LLTR-89-2

FLUCTUATION HISTORY OF GREAT SALT LAKE, UTAH, DURING THE LAST 13,000 YEARS

By

Stuart B. Murchison

NASA Contract NAS5-28753, Final Report, Part II

Limneotectonics Laboratory Technical Report 89-2

July 25, 1989

Department of Geography

University of Utah

Salt Lake City, Utah 84112

LLTR-89-2

FLUCTUATION HISTORY OF GREAT SALT LAKE, UTAH, DURING THE LAST 13,000 YEARS

By

Stuart B. Murchison

NASA Contract NAS5-28753, Final Report, Part II

Limneotectonics Laboratory Technical Report 89-2

July 25, 1989

Department of Geography

University of Utah

Salt Lake City, Utah 84112

ABSTRACT

Great Salt Lake level fluctuations from 13,000 yr B.P. to the present were interpreted by examination of shoreline geomorphic features, shoreline deposits, archeologic sites, isotopic data, and palynologic data.

After the conclusion of the Bonneville paleolake cycle, between 13,000 and 12,000 yr B.P. the lake regressed to levels low enough to deposit a littoral oxidized red bed stratum and a pelagic Glauber's salt layer. A late Pleistocene lake cycle occurred between 12,000 and 10,000 yr B.P. depositing several beaches, the highest reaching an altitude of about 4250 ft (1295.3 m). The lake regressed after 10,000 yr B.P., only to rise to 4230 ft (1289.2 m) between 9700 and 9400 yr B.P. and then gradually lower at least 15 ft (4.5 m) or more. Lake levels fluctuated between 4212 and 4180 ft (1284 and 1274 m) for the next 4000 years. A late Holocene lake cycle, constrained by radiocarbon ages between 3440 and 1400 yr B.P., is reported at a highest static level of 4221 ft (1286.5 m). After a lake level drop to altitudes ranging between 4210 and 4205 ft (1283.2 and 1281.6 m), a 4217 ft (1285.7 m) level was reached after 400 yr B.P. This level lowered to 4214 ft (1284.4 m) in the mid

to late 1700s A.D. The lake levels have since stabilized around a 4200 ft (1280 m) mean.

PRECEDING PAGE BLANK NOT FILMED

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Many publications have been written about Pleistocene Lake Bonneville, but relatively few have concentrated on the post-Pleistocene history of Great Salt Lake (Gilbert, 1890; Eardley et al., 1957; Morrison, 1965; Scott et al., 1983). The obvious geomorphic shoreline features have been and continue to be studied, since the pioneering work of G. K. Gilbert (1890). Gilbert provided only limited observations about Holocene shore features because his main efforts concerned the geologic history of Lake Bonneville (Hunt, 1980). This legacy remained until the lake level drastically lowered in 1950s and 1960s and then began to rise to economically adverse levels in the 1970s and 1980s. These poorly documented Holocene lake rise phenomena led to the inception of this study. The objective of this dissertation is to examine shorelines and shoreline deposits of Great Salt Lake to clarify and explain the history of lake level fluctuations during the Holocene Epoch.

Historic accounts from early lake investigators reveal some important fluctuations of Great Salt Lake. John C. Fremont in 1843 observed the elevation of Great Salt Lake at

4200 ft above sea level (1280 m) from barometer readings. Between 1850 and 1860, early pioneers recorded a 5-foot (1.5-meter) lake rise and fall (Arnow, 1984). During the early 1860s the lake began to rise so steadily that the settlers feared Salt Lake City would be inundated (Stokes, 1966). In 1873, the lake attained its then highest historic level of 4211.5 ft (1283.5 m) (Arnow, 1984). These fluctuations led officials to install a gauge, and later a benchmark, on the south end of the lake near Black Rock in 1875 (Mabey, 1986). Lake levels have since been gauged and recorded, usually in hydrograph form (Figure 1). Stokes (1966, p. 2) reported widespread concern in 1966 that the lake would totally disappear "to leave only barren odorous flats behind."

Data previous to 1847 are incomplete, with estimates of prehistoric levels based on oxygen isotope ratios from sediment cores (McKenzie and Eberli, 1985), pollen studies (Mehringer, Jr., 1985, 1986), geomorphic shoreline features (Ross, 1973; Rudy, 1973; Currey, 1980), and correlations with regional environmental evidence, including other pluvial lakes in the Great Basin (Currey and James, 1982; Smith and Street-Perrott, 1983). Incomplete interpretation of the Holocene lake history along with a lack of corroborating physical evidence has left a void of reliable knowledge concerning Great Salt Lake level fluctuations from 10,000 yr ago to 1847.

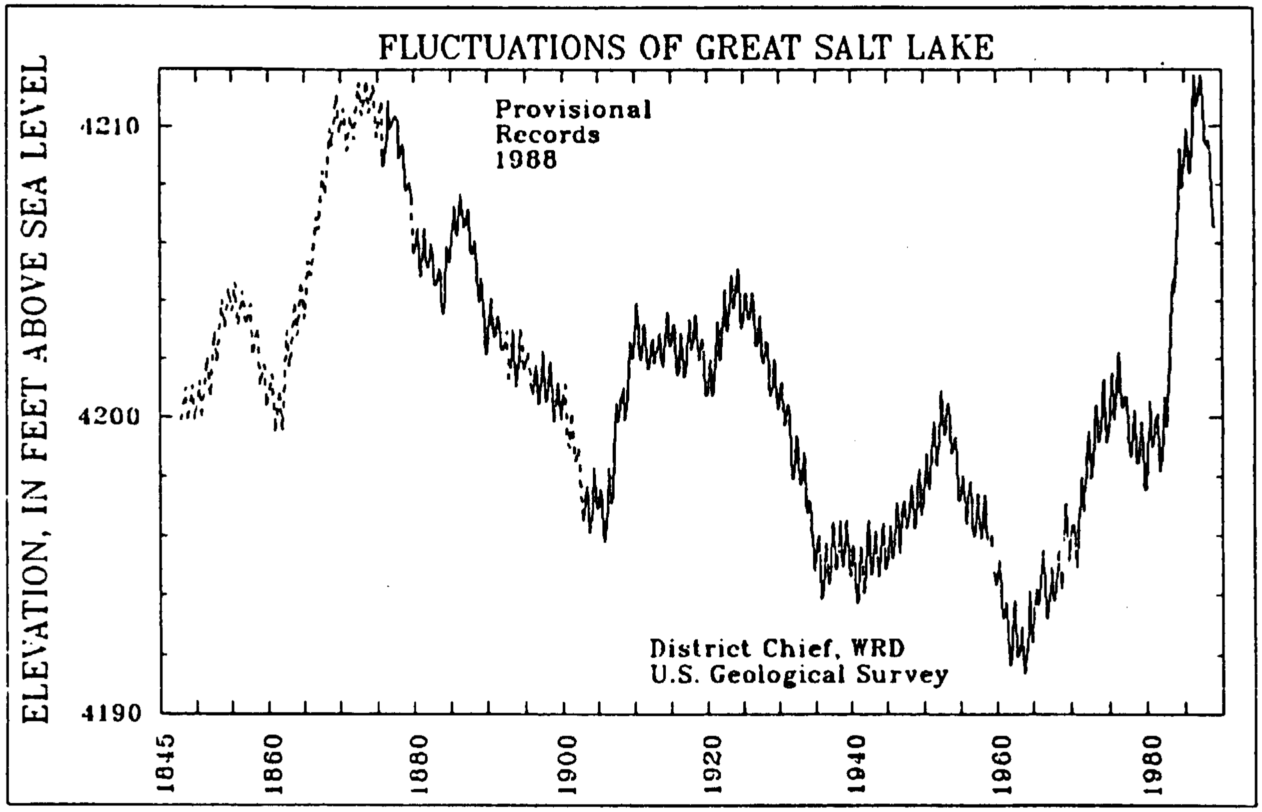


Figure 1. Historic Hydrograph of Great Salt Lake.

There exists a need to refine prehistoric lake levels for the safety of the population as well as a predictive tool for industry, construction, development, recreation, wildlife management, and ecological endeavors concerned with the lake. Several private and governmental entities (Arnow, 1984; Utah Water Resources, 1984; Kay and Diaz, 1985; May, 1985; FEMA, 1986; U.S.Army Corps of Engineers, 1986) have underscored the need for additional data on Holocene lacustrine fluctuations to determine a "planning level," i.e., a level above which lake rise flooding has an acceptably minimal probability.

In the Bonneville Basin, the Pleistocene-Holocene boundry has been age estimated by several investigators (Miller, 1980; Miller et al., 1980; Currey et al., 1983; Scott et al., 1983; Currey et al., 1984; Currey and Oviatt, 1985). These authors have identified geomorphic evidence of a shoreline that temporally straddles the boundry. This shoreline, called the Gilbert shoreline, was a minor late Pleistocene lake cycle of approximately 11,000 yr B.P. Since the Holocene Epoch, as described by Hopkins (1975) and Bowen (1978) begins at 10,000 yr B.P., this dissertation encompasses the Gilbert lake cycle that was well in progress at the beginning of the Holocene. The spatial domain of this study is directly related to Great Salt Lake and portions of the Great Salt Lake Desert region.

Isotopic, biologic, and geomorphic age estimates follow the nomenclature of Coleman et al. (1987) and the North

American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Since a date is a specific point in time, the words age and age estimate are used when referring to radiocarbon dates, fossils, and stratigraphic profiles including soils, lithologies, and prehistoric cultural artifacts. All radiocarbon age estimates are measured from 1950 A.D. and include the standard deviation (+/-), adjustments normalized to -25 per mil δ carbon 13 (unless otherwise indicated), and lab number.

Study Area

Great Salt Lake is a terminal lake with a historic average area of 1700 square miles (4403 sq.km) in northwest Utah. This lake has varied in depth and area in the last 150 yr due in part to climatic changes (Arnow, 1984).

During the late Pleistocene and Holocene the lake expanded into the Great Salt Lake Desert as far west as Wendover. Inundated areas to the north include Kelton, Bear River City and the base of the Hansel Mountains. A portion of west Salt Lake City is the farthest eastern paleolake margin. The southern margin of lake expansion culminated near the Deep Creek Mountains. The lake has also regressed to a known historic low level of 4191 ft (1277 m) in 1963 (Figure 2). Table 1 lists all of the localities mentioned in this dissertation, the UTM coordinates, and any previous reference utilized at that locality.

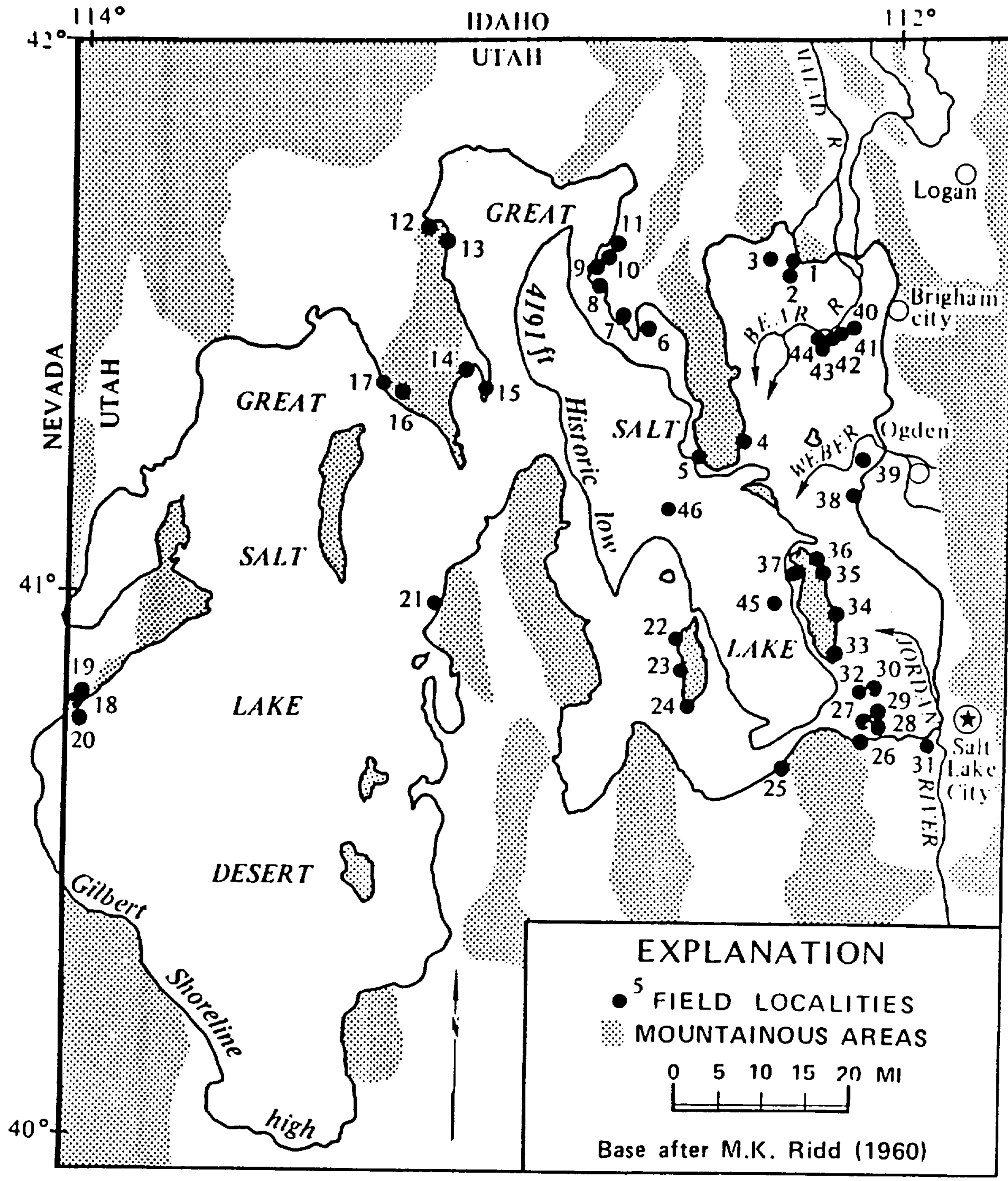


Figure 2. Localities mentioned in the text that are relevant to the late Pleistocene and Holocene chronology of Great Salt Lake.

Table 1. Localities mentioned in the text that are relevant to the late Pleistocene and Holocene chronology of Great Salt Lake.

Locality* # Name	UTM Coordinates	Reference
	Geomorphic localities	
1 Little Mountain	0395000E/4604250N	This paper
2 Mollys Stocking	0391950E/4602200N	This paper
3 W. Pub. Shooting Grds.	0390500E/4606400N	Murchison, 1989
4 Promontory East	0381050E/4566200N	This paper
5 Promontory Point	0372000E/4563850N	This paper
6 Rozel Point	0363100E/4589400N	This paper
7 Horseshoe Bay	0358350E/4592300N	Ross, 1973
8 Coyote Bay	0353500E/4597500N	Ross, 1973
9 Desolation Bay	0351500E/4602000N	Ross, 1973
10 Black Mountain Bay	0352450E/4604850N	Ross, 1973
11 Windmill Bay	0356000E/4609050N	This paper
12 Peplin Bar	0322850E/4615000N	Rudy, 1973
13 Hogup Bar	0323000E/4609700N	Rudy, 1973
14 Big Wash Bar	0329000E/4584450N	Rudy, 1973
15 Fingerpoint Spit	0332000E/4579650N	Rudy, 1973
20 Juke Box trench	0247300E/4516250N	This paper
21 Grassy Mtn. dunes	0314700E/4541200N	Currey, 1987
23 Stansbury Island West	0371100E/4513000N	This paper
24 Stansbury Island South	0370000E/4528000N	This paper
25 Mills Junction	0393150E/4505000N	Currey et al., 1983
26 Magna Spit	0413090E/4507050N	This paper
27 1300 South borings	0415600E/4510200N	This paper
28 Goggin borings	0416300E/4512800N	This paper
29 Three Flags borings	0415580E/4512810N	This paper
30 USGS borings	(see Table 8)	Keaton, per. comm., 1988
31 Jordan paleochannel I	0422010E/4505300N	This paper
32 Jordan paleochannel II	0412100E/4516400N	This paper
33 Unicorn Point	0400750E/4522500N	This paper
34 Seagull Point	0402000E/4534000N	This paper
35 Camera Flats	0397500E/4540400N	This paper
36 Tin Lambing Shed	0399450E/4543650N	Currey, unpub. data
37 White Rock Bay	0395200E/4541500N	Ross, 1973
38 Hooper	0404150E/4557400N	Rubin and Alexander, 1958

Table 1. Continued.

