pumice deposit, fills a channel cut below the level of the topographically higher basalt. Locally derived boulders of basalt in the basal part of the channel fill show that the basalt is older than the tephra. Also, the pumice deposit clearly laps up against the valley wall cut adjacent to the basalt, indicating that the pumice does not lie beneath the basalt.

The pumice deposit is at least 10 m thick, as measured in the road cut. Exposures of the pumice in quarries upstream are even thicker, indicating the deep level of stream incision during deposition of the pumice, 0.55 m.y. B.P. Scattered outcrops of the pumice are found near stream level along Cunningham Wash, Wildcat Creek, and Indian Creek as far south as Adamsville. The basalt of Cunningham Hill, erupted 1.1$\pm$0.3 m.y. B.P., flowed along an ancestral, southeast-trending channel of Cunningham Wash and projects to a much higher base level than the pumice-filled channel. These relations strongly suggest that middle Pleistocene streams (in this part of the basin) were incised below the early Pleistocene depositional level of the basin and that these streams were flowing towards an outlet at Minersville Canyon, not towards the central part of the basin as they were during the early Pleistocene. The widespead planation of basin-fill deposits, some of which were structurally elevated by the Last Chance Bench antiform, was accomplished soon after 0.55 m.y. B.P., as evidenced by reworked pumice in the basal part of the gravel of Last Chance Bench. Thus, I argue that sediment deposition continued in a closed-basin environment until after 1.1 m.y., but ceased well before 0.55 m.y.

Using these constraints, and the degree of soil development on Last Chance Bench and Table Grounds, I estimate that basin-fill sediments were deposited until about 0.75 m.y. B.P. in the Beaver basin (see discussion at stop 1 and in text). Since 0.75 m.y. B.P. the history of basin sedimentation has been one of drainage integration and base level lowering, extensive lateral planation (Last Chance Bench), and periodic downcutting and subsequent depostion of the old, middle, and young alluvial- fan, piedmont-slope, and terrace deposits.