* Locality # Name	UTM Coordinates	Reference
Archeologic localities		
16 Hogup Cave	0311350E/4582200N	Aikens, 1970
18 Danger Cave	0246150E/4545000N	Jennings, 1957
19 Juke Box Cave	0247000E/4516500N	Jameson, 1958
22 Sandwich Shelter	0371100E/4523650N	Aikens, 1966
39 Injun Creek	0404850E/4574010N	Aikens, 1966
40 Bear River 1	0403750E/4592600N	Aikens, 1967
41 Bear River 2	0405100E/4593120N	Shields and Dalley, 1968
42 Bear River 3	0402080E/4591160N	
43 Knoll	0403940E/4594900N	Fry and Dalley, 1979
44 Levee	0402520E/4592220N	Fry and Dalley, 1979
Isotopic and Palynologic localities		
17 Cresent Springs	0309550E/4581850N	Mehringer, 1985; Grey and Bennett, 1972
45 Great Salt Lake core	0365800E/4556900N	Grey and Bennett, 1972
46 Core site I	0389000E/4538500N	McKenzie and Eberli, 1985, 1987

* Number refers to localities on Figures 2, 6, 21, 22, 26, 32 and Tables 11 and 19.

Previous Work

Geomorphic

Many of the early documents that included lake information were compiled by investigators interested in the exploration of the Great Basin (Stansbury, 1852 and Miller, 1980). G. K. Gilbert (1890) provided scant observations about Holocene shore features, although he did record fossil assemblages and isostatic diastrophism. Gilbert also deduced a short chronology based on verbal and recorded evidence of historic changes in lake levels from 1845 to 1883. He also commented on lake volume changes and salinity percentages from the historic record (Hunt, 1980).

Other 20th century authors in the Great Basin have long recognized lacustrine phenomena during recent or post-Pleistocene activity, usually, while still concentrating on Pleistocene Epoch. Antevs (1948, 1952, 1955) proposed that lake-periphery occupation by early humans was related to Neothermal and Altithermal intervals, and a mid to late Holocene lake desiccation period. Much of Antevs' work today is regarded with respect and is cited often.

Morrison (1966) inferred Holocene lake oscillations on the basis of post-Lake Bonneville deposits and soils that were excavated by the Southern Pacific Railroad in gravel pits on Promontory Point during 1955-1957. This stratigraphic and soil study was correlated with pre-

Holocene radiocarbon ages, other regional soils, and glacial cycles for an inferred extention of Quaternary chronology of Lake Bonneville. Morrison's chronology suggests altitudes in excess of 4700 ft (1432 m) asl during the early Holocene (see Figure 3a). The Graniteville and Midvale soils, which Morrison used as stratigraphic markers, were thought to be formed during interlacustrine periods. Morrison also identified a lesser lake cycle between 3800 and 750 yr B.P.

Ross (1973) and Rudy (1973) inferred nearly identical chronologies utilizing shoreline geomorphic features on respective eastern and western shores. Their 10,000-year chronologies include eight lake levels (5 high and 3 low) based on radiocarbon ages, relic shore stages, and correlations with soil, pluvial, and glacial chronologies (see Figure 3b). Their correlations with other regional chronologies, such as the Rocky Mountain and Sierra Nevada glacial chronologies, may explain the extreme altitudes of their late Holocene lake levels.

Currey's (1980) coastal geomorphic interpretation of late Pleistocene to Holocene lake fluctuations introduced inferred models of lake levels that are being examined today by morphostratigraphic and chronostratigraphic techniques. An integration of geologic and biologic evidence from late Pleistocene to Holocene times, in the northeastern Great Basin region, was thoroughly examined by Currey and James (1982). Their paleoenvironmental scenario, which is supported by numerous radiocarbon dates, suggests three

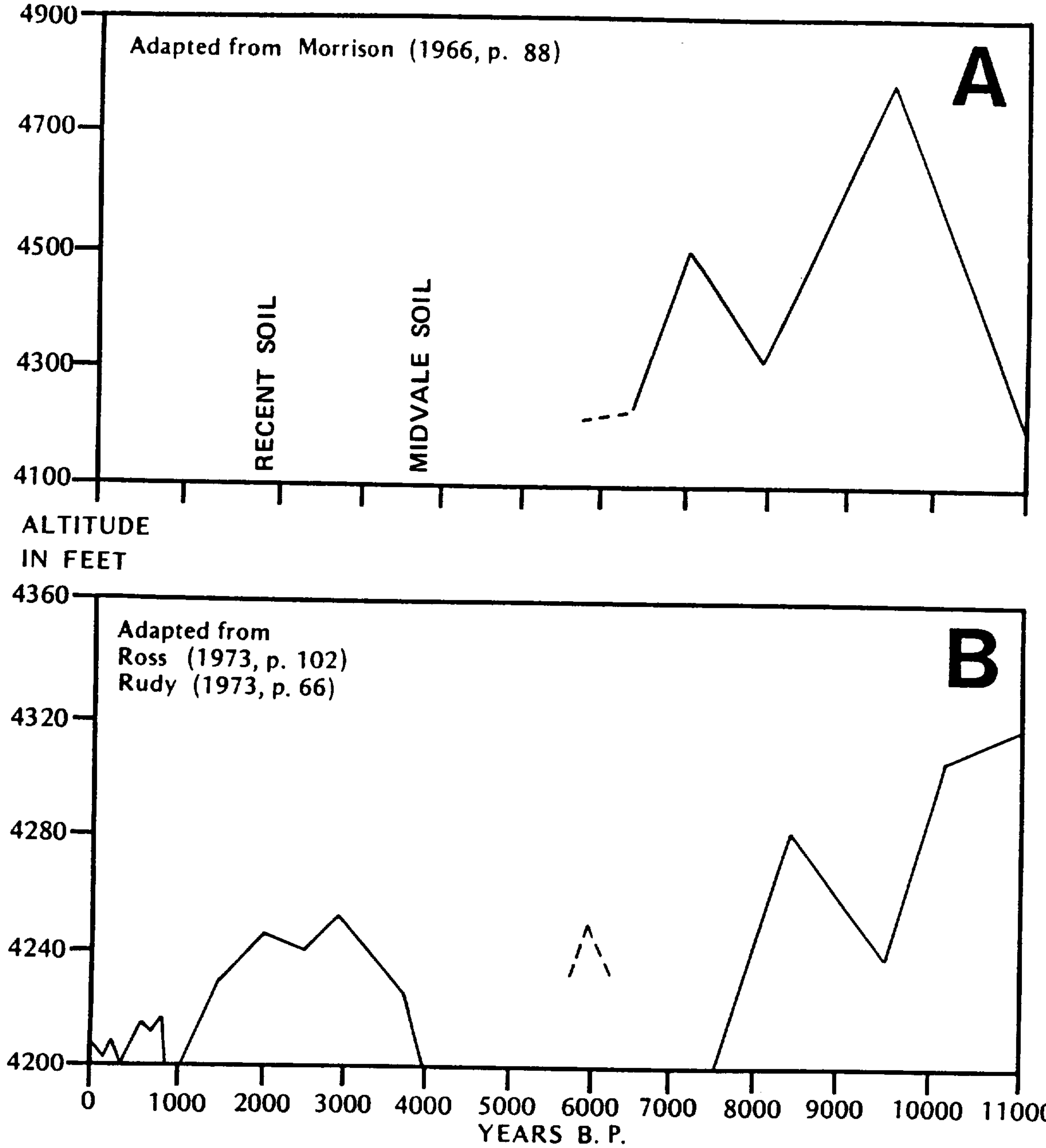


Figure 3. The late Pleistocene and Holocene chronologies of Morrison (A), Ross, and Rudy (B).

provincial isotope substages of 12,500 to 7500, 7500 to 5000, and 5000 yr B.P. to present (Figure 4a).

Currey, Atwood, and Mabey (1984) produced a hydrograph based on coastal geomorphology, aerial photographs, relevant radiocarbon ages, and deltaic as well as shoreline interpretation (Figure 4b). This chronology suggests a Holocene envelope of probable maximum fluctuations and describes significant shorelines.

Murchison (1989) reported the Gilbert shoreline (1292-1310 m) to be product of a transgressive stand that followed a period of minor oscillations at lower lake levels. A large death assemblage of gastropods occurs at 4232 ft (1290 m), northwest of Corrine, suggesting a series of inundations of saline water into a paludal environment at 10,900 yr B.P.

<u>Isotopic and Palyonologic</u>

Grey and Bennett (1972) infer a 7000-year chronology from oxygen, carbon, and sulfur isotope data collected at Cresent (Hogup) Spring and in Great Salt Lake bottom sediments near Bird Island. A general qualitative water-budget/ water-volume graph by Grey and Bennett (1972) indicates an early Holocene lake transgression between 4300 and 1500 yr B.P. (Figure 5).

Mehringer's (1985, 1986) pollen based chronology from Cresent Spring indicates a mid-Holocene xeric period before prevailing mesic conditions between 3800 and 2000 yr B.P. His environmental senario is based on smoothed pollen ratios of salt desert halophytes and shadescale to sagebrush and

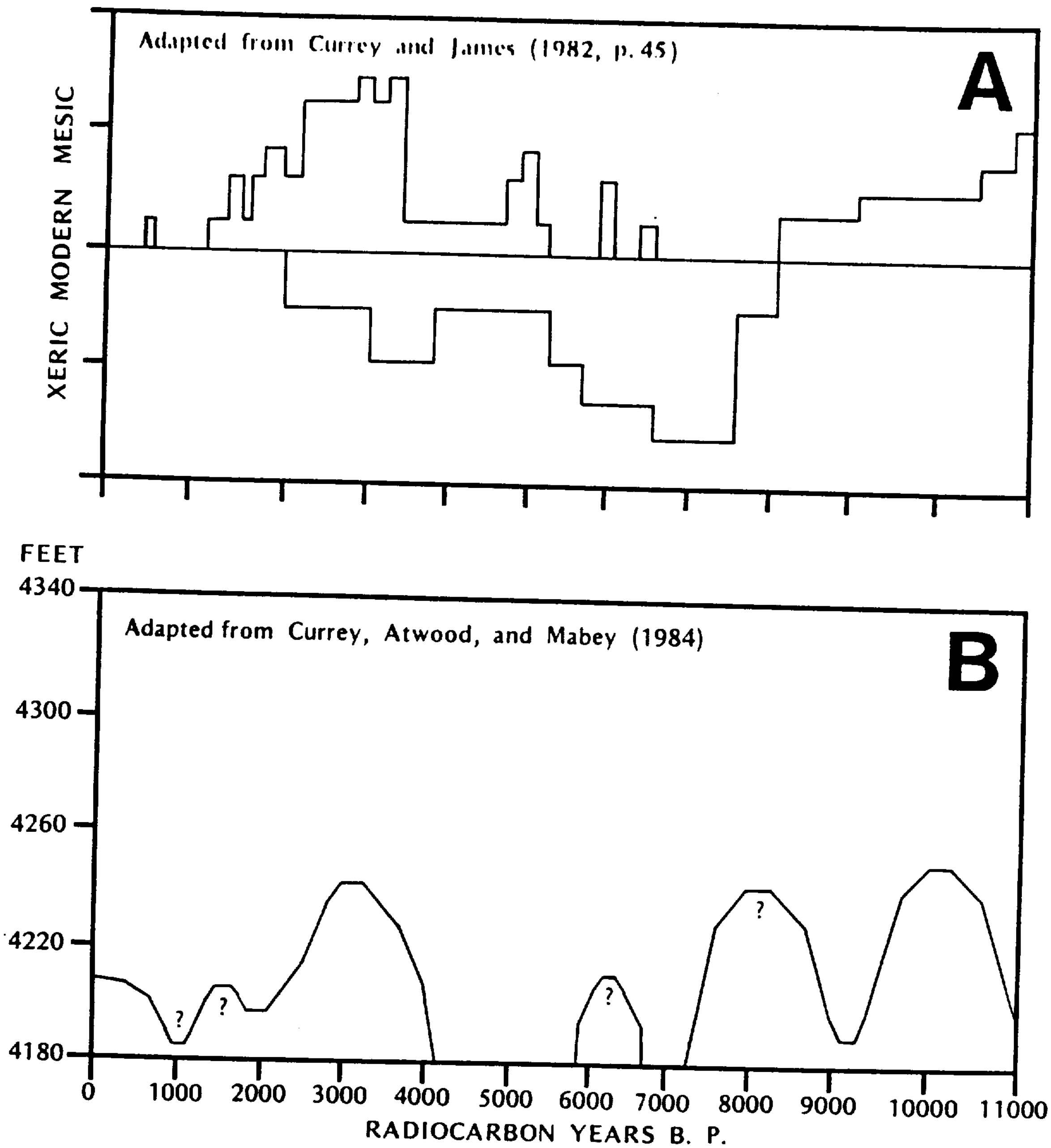


Figure 4. Holocene chronologies of Currey and James (A) and Currey, Atwood, and Mabey (B).

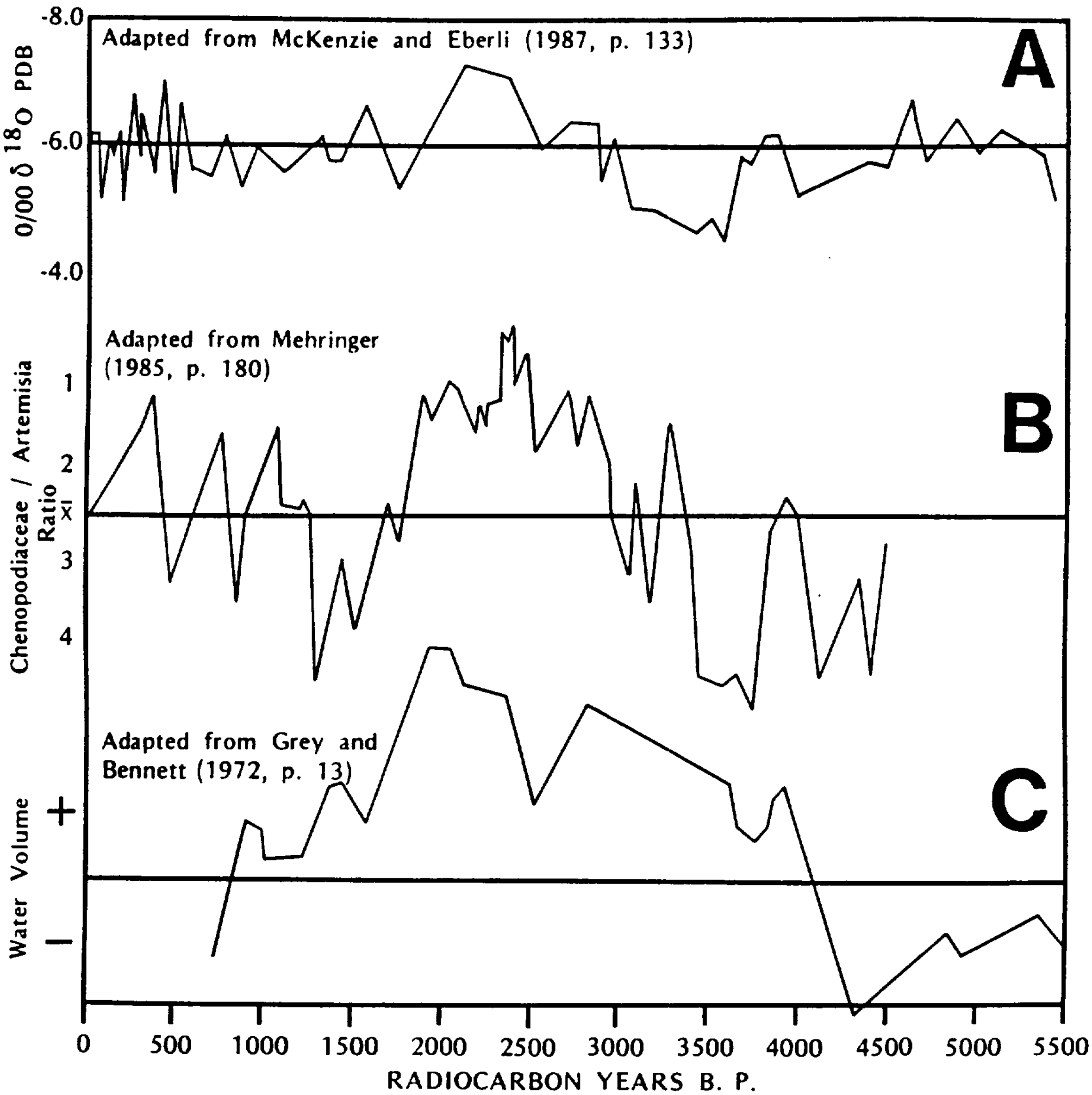


Figure 5. Isotopic and palynologic chronologies from McKenzie and Eberli (A), Mehringer (B), and Grey and Bennett (C).

conifer pollen, plotted around their mean values (Figure 5).

A recent chronology based on stable isotopes have reinforced age estimates of known littoral zones and other geomorphic features. McKenzie and Eberli (1985, 1987) have deduced a 5500 year chronology, utilizing oxygen-isotope ratios from cores west of Antelope Island, suggesting two minima and three maxima periods. The late Holocene high of 3000 to 2000 yr ago is believed to be only 1.9 m too low, based on shoreline measurements in this study (Figure 5).

Methods

The surveying of shorelines, geomorphic features, and trench or drill sites was conducted utilizing a Topcon GTS-3B EDM theodolite. Altitude control for electronic surveying was obtained from the USGS bench mark nearest to each survey site. Lake level altitudes were obtained from twice-monthly gage data reported by the USGS District Chief. Altitudes are reported in feet (ft) above sea level (asl) and converted into metric or SI units (m). Sediment and textural analyses were accomplished at the Vasyl Gvosdetsky Laboratory for Environmental and Paleoenvironmental Studies at the University of Utah.

Soil samples were allowed to air dry for 2 days. The samples were then dry sieved through a series of seven sieve mesh sizes (16 mm to .063 mm), for gravel, sand, and silt size distribution (SCS, 1972). Silt and clay particle size distribution was determined using the hydrometer method described by Head (1980). Fifty grams of each sample were weighed and mixed with 10 grams of sodium hexametaphosphate ($NaPO_3$), a dispersing agent, in a distilled water solution of 100 ml. The solution was electromechanically mixed for 20 minutes, poured in a 1000 ml cylinder, and filled with distilled water to the 1000 ml mark. The solution settled for 2 hours, then mixed with a glass stirrer until sediments were no longer visible at the bottom of the cylinder. At this time, zero, the temperature was recorded. Forty seconds later, a hydrometer reading, R_1, was recorded. Two hours later, the temperature and second hydrometer reading, R_2, were recorded. After temperature compensation was taken into account, the percent silt and clay were determined for each sample.

$$\% \text{ sand} = (R_1 - R_2) / 50 \text{ g} * (100) \tag{1}$$

$$\% \text{ clay} = R_2 / 50 \text{ g} * (100) \tag{2}$$

Relative ages beach crests were estimated using a near-surface sample at a depth of 10 cm and subsurface sample at a depth of 30 cm. Each of the two samples was sieved, as previously described, to determine percent of silt and clay for each sample. The greater the percent of silt and clay present, the greater the relative age of the beach crest.

Soil pH was measured by the electrometric method using a Fischer pH meter (SCS, 1972). Two parts distilled water were mixed with one part soil, shaken for twenty minutes, and left to settle for 2 hours. A buffer solution (Fischer pH 7.0) was utilized to calibrate the electrodes before and after each test. The electrode was immersed in the upper one-third of the suspension and the pH was recorded after 1 minute of elapsed time.

Soil color was observed on dry and wet soil using a Munsell color chart (Soil Survey Staff, 1975). Hue, value, and chroma were recorded for the samples.

Humates were extracted from organic soils at selected sites for the purpose of radiocarbon dating. The humate extraction procedure is found on Table 2. The pretreated humate material was sent to Beta Analytic Inc. for radiocarbon age estimation.

Lakeshore Field Measurements

To revise and enhance the known late Pleistocene and Holocene history, many techniques were utilized to identify subaerial, littoral, and pelagic materials deposited or eroded by the fluctuating lake (Table 3 explains the symbols used in stratigraphic cross sections). Studies of USGS and other maps, aerial and satellite photos, and field work including beach surveying, sediment analysis, boring, and trenching were incorporated to determine how many and when fluctuations had occurred. Additional data such as early human occupational sites, prehistoric human diets, and radiocarbon age estimates will lend support to the hydrogeomorphic data. Isotopic and pollen data are also

Table 2. Procedure for acid base acid extraction of humates. This procedure is intended to extract humates from organic soils for the purpose of radiocarbon dating. A field sample of at least 2 pounds of soil is recommended.

---

1. Empty the organic soil into a stainless steel bowl. Measure out a 5 to 1 (500 ml of distilled water to 100 ml of HCl) HCl ratio for removal of calcium carbonates. Continue adding 5 to 1 (Water-HCl) until reaction stops (Fizzing ceases).

2. Decant off HCl solution overnight. Whatman filter papers, folded triangularly, work well. Periodically wash with distilled water to keep the filter paper from dissolving.

3. Mix one liter of 3N Sodium Hydroxide in a flask. This will be 120 g of reagent to one liter of distilled water. Now add 100 ml of NaOH and 300 ml of distilled water in a beaker. Then add the acid washed soil to the solution until the 500 ml mark is reached. Heat the solution for 30 minutes on high to leach the colloidal humus.

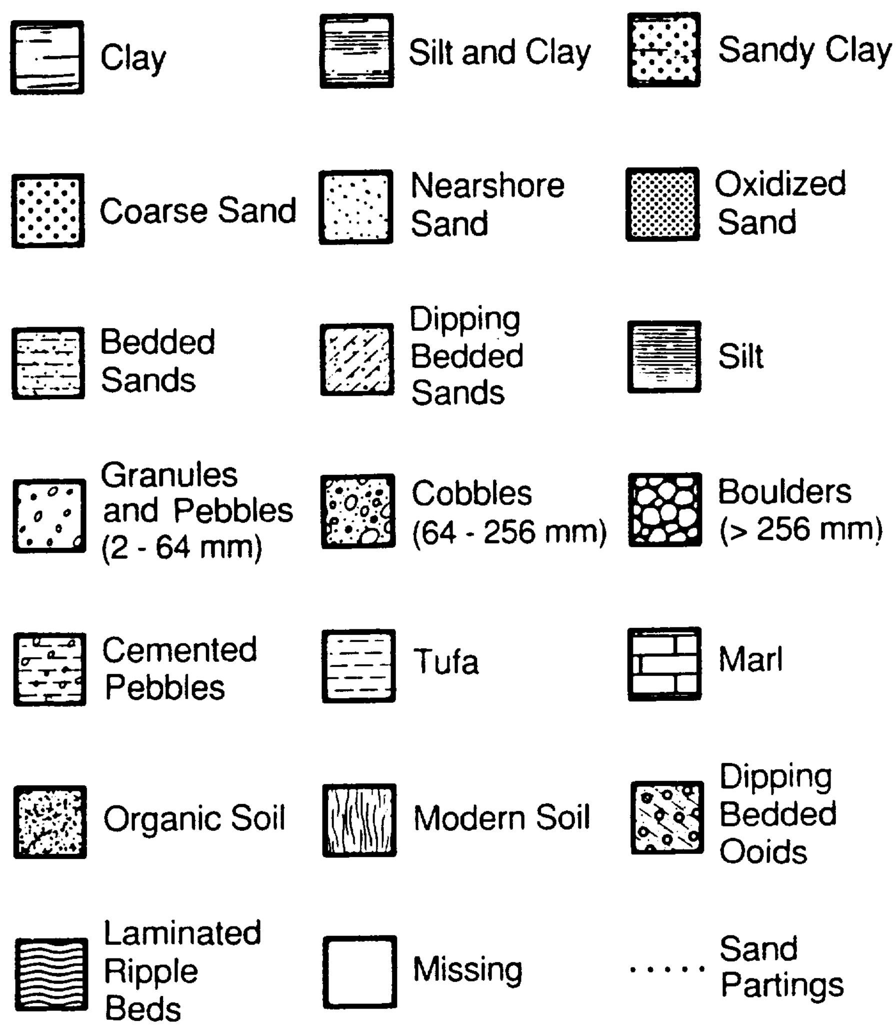
4. Pour the mixture into a filtered (Whatman # 1) water vacuum flask (Ceramic funnel with two filter papers). The soil will be trapped on the filter paper, while the humic liquid will be decanted into the flask. The humic liquid will be a dark brown to black color. Save the solution in the bottom of the flask and discard soil.

5. The solution must now be brought back to pH 7. Slowly neutralize the solution by adding concentrated HCl until the humus becomes insoluble. As the solution reaches neutrality, it will become clear and the humates will coalesce into clumps. Litmus paper testing will suffice estimated pH values.

6. Prepare a ceramic funnel with a fiberglas filter paper (Whatman 1827 P 105) and connect to vacuum pump. Pour the solution with the insoluble humates into the funnel. It will take a while for the liquid to be removed. Occasionally wash the funnel with distilled water to prevent the growth of NaCl crystals on the filter paper. Save the humates that are on the fiberglas filter paper. Allow the filter paper to dry. Weigh the paper with the humate extract on it and send it to the radiocarbon lab.

REFERENCES: (Black, 1965; Head, 1980)

Table 3. Symbols and patterns used in stratigraphic figures throughout the text.



R Pre-Gilbert red beds

G Gilbert transgressive sands

mentioned for additional refinement of stratigraphic evidence that is not available by using the above techniques.

The following chapters give a brief outline of known lake history, followed by locality descriptions. Additional data are then discussed and interpreted for each section. A 4000 yr summary at the conclusion of each chapter documents the lake level fluctuation history during that period.

CHAPTER 2

LATE PLEISTOCENE TO EARLY HOLOCENE (12,000 TO 8000 YR B.P.)

Introduction

Previous Concepts

The last Pleistocene paleolake minicycle occurred between 12,000 and 10,000 yr B.P. Miller (1980) and Currey et al. (1983) postulate that oxidized lacustrine sediments at 4226 ft (1288 m) indicate a low stand prior to the Gilbert lake expansion near 10,920 ± 150 yr B.P. (W-4395; ^{13}C adjustment unknown). The Gilbert shoreline is geomorphically expressed at several localities around Great Salt Lake and the Great Salt Lake Desert. Jennings (1957) was the first to provide limiting radiocarbon age estimates of 11,151 ± 570 yr B.P. (C-610) and 10,400 ± 700 yr B.P. (M-119) (^{13}C adjustments unknown) from archeologic sites, inferring the absence of any lake inundation younger than the above radiocarbon ages in Danger Cave. Currey (1980) believes that the Gilbert shoreline dates from 11,000 to 10,000 yr B.P. based on his study of transgressive facies, erosional platforms, depositional ridges, and deltaic sediments. This lake expansion could be responsible for the inferred hydrologic equilibrium of Lake Gunnison and the Sevier River as well as the Gilbert age drainage at Old

River Bed reported by Currey and James (1982) and Oviatt (1984).

Author's Research Strategy

The review of previously collected data, gathering and analysis of sediment samples at new localities, surveying both old and new localities, attempting to confirm previously obtained radiocarbon ages with newly collected samples, and statistically quantifying gathered data is the research design for this time period. It is anticipated that a higher resolution hydrograph of the late Pleistocene and Holocene can be produced along with an understanding of the Gilbert lake cycle.

Chapter Overview

From the evidence gathered by the author and an analysis of geomorphic and archeologic data, new findings suggest a fluctuating lake during this period. After a low lake level deposition of a pre-Gilbert red bed stratum, an overlying ocillating transgressional layer of predominantly green sand is documented as the Gilbert lake cycle of approximentally 12,000 yr B.P. This Gilbert cycle, which consisted of at least three static levels the highest reaching 4250 ft (1295.3 m), regressed after 10,000 yr B.P. to as low as 4220 ft (1286.2 m). A 4230 ft (1289.2 m) lake level formed between 9400 and 9700 yr B.P., then lowered an unknown level. Rising temperatures probably continued to lower the lake well into the next period which begins at

8000 yr B.P. This chapter will present data from site investigations at various localities summarized in Figure 6.

Geomorphic Site Descriptions

Little Mountain (1)

Road cuts and small bluffs along State Highway 83, between Little Mountain and Lampo Junction, provide ideal locations for the examination of Gilbert age deposits. Currey (1980), Miller et al. (1980), Scott et al. (1983), and Currey and Oviatt (1985) have used lithofacies at these sites to interpret very late Pleistocene environmental history.

Just west of Little Mountain, pre-Gilbert red beds, as described by Currey et al. (1988a), are exposed. The red beds are calcareous muds and very fine sands that were reddened offsite and washed basinward. Lying unconformably over the red beds are green muddy silts and sands of the Gilbert transgression, which are capped by a desert pavement rock layer near the bedrock highlands.

Mollys Stocking (2)

Westward from Little Mountain, the topography slopes toward a fluviodeltaic lowland, possibly a former distal reach of the Malad River system. This lowland now comprises disconnected hummocks of lacustrine and eolian deposits that have been partially dissected by drainage of local origin.