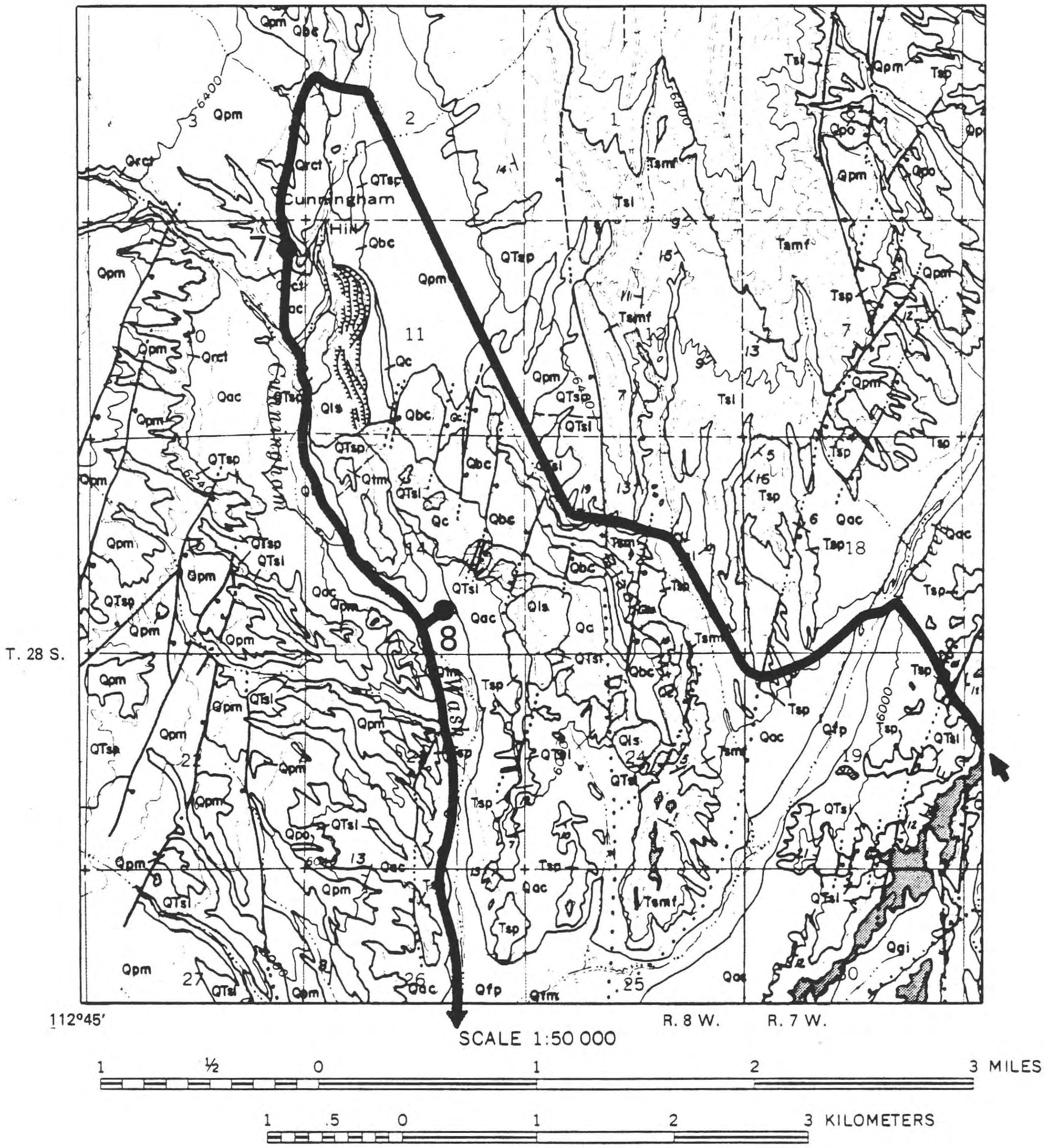

Figure 7. Geologic map of deposits near stops 7 and 8 (from Machette and others, 1981). Map symbols and units are the same as on figures 1 and 2.

27.9 0.4 Note the large landslide mass of toreva blocks. The heavy basalt that forms the high ridge to the left (E) rests on incompetent beds of the upper basin fill. The slide mass is about 1/2 km long and 250 m wide, and has a relief of about 40 m. Old remnants of landslide basalt are present along the east side of the road.

29.3 1.6 Break out into open valley of Cunningham Wash. High remnants of middle and old terrace and piemont-slope alluvium to the east and west indicate the deep incision of Cunningham Wash since middle Pleistocene time. Watch carefully on the left (10:00) for the road that leads to the south end of the basalt of Cunningham Hill. Exit and park on this road. Walk north of the parking area to large bulldozer cut below the basalt.

STOP 8. Faulted Huckleberry Ridge ash bed and lacustrine facies of basin-fill deposits

The Huckleberry Ridge ash bed and enclosing lacustrine deposits are well exposed in a bulldozer cut on the southwest side of Black Mountain (the ridge formed by the basalt of Cunningham Hill). The ash bed, exposed intermittently for a distance of 1-2 km along the south side of the ridge, is cut by numerous north-trending, down-to-the-east normal faults (fig. 7). One such fault (N. 50^{o} E., 65^{o} S.), exposed in the west end of the cut, has about 4 m of displacement. Of interest here are the basal airfall part of the ash bed, the overlying horizontally bedded ash, and the flame-like and contorted structures caused by penecontemporaneous loading of the ash bed.

The Huckleberry Ridge ash bed is about 2.2 m thick and is enclosed by lacustrine deposits that dip between about 8^{o} and 12^{o} to the west. These attitudes are consistent with the general dip of beds on the west limb of the antiform and horst. The overlying basalt flow has fault-induced dips of 0-5^{o}, indicating a 5-10^{o} angular unconformity between these two units. Because the lacustrine beds between the ash and the basalt flow must be 1.1-2.0 m.y. in age, uplift of the horst and antiform must have continued into the early Pleistocene. Likewise, the deformation of the basalt flow shows continued post-1.1 m.y. B.P. uplift of the horst and rotation of outlying beds.