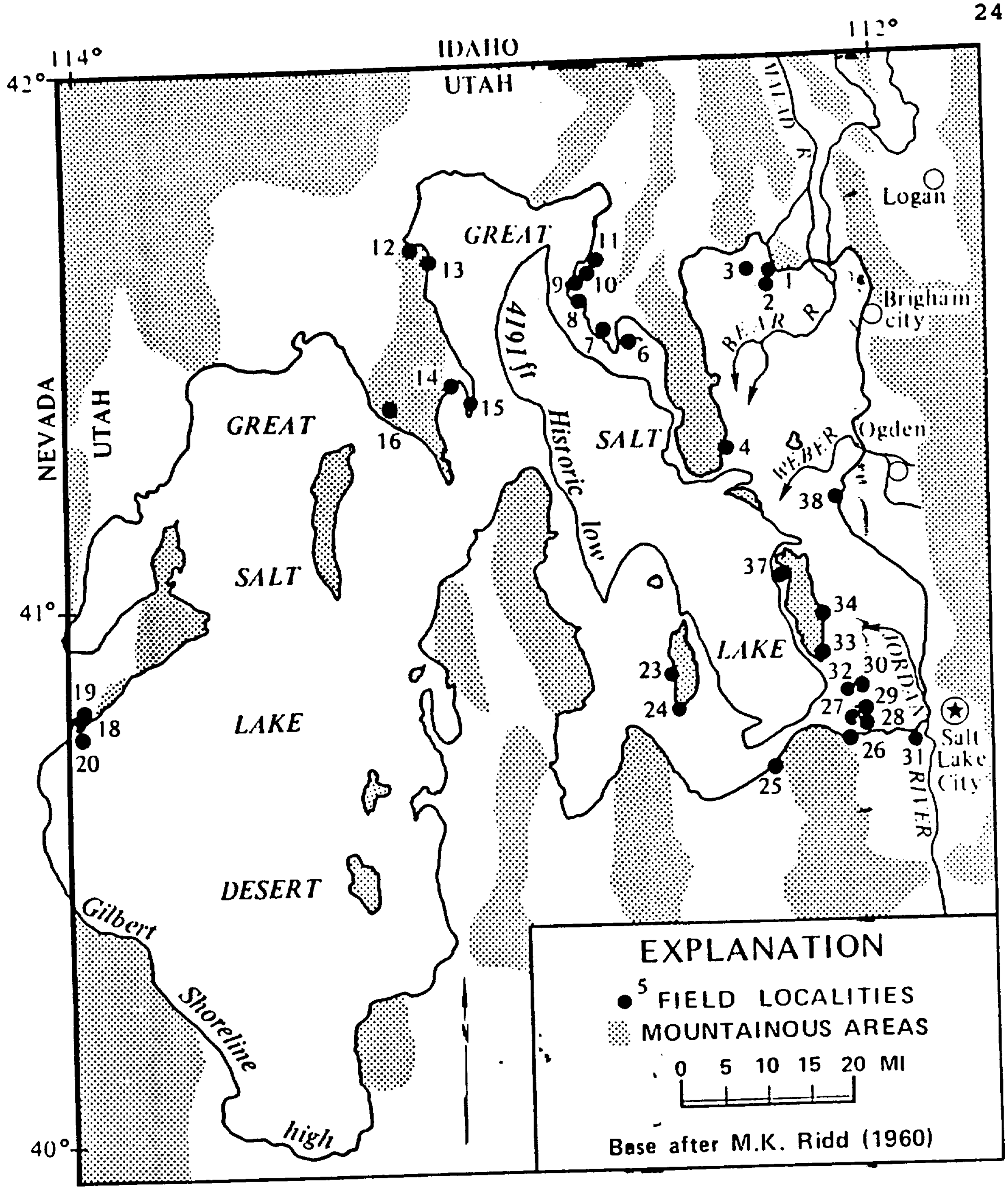


Figure 6. Map of localities mentioned for the period between 13,000 and 8000 yr B.P.

Mollys Stocking, a remnant birdfoot delta of Gilbert age (Currey et al., 1988b), is 2.5 mi (4 km) long and thought to have formed as the distal part of the Malad River (?) paleodelta system.

West Public Shooting Grounds (3)

A large death assemblage of late Pleistocene gastropods, exposed in a roadcut along State Highway 83, were reanalyzed for stratigraphic and biostratigraphic significance. Biochronologic data from the roadcut area as discussed by Miller et al. (1980), Scott et al. (1983), and Currey and Oviatt (1985) provide a maximum limiting age of 12,000 yr B.P. for the beginning of the Gilbert transgression. Radiocarbon ages that were obtained earlier on the gastropod assemblage are as follows:

* 10,920 ± 150 C-14 yr BP.	W-4395	Miller (1980)
11,990 ± 100 C-14 yr BP.	Beta-16912	Currey, written communications
11,570 ± 100 C-14 yr BP.	Beta-16913	

* ^{13}C adjustment unknown

A gastropod sample was dug from the roadcut exposure and collected in plastic bags. The sample was examined for further identification of constituent genera and species, indications of habitat, and radiocarbon age. The gastropods genera Amnicola, Helisoma, Lymnaea, and Physella (Table 4) were excavated from a sand unit overlain by an organic-rich marsh deposit (Figure 7). The shells were washed in an ultrasonic cleaner in deionized water and air dried. A 25-g species-specific sample of Lymnaea stagnalis shells provided a radiocarbon age of 10,990 ± 110 yr B.P. (-10.2 0/00 ^{13}C;

Table 4. Gastropod fauna sampled at W. Public Shooting Grds. (3) in January, 1987. Sources: Chamberlin and Jones (1929) and fieldwork (1987-88).

Species	Habitat	Abundance %
Helisoma trivolvis	Quiet to stagnant fresh water	5
Physella utahensis	Ponds and streams	7
Lymnaea stagnalis	Ponds, lakes, and streams often attached to plants	8
Amnicola limosa	Streams, rivers, and more quiet bottom waters	80

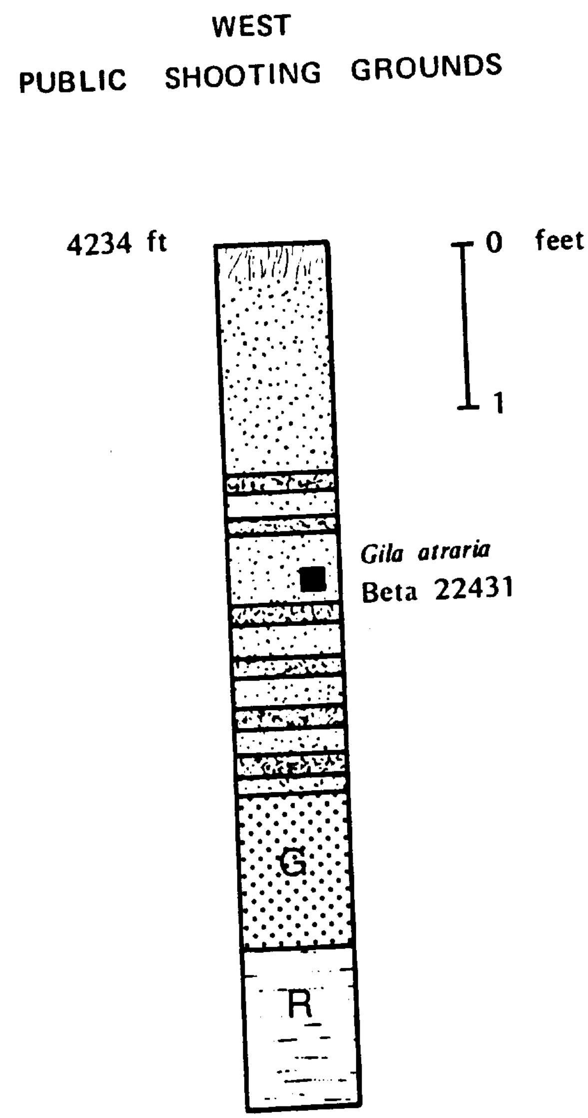


Figure 7. Stratigraphic column at West Public Shooting Grounds (3) showing the Pre-Gilbert red beds (R), the Gilbert transgressive sediments (G), and the location of the Gila atraria sample. See Table 3 for an explanation of symbols and patterns.

Beta-22431).

Several rib, pharyangeal, vertebral, and maxillary bones belonging to Utah chub or Gila atraria (Girard) were discovered within the gastropod-rich sand unit at 4232 ft (1290 m). Stokes et al. (1964) report 13,000 yr B.P. remains of G. atraria and other fish species in a coarse sand unit just below the Stansbury level, at an elevation of 4440 ft (1353.2 m) in North Salt Lake City. Smith et al. (1968) report 12,860 ± 100 yr B.P. (W-2000; ^{13}C adjustment unknown) G. atraria among numerous fish bones and gastropods from a fine- to medium-grained sand lens at an altitude of 4671 ft (1423.6 m) in Black Rock Canyon. The G. atraria were probably remnant populations inhabiting an increasingly saline regressive lake and fresh water tributaries. Their contemporaries today inhabit freshwater areas around the Great Basin (Currey and James, 1982).

The oldest exposed sediments at West Public Shooting Grounds (3) are the pre-Gilbert red beds. The red beds are unconformably overlain by green muddy fine to coarse sands, which have a minimum limiting age of about 12,000 yr B.P. (Beta-16912; Currey et al., 1988b), and grade upward into the Gilbert shoreline deltaic sediments. Green colored sediment is common to ancient lake basins and represents a reducing environment (Reeves, 1968).

Six successive couplets of alternating fine clean silty sands and marshy deposits lie conformably over the green muddy sand. The first layer consists of clean fine sands and is interpreted as a minor transgression. As the lake began to regress, a dark organic layer, indicating a marsh environment appears. This organic layer is overlain by lacustrine silts and represents the second transgressive saline inundation of the fluctuating Gilbert stand. Three additional cycles of clean fine sandy fossil-rich sediment layers and subsequent dark marsh sediments are recorded in this banded exposure.

During one of these minor regressions, the four genera of gastropods and G. atraria (see previous radiocarbon age, Beta-22431) migrated basinward. A transgression of saline water probably killed the organisms and deposited them in a matrix of lacustrine sands and silts. The beginning of the next transgression probably killed the remainder of fresh water organisms in this paludal margin, laying down the final fossiliferous layer. This final fossiliferous layer is 7.5 in (19 cm) thick and is overlain by fine to coarse sands. Two organic marsh layers, of 1.75 to 3 in (4.4 to 7.6 cm), overlie the death assemblage. These undated layers are thought to be the last marsh deposits prior to the transgression that geomorphically marks the highest stage of the Gilbert shoreline. A 2.7-ft (0.8-m) fine poorly sorted nearshore sand layer has been deposited by the Gilbert high stage. A 4 to 5 in (10 to 12.7 cm) modern eolian soil is the uppermost unit in this exposure (Figure 7).

Promontory East (4)

On the southeast slope of the Promontory Mountains the Gilbert shoreline is expressed as three distinct beach ridges. The author surveyed ridge crests at elevations of 4282 ft (1305.0 m), 4284 ft (1305.9 m), and 4278 ft (1304.2 m). A possible contemporaneous beach ridge is located at 4238 ft (1292.1 m) (Figure 8).

Surficial sediment samples taken at depths of 10 and 30 cm on the crest of each ridge revealed that enrichment with post lacustrine silt and clay had proceeded sequentially in altitudinal order, except for the lower berm at 4238 ft (1292.1 m) (Table 5).

Table 5. Measured beach ridge elevations at Promontory East (4).

Site		Alt.(ft)	% Gravel	% Sand	% Silt+clay
1	10cm	4282	24.3	54.5	16.3
	30cm		5.5	84.9	9.7
		1 ft (30 cm) marshy depression behind			
2	10cm	4284	53.5	42.7	3.8
	30cm		48.5	50.6	0.9
		10 ft (300 cm) marshy depression behind			
3	10cm	4278	26.5	72.1	1.5
	30cm		56.5	43.0	0.5
		3 ft (90 cm) marshy depression behind			
4	10cm	4238	7.9	90.3	1.7
	30cm		1.0	93.6	4.8

Source: Author's original data collected in 1988.

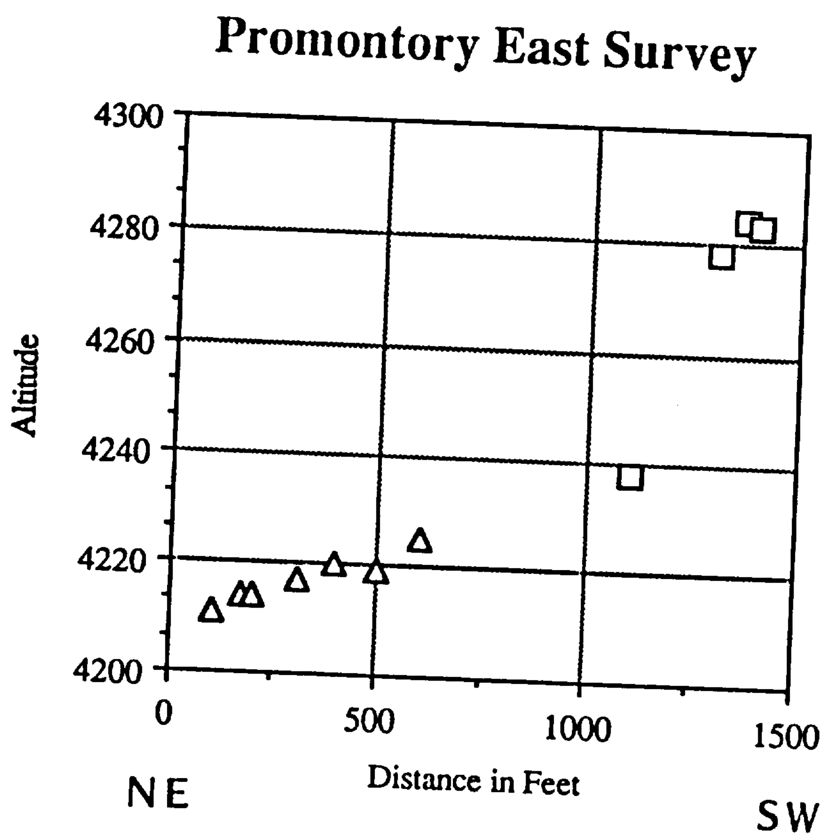


Figure 8. Profile of stations at Promontory East (4) locality; altitudes and distances in feet. Triangles represent late Holocene berms and squares represent late Pleistocene and early Holocene berms.

The crests of the Promontory beach ridges were the highest measured beaches in this study. It is estimated that these high elevations of Gilbert shore activity are due to isostatic rebound discussed by Crittenden (1963), Rudy (1973), and Currey et al. (1983).

Rozel Point (6)

Rozel Point is a locality that has been influenced by many different stratigraphic and tectonic processes as well as a high-energy wave environment. Faulting has occurred along a north-south fracture zone near the locality.

Gilbert shorelines are laterally traceable from aerial photographs and topographic maps near the 4273 ft (1302.3 m) and 4250 ft (1295 m) contours (see Figure 29). Ross (1973) measured a wave-cut bluff at 4253 ft (1296.3 m) and a wave-cut terrace at 4243 ft (1293.2 m). More recent investigations, using the same vertical control, confirm the higher elevations while measuring the lower at 4244 ft (1293.7 m). A surficial sediment analysis of this later site is listed on Table 6.

Table 6. Measured beach ridges at Rozel Point (6).

Site	Alt.(ft)	% Gravel	% Sand	% Silt+clay
1 10cm	4244	16.7	54.5	28.8
30cm		3.2	84.2	12.7

Source: Author's original data collected in 1988.

Two miles (3.2 km) north of Rozel flats is an exposed sequence of sediments observed in a small tract of badland topography. The sediment sequence is similar to that of the+ Little Mountain sediments. The lowest portion of the exposure was composed of the diagnostic pre-Gilbert red beds overlain with a 2 to 4 in (5 to 10 cm) organic deposit. This organic-rich deposit probably represents a marshy environment before the Gilbert transgression. Above the organic soil, the green sand transgressive unit is overlain by later lacustrine, then eolian sands.

Horseshoe Bay (7)

Horseshoe Bay is exposed to less vigorous wave action than Rozel point. Ross (1973) described four sets of Gilbert age geomorphic features. The highest set of features Ross interprets are a bluff and terrace between 4281 ft (1304.7 m) and 4276 ft (1303.2 m). A wave-cut cliff, associated terrace, and an offshore beach are located between 4253 ft (1296.3 m) and 4250 ft (1295.4 m). A depressional lagoon feature at 4245 ft (1293.70 m) and barrier beach at 4246 ft (1293.9 m) is thought to be a regressive Gilbert feature. A possible early Holocene bar at 4230 ft (1289.3 m) with an associated sea cliff at 4231 ft (1289.6 m) were reported by Ross (1973). All of these features are transected by an ephemeral stream originating upslope.