From this site we can look due south about 1 1/2 km to the area in which G. A. Izett and J. G. Honey collected the first Blancan land mammals in Utah. The fossils include the zebra *Dolichohippus*, the muscrat *Ondatra* cf. *O. idahoensis*, and the microtine rodent *Mimomys meadensis*. The small-mammal taxa suggest a Blancan-5 age of 2.0 to 2.5 m.y. B.P. (C. A. Reppening, written commun. to G. A. Izett, 1980). They also collected less diagnostic bones of frog and fish, and teeth and bones of Pliocene horse and mastodon. To date, all of the fossils collected in the Beaver basin are from interbedded lacustrine and piedmont-slope sediments 25 to 50 m below the Huckleberry Ridge ash bed.

Return to graded dirt road along Cunningham Wash and proceed south.

30.1 0.8 Low ridge at 9:00 (E) is composed of piedmont facies of the lower basin fill (Tsp) and overlying lacustrine facies of the upper basin fill (QTsl). These two units are placed in contact by a north-trending, west-dipping normal fault. Late Pliocene fossils were collected from the varigated orangish-brown and light-green sands and silty-clays near the south end of this ridge. The high ridge to the east is formed by the conglomerate of Maple Flats and small remnants of the gravel of Last Chance Bench.

31.3 1.2 Continue straight (S) past junction with road around south end of high ridge. Sediments below the gravel cap of the Hogsback (10:00) contain, in descending order, the Huckleberry Ridge ash bed (2.0 m.y.), the Taylor Canyon-C ash bed (the middle ash, 2.1 m.y.), and the Indian Creek (lower obsidian pellet bed, 2.3-2.4 m.y.?) and the Hogsback ash beds from the Cudahey Mine area (2.3-2.4 m.y.?, Izett, 1981).

32.0 0.7 The low ridge at 12:00 is formed by gravel of ancestral Indian Creek (Qgi) that lies well below Last Chance Bench, but above old terrace alluvium (Qto). The irregular topography of the ridge top is caused by north-trending faults that form the Last Chance Bench antiform to the south.

33.1 1.1 The road cutting off sharply to the left (8:00) was constructed for the Beaver Lulu Federal No. 1, a wildcat oil-and-gas well drilled by Bagder Oil Company in the spring of 1981. The well site lies about 200 m south of Indian Creek and was spudded near the top of the Pliocene, slightly west of the surficial axis of the antiform. The well penetrated 4,600 ft (1,400 m) of Pliocene and Miocene basin fill; unofficial sources said that the well then penetrated thin Cretaceous(?) with a trace of coal, about 4,050 ft of overthickened Middle Jurassic Arapien Formation, about 1,050 ft of Navajo Sandstone, about 1,000 ft of quartzite, about 600 ft of red beds (Moenkopi? Formation), and entered the Kaibab Limestone at about 11,400 ft. The well was reported as dry.

33.7 0.6 Road bends to the right (SW). The Huckleberry Ridge ash crops out as a 15°-west-dipping resistant bed on the west face of the low saddle at 10:00. The Indian Creek ash bed is in base of the saddle, about 30 m lower than the Huckleberry Ridge ash bed. The wide surface to the west of the ridge is formed by middle terrace alluvium (Qtm).

34.9 1.2 Road makes a sharp bend to the left (S). Note the stream-cut embankments along Wildcat Creek on the left (E). These cuts expose the tephra of Ranch Canyon disconformably overlain by middle terrace alluvium. The broad piedmont surfaces to the right (W) are formed mainly by granitic piedmont-slope alluvium (Qpy and Qpm) derived from the Mineral Mountains.

35.5 0.6 On the left (E) the well preserved Indian Creek terraces are formed by young, middle, and old alluvium. The old terrace alluvium forms the highest ridge directly east of the creek and buries west-dipping gravel of Last Chance Bench.

36.8 1.3 Four-way intersection with the Pass Road; continue south to Adamsville. The Pass Road extends northwest across the Mineral Mountains to the Milford Valley.

38.2 1.4 Road passes under powerlines; turn left and continue under powerlines. Merge with road from northwest and cross cattle guard. Directly ahead is the small town of Adamsville.

39.3 1.1 Turn left onto Main Street, Adamsville, Utah. Continue east on this road to intersect Hwy 21.

39.8	0.5	Road cuts on left (N) are in middle and old terrace alluvium of Indian Creek. The Beaver River forms a wide Holocene and late Pleistocene flood plain directly south of the road.
41.4	1.6	Intersection with Hwy 21 (Beaver-Milford). Turn left, proceed about 100 m, and turn right onto Hwy 26 (to Greenville). For the next 2 miles, Hwy 26 lies on old terrace alluvium (Qto) of the Beaver River. Middle alluvium forms a terrace 2-6 m below the old terrace and is present mainly south of the highway. The small north-trending ridges and swales on this road are scarps formed by southward extensions of the same faults that form the Last Chance Bench antiform; they have predominantly down-to-the-east movement in this area (see figure 8 for local geology).

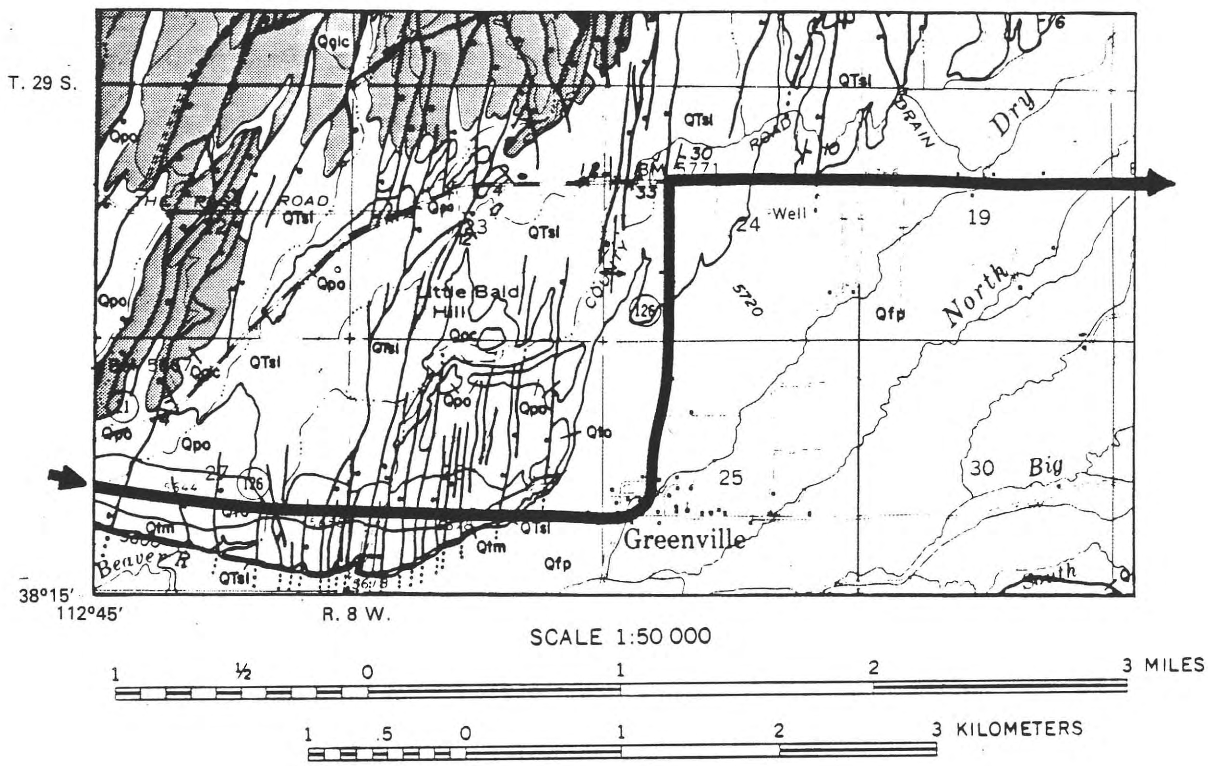

Figure 8. Geologic map of deposits north of the Beaver River showing deformation of surficial units (from Machette and others, 1981). Map symbols and units are the same as on figures 1 and 2.