<u>Coyote Bay</u> (8)

Coyote Bay is a long wide bay with several wave-cut cliffs, barrier beaches, and headlands located on both margins. This site contains many late Pleistocene and early Holocene features that have been partially eroded by ephemeral streams. Ross (1973) reports the highest Gilbert age lacustrine features are a wave-cut cliff between 4249 and 4255 ft (1295.1 and 1296.9 m) and associated barrier beaches at 4246 and 4241 ft (1294.2 and 1292.6 m). A small wave-cut cliff at 4234 ft (1290.5 m) and its respective beaches of 4230 and 4228 ft (1289.3 and 1288.7 m) seem to be indicative of a small early Holocene lake fluctuation.

<u>Desolation Bay</u> (9)

Desolation Bay is a small bay located between an elongated promontory and the Black Mountains. Ross (1973) describes four beach crests of Gilbert age found at this site. These beach crests are at 4276 ft (1303.2 m), 4256 ft (1297.2 m), 4242 ft (1292.9 m), and 4232 ft (1289.9 m).

<u>Black Mountain Bay</u> (10)

This site is a north-facing bay with headlands on either end causing uncharacteristic eolian features to form. Ross (1973) identified late Pleistocene and early Holocene beaches at 4280 ft (1304.4 m), 4250 ft (1295.4 m), 4246 ft (1294.2 m), and 4231 ft 1289.6 m). A vegetated sand dune was also surveyed in at 4235 ft (1290.8 m), but its estimated age is in question because of inordinate wind exposure and eolian deposition.

Windmill Bay (11)

Information collected by the author from aerial photographs, topographic maps, and fieldwork indicates that several easily discernible Gilbert beaches are geomorphically expressed within this small bay. Windmill bay is located on the northwestern margin of the Promontory Mountains. A wave-cut bluff near an altitude of 4273 ft (1302.3 m) and an erosion platform at 4266 ft (1300.4 m) are thought to be the highest expression of Gilbert age lacustrine activity. Beach crest exposures, each with an associated landward marsh, were surveyed at 4258 ft (1297.5 m) and 4244 ft (1293.6 m). A possible late Gilbert beach crest is located at 4230 ft (1289.5 m) (Figure 9).

A surficial sediment analysis of post lacustrine silt and clay accumulations are found on Table 7. The elevation differences between this site and other Gilbert localities are believed to be a result of isostatic rebound of different magnitudes.

Peplin Bar (12)

Peplin Bar is a northeast facing barrier bar with an associated landward lagoon. During the higher Gilbert lake

Table 7. Measured beach ridges at Windmill Bay (11).

Site	Alt.(ft)	% Gravel	% Sand	% Silt+clay
1 10cm	4266	13.3	76.7	9.9
30cm		8.5	78.7	12.8
2 10cm	4258	0	72.6	27.4
30cm		0	71.9	28.1
3 10cm	4244	0	61.4	38.6
30cm		0	67.4	32.6
4 10cm	4230	0	83.6	16.4
30cm		0	80.9	19.1
approx 5 ft (150 cm) depressions behind each berm				

Source: Author's original data collected in 1988.

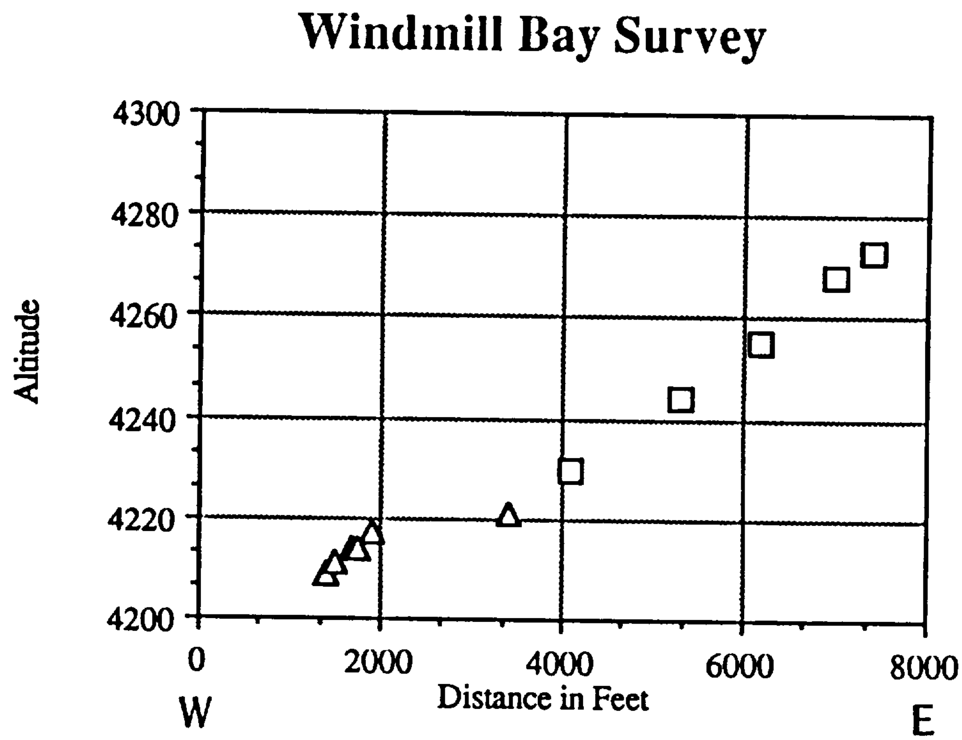


Figure 9. Profile of stations at Windmill Bay (11) locality; altitudes and distances in feet. Triangles represent late Holocene berms and squares represent late Pleistocene and early Holocene berms.

rises, Peplin flats became inundated by lake waters. The prominent ridge, called Peplin Bar, is reported by Rudy (1973) at an altitude of 4269 ft (1301.2 m). A terrace at 4245 ft (1293.9 m) and a wave-cut bluff at 4235 ft (1290.8 m) comprise the Gilbert age features Rudy surveyed at this locality.

Hogup Bar (13)

Rudy (1973) surveyed a Gilbert age beach at 4269 ft (1301.2 m) with a 5-ft (152-cm) deep lagoon behind it. A boulder beach at 4240 ft (1292.3 m) and two minor silty ridges at 4235 ft (1290.8 m) are the only other Gilbert features Rudy found at this locality.

Big Wash Bar (14)

Big Wash Bar is an arc-shaped feature northwest of the Fingerpoint spit. Rudy (1973) found a Gilbert age baymouth bar at 4271 ft (1301.8 m), a wave-cut cliff at 4255 ft (1296.9 m), and a barrier beach at 4247 ft (1294.5 m).

Fingerpoint Spit (15)

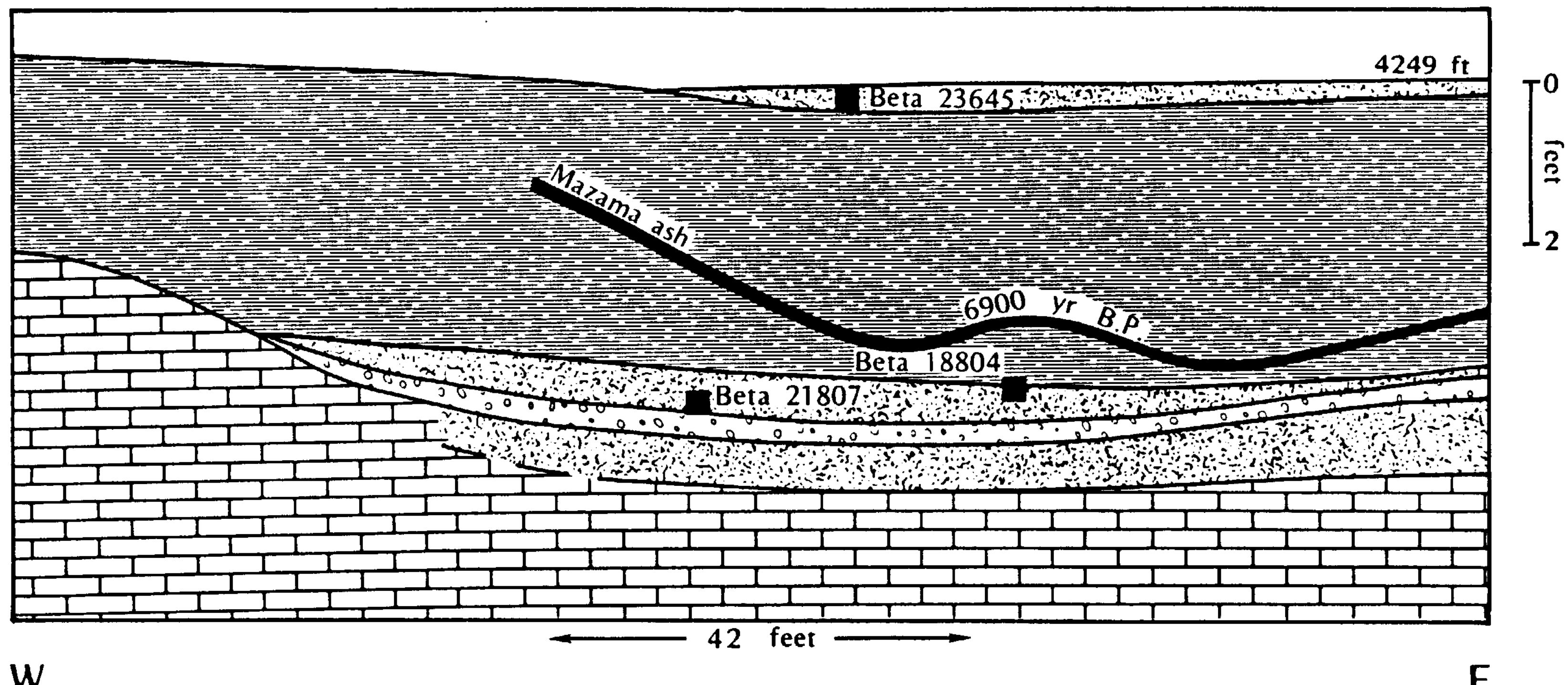
Fingerpoint spit consists of material carried southward by longshore currents in the north arm of Great Salt Lake and north eastward by currents originating in the Great Salt Lake Desert. A transect by Rudy (1973) revealed Gilbert age beaches at 4235 ft (1290.8 m) on the east side and 4237 ft (1291.4 m) on the west side of the spit. Rudy (1973) also surveyed a Gilbert age at 4250 ft (1295.4 m) and a Gilbert crest at 4255 ft (1296.9 m). A recent reexamination of

Fingerpoint spit by the author, reveals the highest Gilbert age crest altitude is approximately 4270 ft (1301.4 m).

Juke Box trench (20)

Juke Box trench is located 1.4 mi (2.2 km) northeast of Danger Cave State Park and southeast of Juke Box cave. This old trench, reexcavated with a backhoe in 1986 with the assistance of a NSF grant to David Madsen, State Archeologist, stratigraphically documents the Gilbert transgression (Figure 10). The oldest exposed sediments are made up of laminated and massive Lake Bonneville pelagic marls. Those marls are overlain by reworked marls of the Lake Bonneville regression and by sediment of an organic-rich post-Bonneville, pre-Gilbert marsh. The marsh sediments are unconformably overlain by beach granules and pebbles marking the maximum transgressive Gilbert age shore at 4247 ft (1294.5 m).

The Gilbert beach lens out in both directions and grades upward into gastropod-rich sands and silty muds. A brown slightly organic silty mud, with an age of 9450 ± 150 yr B.P. (Beta-21807, no ^{13}C adjustment), overlie these Gilbert transgressive sediments. Next, lies a post-Gilbert marshy-peaty layer, that pinches out in both directions of the trench, having an age estimation of 8360 ± 140 yr B.P. (-26.4 0/00 ^{13}C; Beta-18804). A slightly humic silt layer overlies the post-Gilbert marsh, and grades upward into a gray silty mud. The top of the silty mud is conformably overlain by a 0.3 in (1 cm) thick bed of Mazama



JUKE BOX TRENCH GENERALIZED STRATIGRAPHY

Figure 10. Stratigraphy of the south-facing wall at Juke Box Trench showing the location of radiocarbon age estimates. See Table 3 for an explanation of symbols and patterns.

ash, the age of which Mehringer (1985) estimates at 6900 yr B.P.

Stansbury Island (23,24)

On the western and southern shores of Stansbury Island, remnant beach deposits and landforms of probable Gilbert age are evident in aerial photographs. The highest gravelly strand lines were surveyed by the author at 4278 ft (1303.8 m) and 4262 ft (1298.9 m). Lower beach ridge crests were surveyed at 4244 ft (1293.6 m), 4240 ft (1292.3 m) and 4234 ft (1290.5 m).

Mills Junction (25)

The Mills Junction spit has been referred to by Eardley et al. (1957) and Currey et al. (1983) as a representative locality for a Gilbert beach. The crest of the spit (Eardley et al., 1957) has several benchmarks at an altitude of 4263 ft (1298.9 m) and an associated lagoon (now Stansbury Lake) on the south (landward) side at 4260 ft (1298.4 m).

Magna Spit (26)

Magna Spit is a multiple event Gilbert age spit east of Magna. Currey et al. (1983) reports ages of 10,285 ± 265 yr B.P. (-11.4 0/00 ^{13}C; GX-6614) and 10,300 ± 310 yr B.P. (-9.2 0/00 ^{13}C; GX-6949) on gastropods from a lagoon 100 ft (30.5 m) behind the spit complex. The highest point on the spit was a ridge surveyed at 4251 ft (1295.6 m). The author investigated two minor lakeward spits near the 4245 ft shoreline. The beach crest elevations of both spits are 4245 ft (1293.9 m) and are almost identical in terms of silt+clay percentages. A surficial sediment analysis, conducted by the author, of Magna spit samples, is shown in Table 8.

<u>1300 South Borings</u> (27)

Cores from eight borings and an exposure in the wall of a drainage canal straddling a hypothesized fault scarp at 1300 South Street and 4800 West Street were examined in the field, and logged by the author at the Earthstore Inc. soil laboratory. Logged information included depth in inches, Munsell color (wet and dry), texture , and miscellaneous characteristics such as partings, oxidized layers, and fossils. It was hoped that these cores would help corroborate the Gilbert transgressive sediment sequence, seen in other localities, and aid in identifying Gilbert age channels and deltas.

Table 8. Measured beach ridges at Magna Spit (26).

Site		Alt.(ft)	% Gravel	% Sand	% Silt+clay
1	10cm	4245	8.3	84.2	7.0
	30cm		1.5	87.9	10.6
2	10cm	4245	18.8	74.2	7.0
	30cm		1.1	88.5	10.4

Source: Author's original data collected in 1988-89.

The four upthrown-side borings and the drainage exposure (Figure 11) indicate Gilbert transgressive granules and pebbles at similar altitudes, descending slightly towards the lake basin. Gilbert deposits between 4232 and 4231 ft (1290.1 and 1289.8 m) overlie the red bed clays (5YR to 10 YR) of Currey et al. (1988a). Post-Gilbert calcareous silts and sands overlie Gilbert transgressive granules and pebbles.

The downthrown-side borings, with a modern surface 4 feet (1.2 m) or more lower than the upthrown-side borings, show Gilbert age transgressive sands and pebbles about seven feet (2.1 m) below the surface. Rapid lithofacies change above Gilbert transgressive sands and pebbles is believed to reflect complex incipient paleodeltaic and tectonic reworking of post-Gilbert sediments (Figure 12).

These borings confirm the theory by Currey et al. (1988a) that the pre-Gilbert red beds regionally underlie Gilbert transgressive sediments. The identification, location, and probable sequences of Gilbert age channels and deltas are shown in Figure 13.