The Beaver fault forms a well-defined scarp in the town of Beaver and north to the KOA campground. During an informal field trip to this stop in 1979, the proprietor of the Ready Mix Plant dug a pit at base of a pre-existing trench across the fault scarp. This pit exposed faulted gravels that are buried by a thin wedge of scarp colluvium, indicating that the total throw in the gravels is slightly more than the 2.5 m height of the fault scarp.

Scarps profiles were measured by H. M. Steer (1980) and R. E. anderson (written commun., 1982) along the Beaver fault and a similar fault (no. 49) about 1 km to the east of Stop 9. These fault scarps have maximum scarp-slope angle (θ) and height (H) values (fig. 9) that are similar to, but slightly less degraded than, the highest wave-cut shoreline of Lake Bonneville (Bucknam and Anderson, 1979) which was formed 14,000-15,000 yr B.P. (W. E. Scott, written commun., 1981). These fault scarps are more degraded than the scarps of the Drum Mountains, which are probably of Holocene age. These data indicate that the low scarps along the Beaver fault (less than 3 m high) must have been formed during the late Pleistocene or early Holocene. Recurrent movement of the Beaver fault and other faults in this part of the basin is shown by the large range of scarp heights (10-70 m) formed in deposits of late to early Pleistocene age.

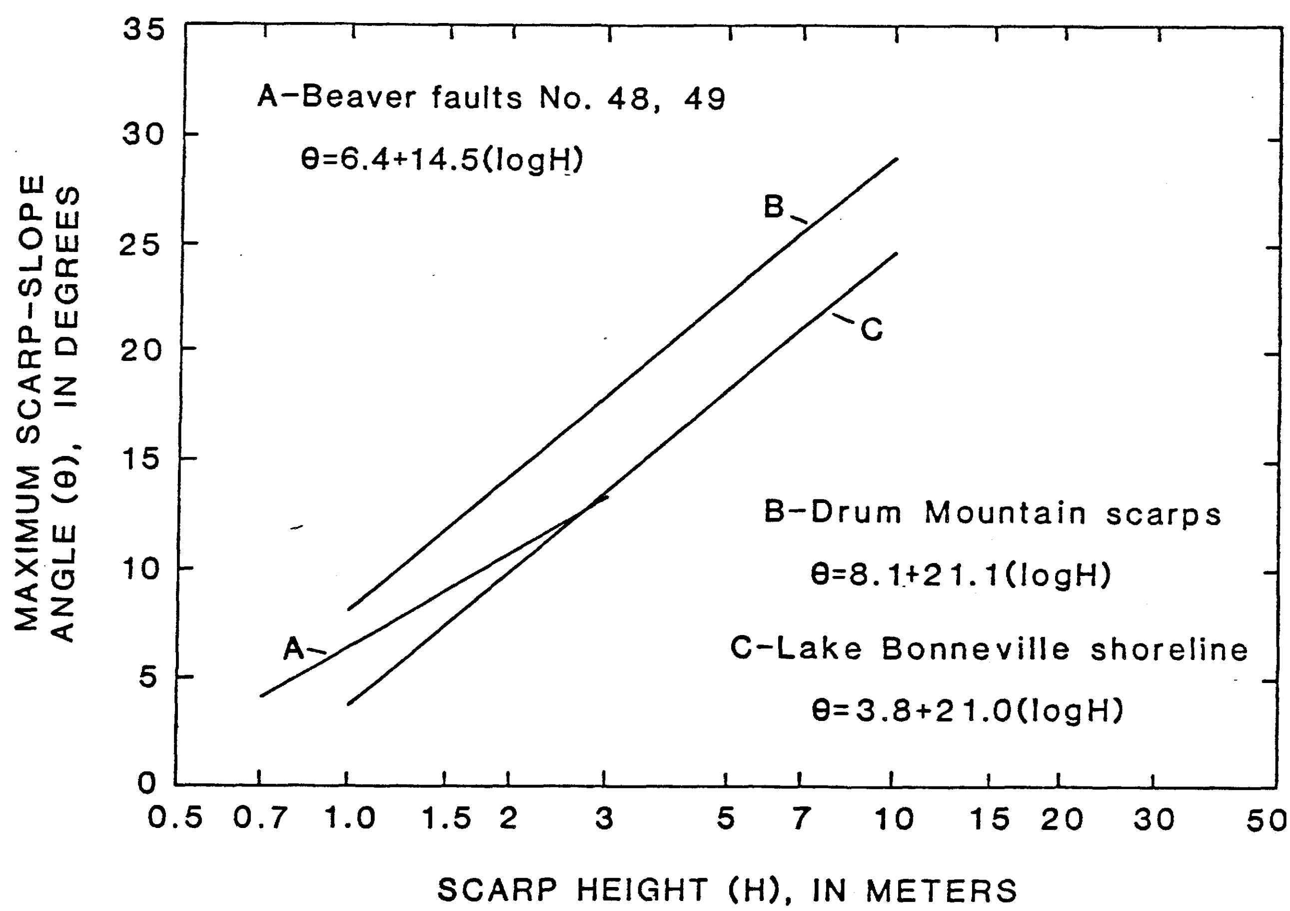

Figure 9. Morphometric data for two late Pleistocene fault scarps near Beaver.

The soil exposed on the upthrown side of the Beaver fault is typical of those formed on young gravelly alluvium of the Beaver basin (tables 1 and 6). These soils usually have A and B1 horizons formed in fine-grained deposits that overlie a weak argillic B2 and oxidized C horizon in loose sandy