<u>Goggin Borings</u> (28)

Twelve borings 3000 ft (914.4 m) south of U.S. Highway 40 were logged by the author at the Earthstore Inc. soil laboratory. Fifteen additional exposures were recorded along an east-west drainage canal 20 to 40 ft (6 to 12 m) north of the borings. These data are analogous to the previous borings at 1300 South in that the cores straddle a

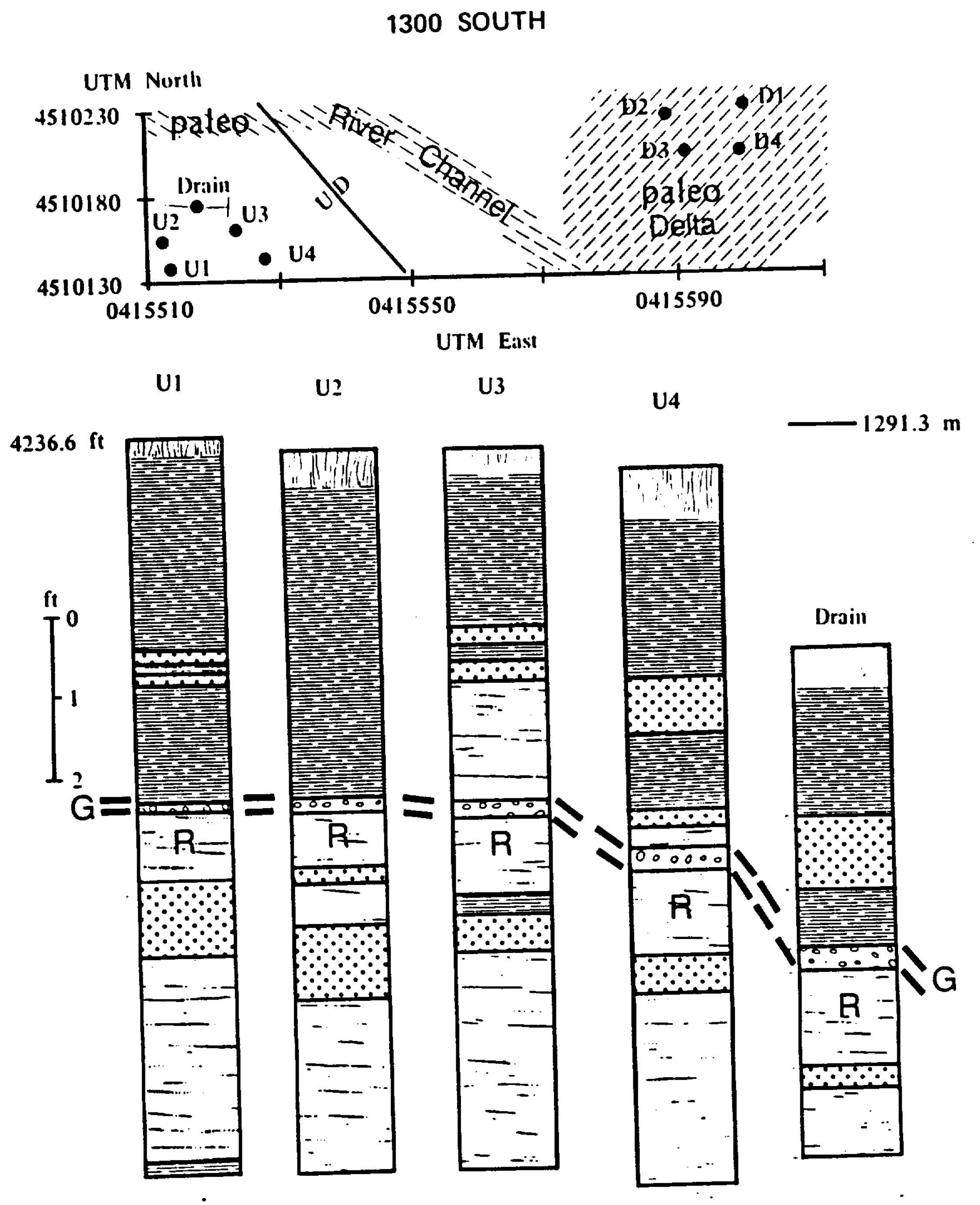


Figure 11. Map location, stratigraphy, and Gilbert transgressive sediments from the upthrown-side borings at 1300 South (27). See Table 3 for an explanation of symbols and patterns.

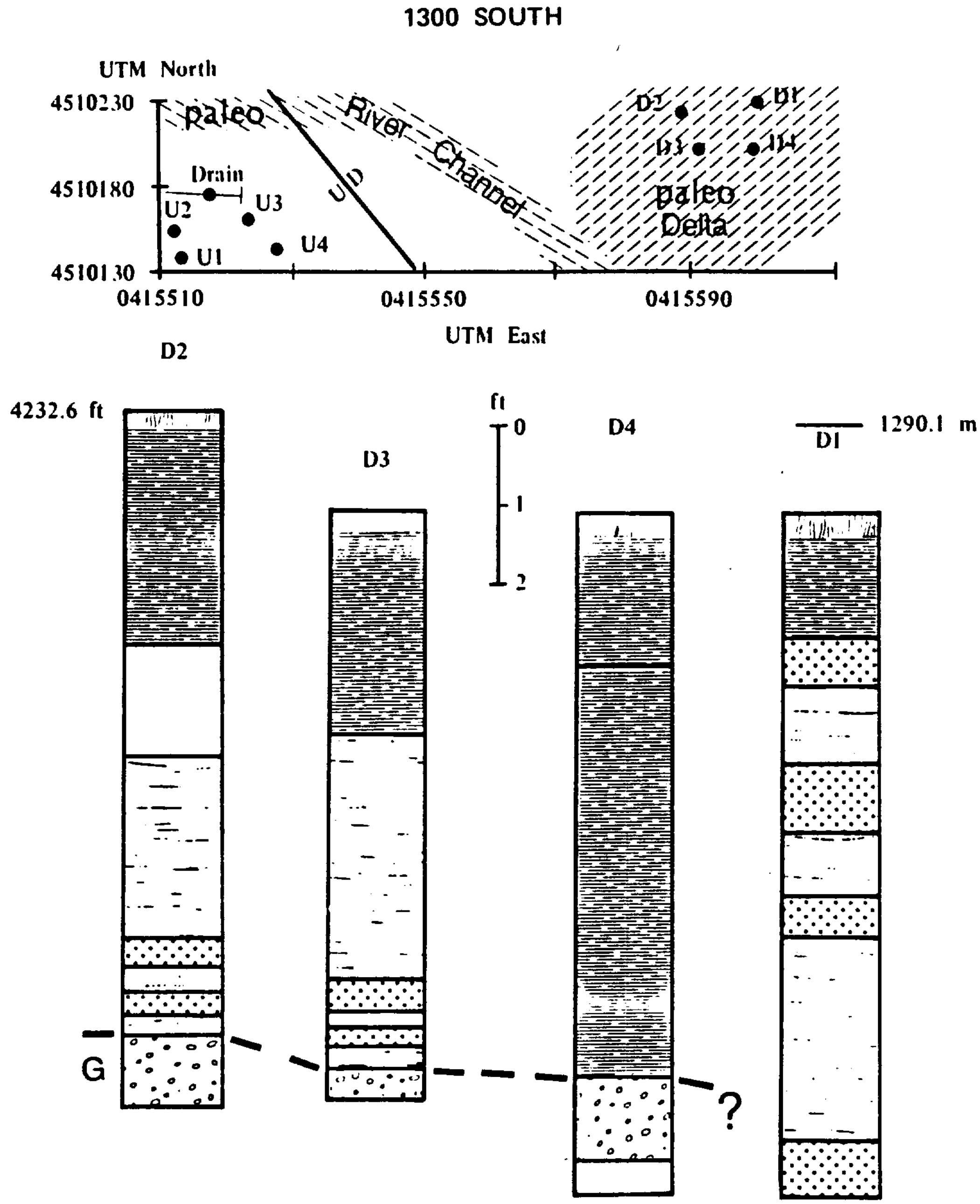
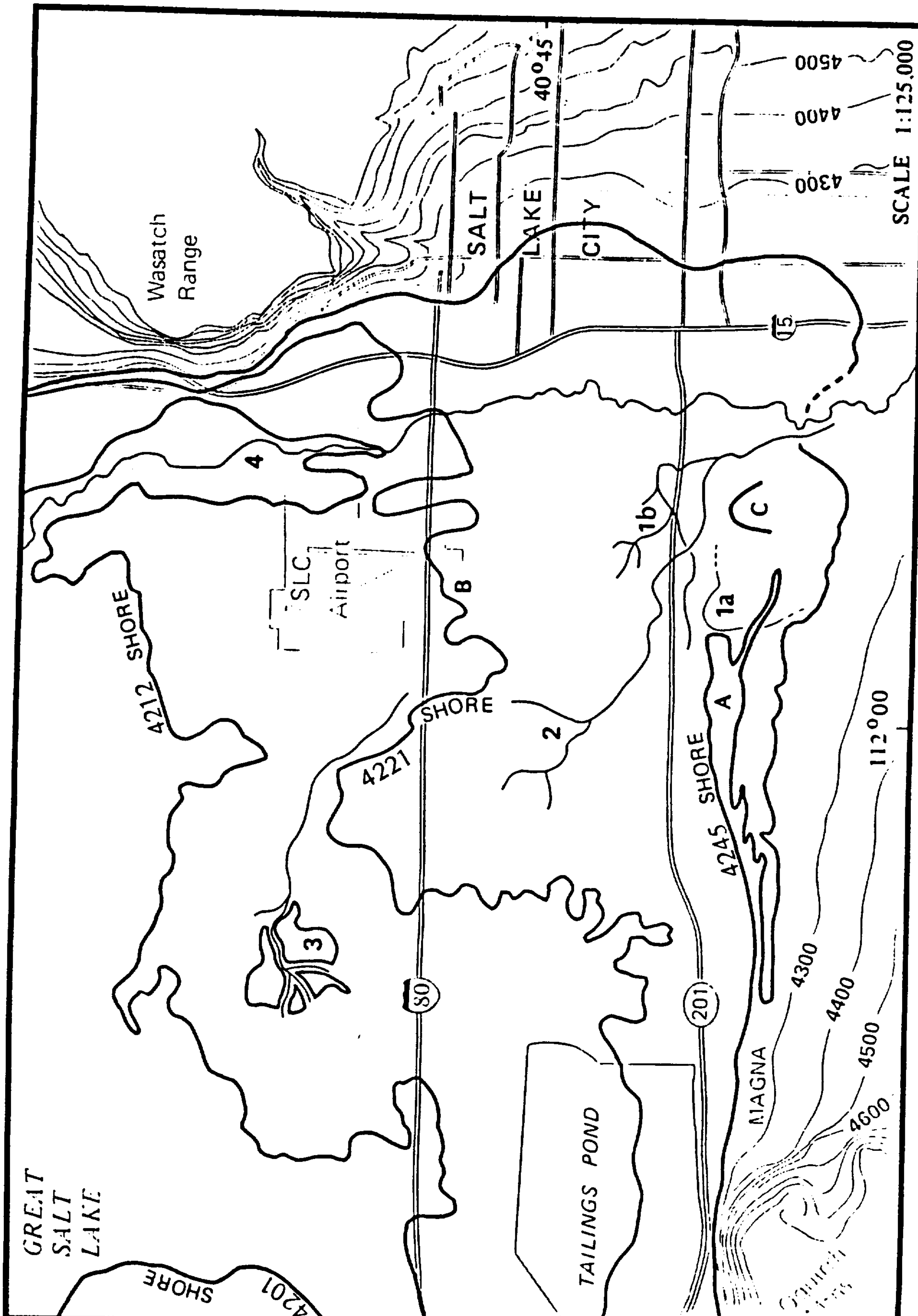


Figure 12. Map location, stratigraphy, and Gilbert transgressive sediments from the downthrown-side borings at 1300 South (27). See Table 3 for an explanation of symbols and patterns.

Figure 13. Location of paleodeltas, paleochannels, three shorelines, and important late Pleistocene and Holocene geomorphic features near the south-east area of Great Salt Lake. Early pre-Gilbert Jordan river paleodeltas (1a) and (1b) underlie later Gilbert shoreline sediment (A). A late Gilbert paleodelta (2) is build farther north-west toward a receding lake. The late Holocene high shoreline (B) shows the formation of a lakeward bird-foot paleodelta (3) which probably formed at the same time as the lunate bar (C). The present Jordan River (4) has migrated east-ward in response to faulting near the Wasatch Mountain margins.



Wasatch Range
SALT LAKE CITY
40°45'
4500
4400
4300
SCALE 1:125,000
15
SLC Airport
4
1b
C
1a
B
A
4212 SHORE
4221 SHORE
2
4245 SHORE
112°00'
3
80
201
MAGNA
4300
4400
4500
4600
TAILINGS POND
GREAT SALT LAKE
4201 SHORE

hypothesized fault scarp.

The bottom of the transgressive green sands, which overlie pre-Gilbert red beds, are composed of coarse grains and are found in all of the upthrown-side borings and in boring C at elevations of 4213 (1284.3 m) and 4214 ft (1284.5 m) (Figures 14 and 15). Characteristic sand partings are found at several horizons in the red beds. No other lacustrine facies are found above these elevations.

The downthrown-side borings D1 through D6 (Figure 15 and 16) contain reworked clays and sands from probable Gilbert age deltas above the red beds. These interbedded clays and sands were likely deposited from reworked lake sediment and fluviodeltaic components, since these borings are an average of 4 feet (1.2 m) lower than the upthrown-side borings to the west. There is a lack of lacustrine deposits above this altitude and a lack of Gilbert age deposits at the 15 drainage exposures east of the center (C) core.

Three Flags Borings (29)

The Three Flags site is located 2000 ft (609.6 m) south of U.S. Highway 40. These four borings also straddle a hypothesized fault. The two upthrown-side borings display the typical red bed, green sand, then silt complex as the previous upthrown-side samples (Figure 17). The Gilbert transgressive sediments are found at 4221 ft (1286.7 m) and 4220 ft (1286.5 m) respectively. No lacustrine sediments

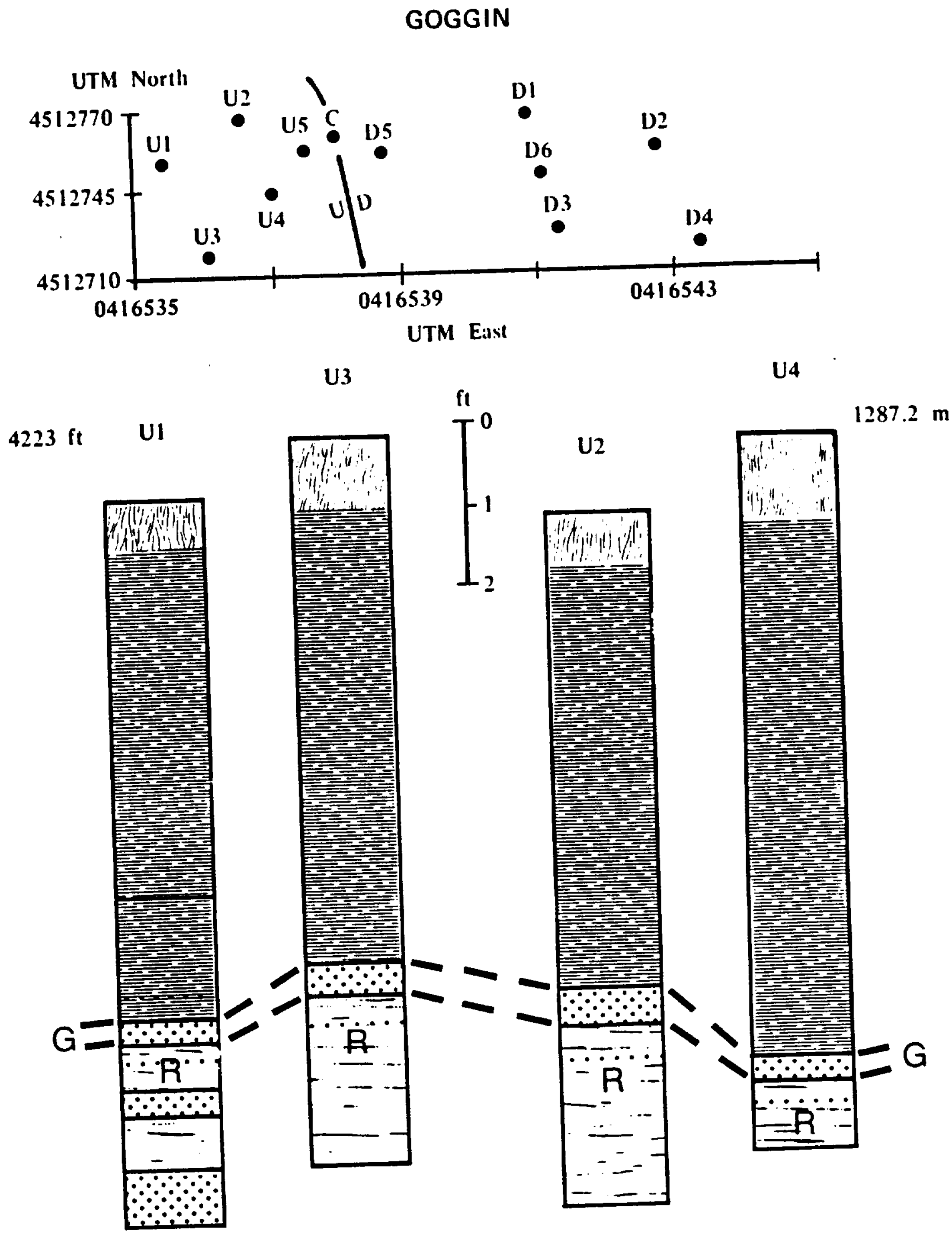


Figure 14. Map location, stratigraphy, and Gilbert transgressive sediments from the four western-most upthrown-side borings at Goggin (28). See Table 3 for an explanation of symbols and patterns.

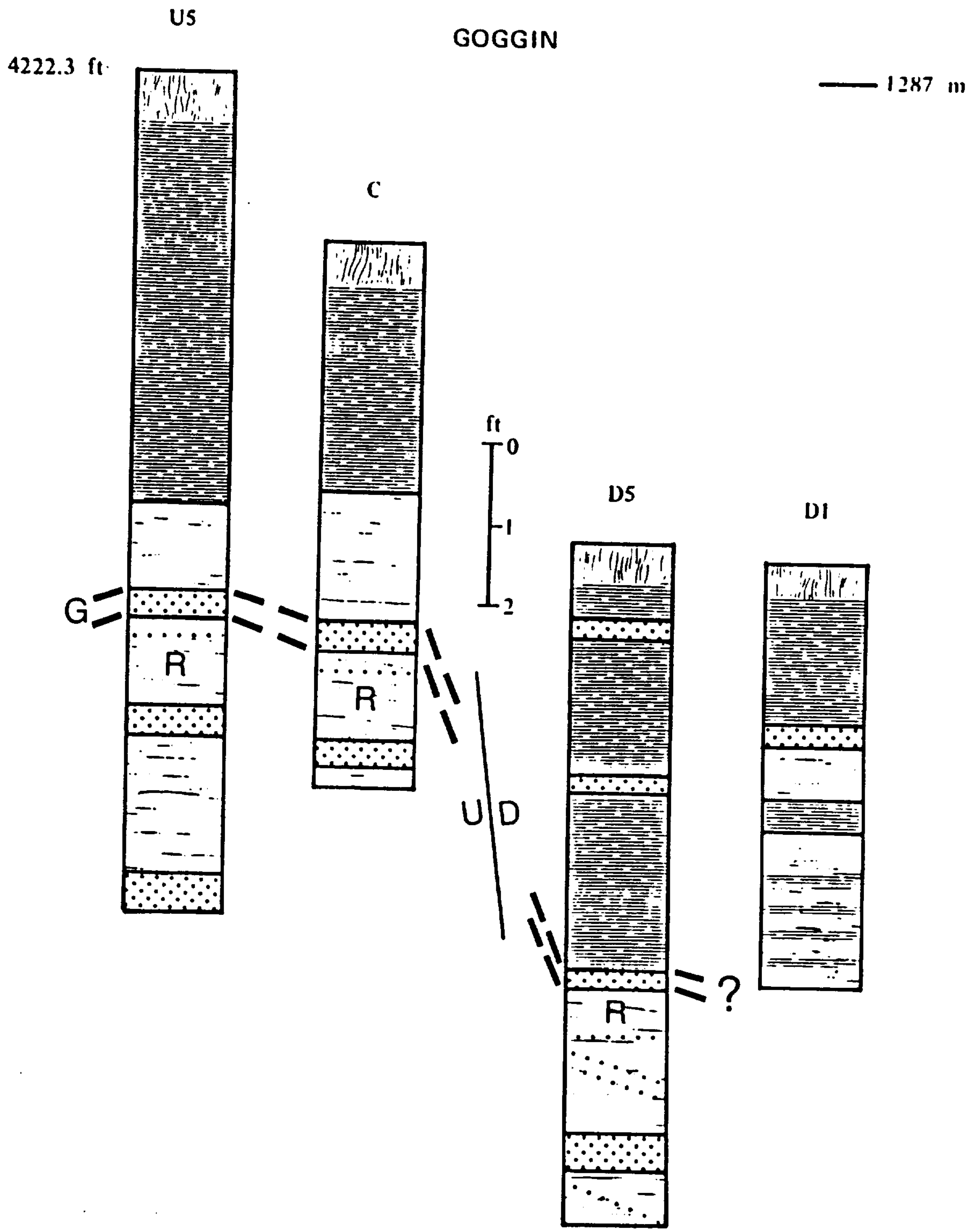


Figure 15. The four Goggin borings (28) that were drilled near the hypothesized fault; the Gilbert age sediments are missing towards the east. See Table 3 for an explanation of symbols and patterns.

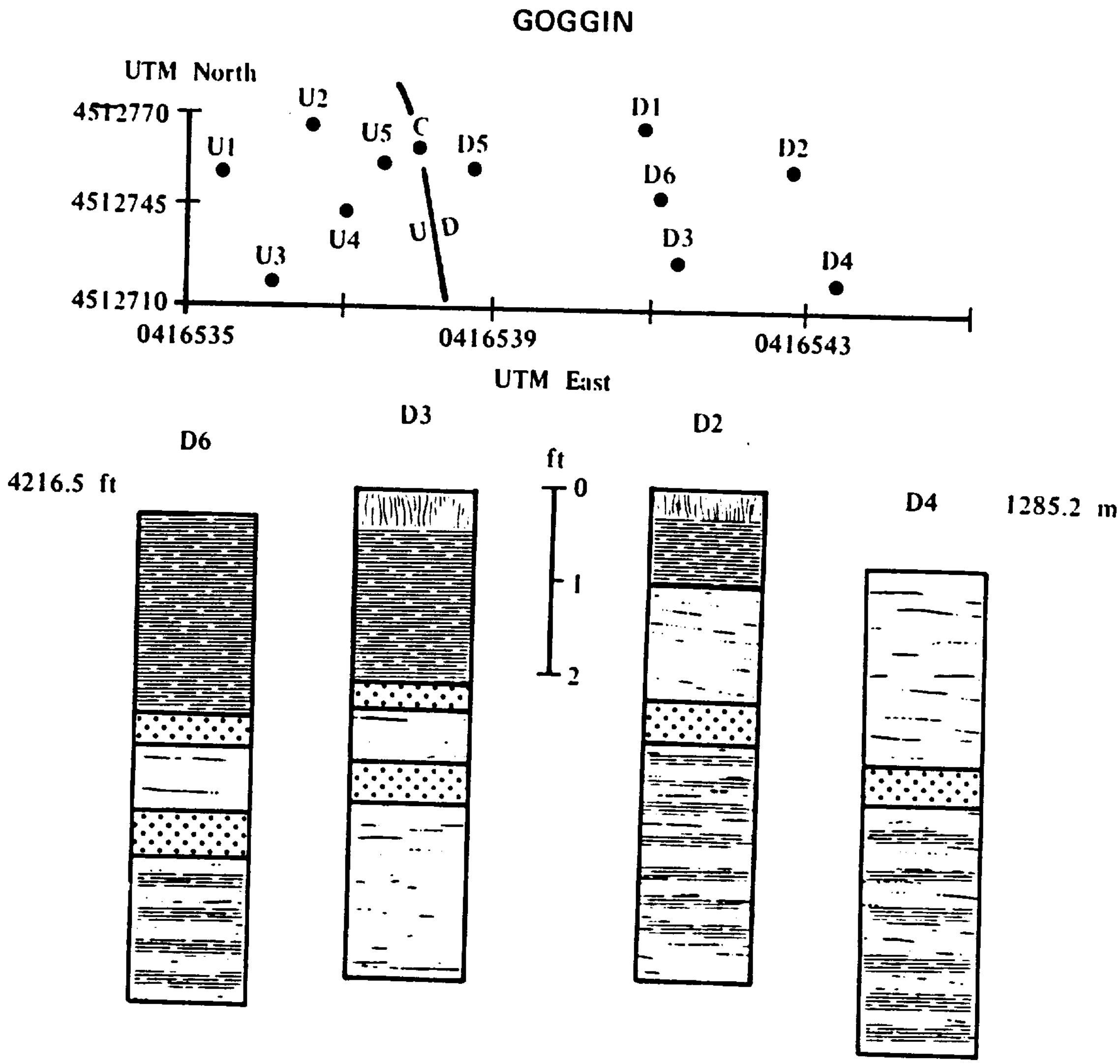


Figure 16. Map location and stratigraphy of the downthrown-side borings at Goggin (28) which are devoid of Gilbert age sediments. See Table 3 for an explanation of symbols and patterns.

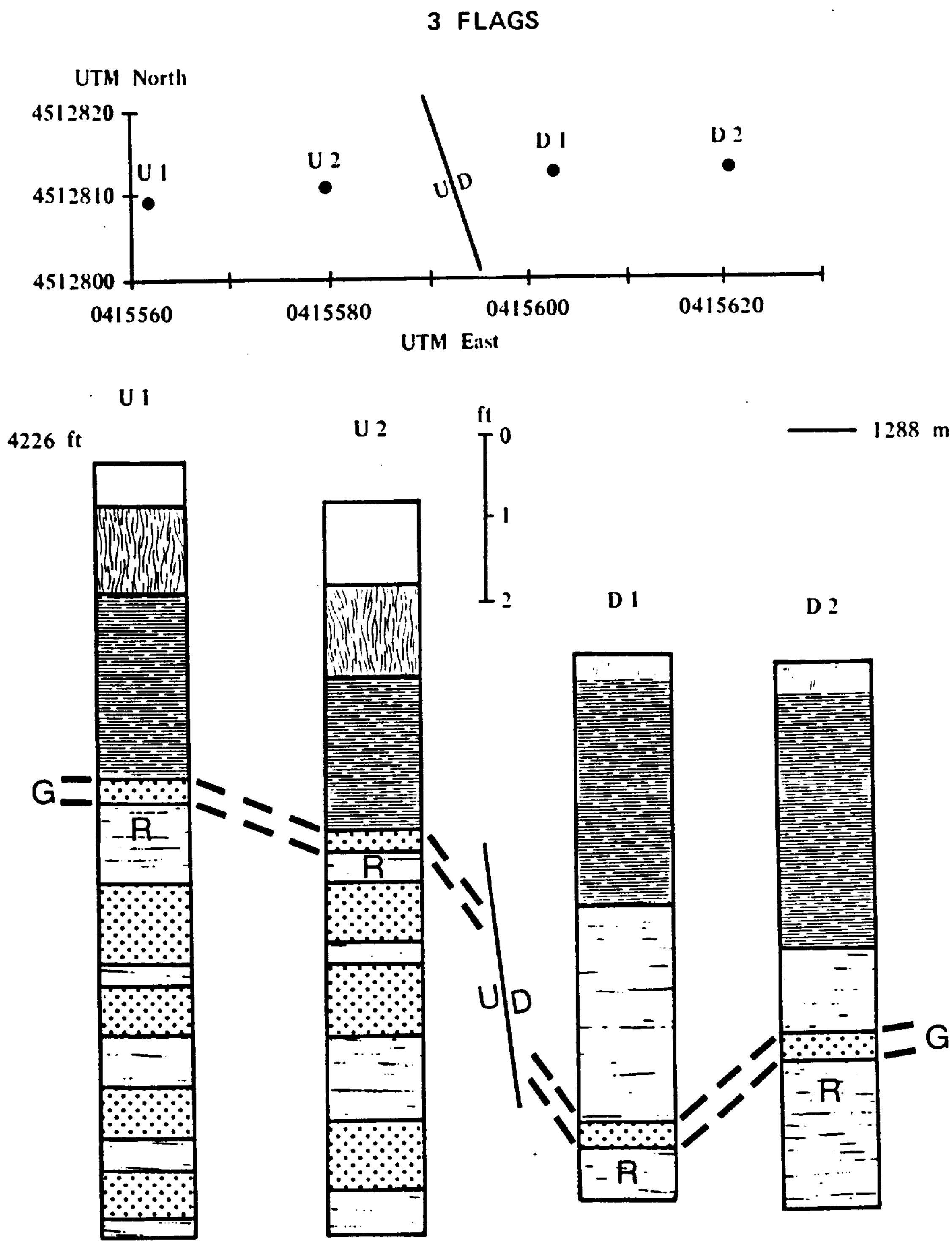


Figure 17. Map location, stratigraphy, and Gilbert transgressive sediments from 3 Flags (29). See Table 3 for an explanation of symbols and patterns.

are found above these elevations.

The downthrown-side borings, being farther west of the Jordan paleodeltas, contain only upslope originated clays overlaying Gilbert sediments. Borings D1 and D2 exhibit Gilbert transgressive sediment at elevations of 4218 ft (1285.6 m) and 4217 ft (1285.4 m).

USGS borings (30)

Nineteen borings drilled by Dames and Moore, Inc. for the USGS show the depth to the base of the Gilbert transgressive facies at various sites (Table 9). These borings define a buried topographic surface, i.e., the sub-Gilbert uncomformity, which shows a pre-Gilbert paleolandscape that parallels the existing topography.

Jordan River paleodelta (31,32)

It is hypothesized that the Jordan River drainage channel (locality 31) entered the lake south and east of Magna spit, producing several subsequent meandering channels and deltas during the Gilbert lake episode (Figure 13). Introduction of fluvial sediment into a lacustrine environment probably produced the interbedding seen in the downthrown-side borings at the 1300 South and Goggin localities. These interbedded strata are similar to Oviatt's (1984) underflow fans at Old River Bed.

Table 9. USGS boring (30) data and the estimated depth to the base of Gilbert sediment.