gravels. This B horizon has a clay content of 18 to 22 percent which, although about 15 percent more than the underlying gravels, is not proof of pedogenic clay accumulation. The colors of the B horizon (7.5YR) are significantly redder than its parent materials at the time of deposition, but are less red than those of the Cox and Cca horizons, indicating probable groundwater oxidation of the soil parent materials.

Near-surface water levels in the floodplain between the Beaver River and North Creek have prevented significant accumulation of $CaCO_3$ in the soil. $CaCO_3$ is present in these soils, but commonly forms only thin discontinuous coatings on clasts to a depth of more than a meter, whereas the soils formed in young alluvium along Indian Creek have as much as 2 percent $CaCO_3$ that forms continuous stage I coatings on gravel clasts and on the sandy matrix.

Table 7. Soil description and selected laboratory data of soil 8/8/78-1, relict soil on young alluvium of North Creek, Beaver Ready Mix Plant.

Horizon depth, in cm	Color m, moist d, dry	Texture	Structure	Consistence wet dry	$CaCO_3$ stage	Percent clay <2 mm total	Percent $CaCO_3$ <2 mm total	Percent gravel total
Spoil								
A 0-7	7.5YR3/3m 7.5YR5/3d	gL	1mpl	ss,ps friable	none	18.3 12.6	tr 0.0	 30.9
B1 7-18	7.5YR3/4m 7.5YR5/3d	L+	2m-1f sbk	ss,ps firm	none	21.6 18.7	tr .0	 13.4
2B2 18-37	5YR3/4m 5YR3.5/5d	vgSL+	1msbk to sg	ss,po loose	none	18.3 4.2	tr .0	 76.9
2Cox 37-66	n.d.(m) 5YR4.5/6d	vgS	sg	so,po loose	I-	4.8 1.1	tr .0	 76.6
2Cca 66-107	n.d.(m) 5YR5/4 to 5YR6/2.5d	vgLS	sg	ss,po loose	I	9.3 1.8	0.4 .3	 80.2
Base covered								

End of field-trip road log. Retrace route to Hwy 153; turn left (E) to Beaver Canyon Campground or right (W) to Beaver.

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