Site	UTM E	UTM N	Alt. of of boring ft	(m)	Estimated Depth to base of Gilbert
Substation group	0415320	4512800	4226.0	1288.0	4 ft (1.2 m)
	0415390	4513110	4225.5	1287.8	4 ft (1.2 m)
	0415750	4513060	4222.0	1286.8	4 ft (1.2 m)
Wastewater west	0407310	4517120	4214.5	1284.5	9 ft (2.7 m)
	0407580	4517125	4214.5	1284.5	6 ft (1.8 m)
	0407575	4516880	4215.5	1284.8	7 ft (2.1 m)
	0407310	4516880	4215.5	1284.8	9 ft (2.7 m)
Wastewater southwest	0408890	4514140	4217.5	1285.4	6 ft (1.8 m)
	0408880	4513890	4217.0	1285.3	6 ft (1.8 m)
	0409130	4513890	4218.0	1285.6	6 ft (1.8 m)
	0409125	4514140	4218.0	1285.6	6 ft (1.8 m)
Wastewater north	0413130	4517490	4215.5	1284.8	4 ft (1.2 m)
	0413130	4517060	4215.0	1284.7	4 ft (1.2 m)
	0412930	4517060	4215.5	1284.8	4 ft (1.2 m)
	0412930	4517500	4215.5	1284.8	5 ft (1.5 m)
East site	0415690	4512150	4228.5	1288.7	5.5 ft(1.7 m)
	0415800	4512140	4229.0	1288.9	6 ft (1.8 m)
	0415800	4512540	4225.0	1287.7	4 ft (1.2 m)
	0415680	4512550	4225.0	1287.7	6 ft (1.8 m)

Source: USGS data provided by Jeff Keaton of Earthstore Inc.

Auger samples and a backhoe trench farther north (locality 32) reveal pre-Gilbert red beds at a depth of 86 inches (218.4 cm) below a surface of 4218 ft (1285.9 m) (Figure 18). Lying conformably on the red beds is a thin bed of calcareous tufa-like material, which is indicative of a hardwater marsh environment prior to the Gilbert episode. Above the tufa-like layer (4212 ft or 1284 m) is a sandy clay with abundant gastropods.

Unicorn Point (33)

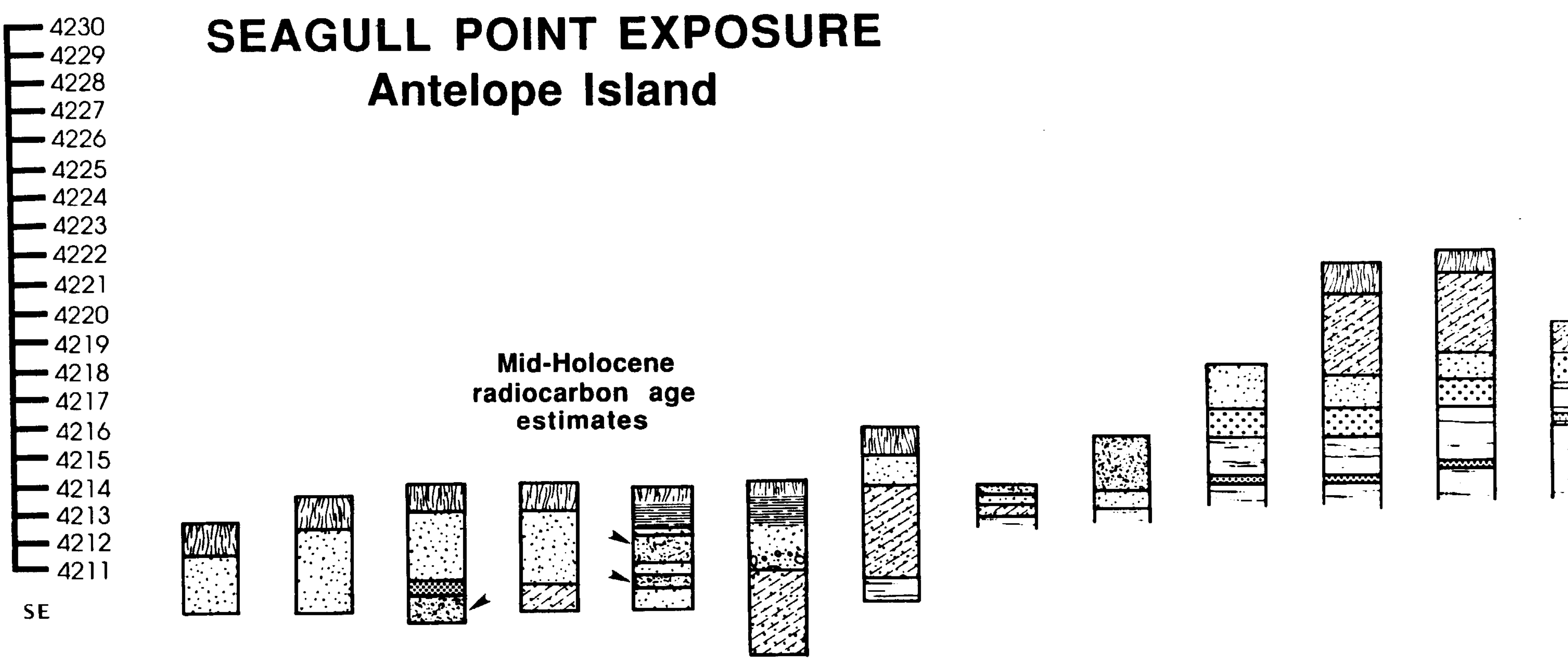
Unicorn Point, named by Genevieve Atwood after the shape of its Holocene spits, is located on the southern tip of Antelope Island. Gilbert age boulder beaches, which are laterally traceable on aerial photographs, have been surveyed by the author at 4250 ft (1295.4 m), 4242 ft (1293.2 m), and 4237 ft (1291.6 m) to 4230 ft (1289.5 m). The clasts range in size from 3 to 12 in (7.6 to 30.4 cm) and at shallow depths have a matrix of sand and ooids.

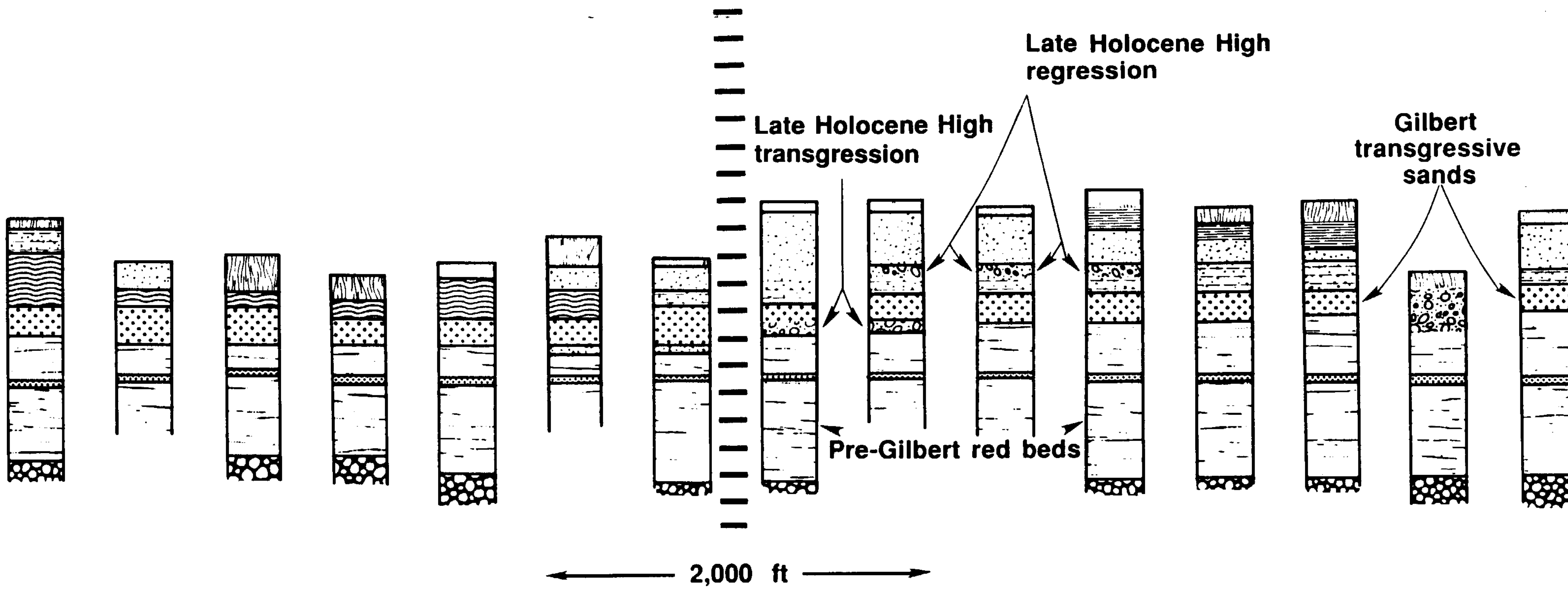
Seagull Point (34)

Seagull Point, a locality that was recently exposed by wave action from the north, contains a sequence of sediments that range from pre-Gilbert red bed deposition to the recent high beach strand of 1987. The north-facing exposure reveals important stratigraphic, geomorphic, and radiometric data (Figure 19, in pocket).

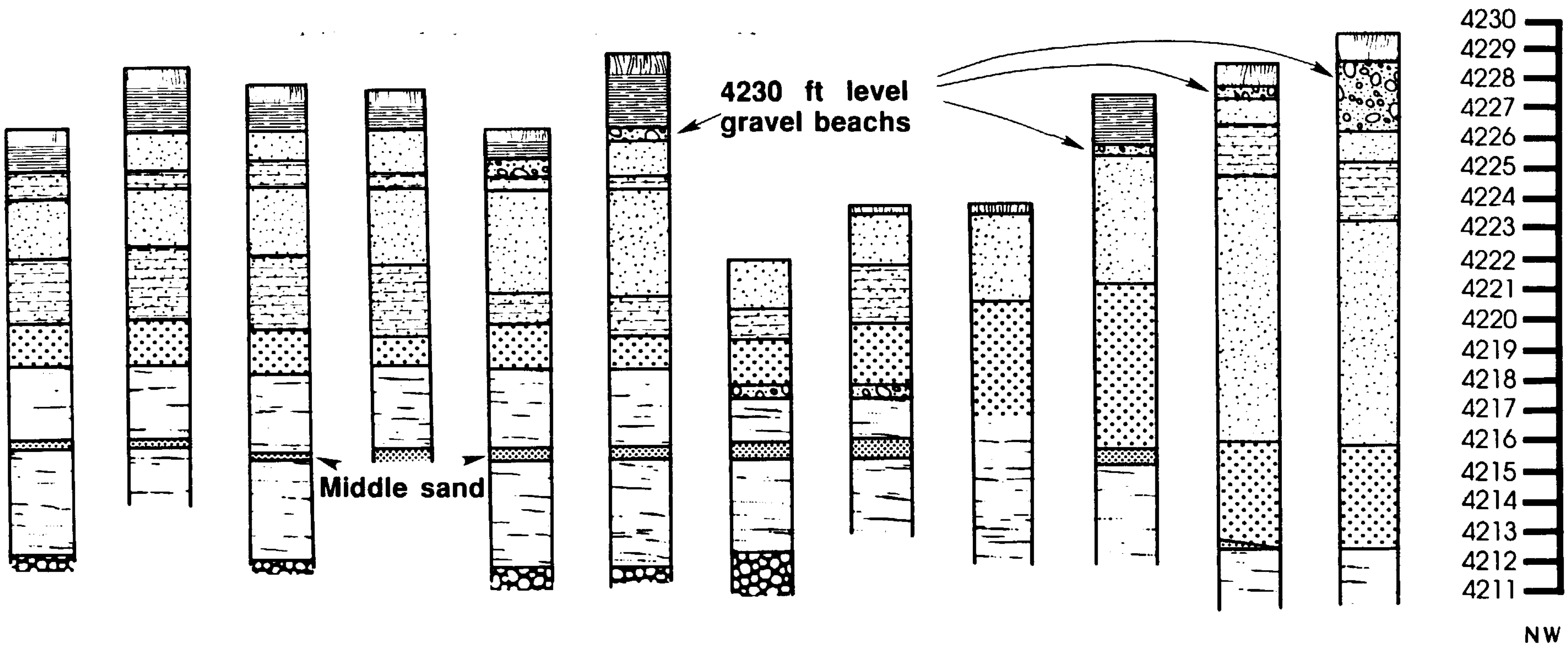
The pre-Gilbert red beds lie unconformably over a groundwater stained boulder unit of probable colluvial

Figure 19. Seagull Point Locality (34)
See Table 3 for an explanation of stratigraphic symbols.





Late Holocene High
regression
Late Holocene High
transgression
Gilbert
transgressive
sands
Pre-Gilbert red beds
2,000 ft


4230 ft level gravel beachs
Middle sand
4230
4229
4228
4227
4226
4225
4224
4223
4222
4221
4220
4219
4218
4217
4216
4215
4214
4213
4212
4211
NW

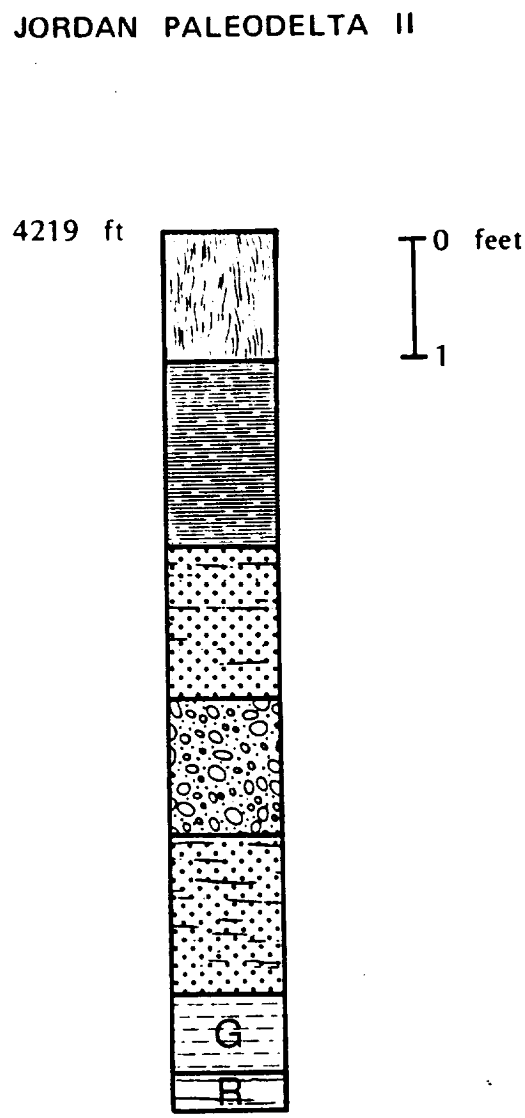


Figure 18. Trench stratigraphy from the Jordan River paleodelta (32) showing the Gilbert age sediment as a tufa-like material that was probably precipitated from a marsh environment. See Table 3 for an explanation of symbols and patterns.

origin. The red beds range in thickness from 4 ft (1.2 m) to 5 ft (1.5 m) and dip below the base of the present exposures 1700 ft (518 m) east of the west end of these exposures. In the western exposures the first 500 ft (152 m) have been altered by ephemeral drainage and hypothesized upslope landslide movement, reworking Gilbert age sediment after they were initially deposited. The red bed unit contains an oxidized red sand and ostracod horizon averaging 0.75 in (2.0 cm) (middle sand on Figure 19 in pocket) that is consistent through most of the exposure, indicating a hiatus in red bed deposition (Currey et al., 1988a). The top of the red bed unit is overlain unconformably by an ostracod layer that is up to 0.3 in (1 cm) thick. This death assemblage of ostracods was probably killed by increasing salinity and decreasing water levels, lending support the theory of a low stand prior to the Gilbert transgression (Currey et al., 1983).

A 1- to 2-ft (30- to 60-cm) green sand unit overlies the red beds and ostracod layer. These Gilbert transgressive sands exhibit alternating bedding with a composition of fine, well sorted sands with infrequent silt and clay layers. Some of these layers are stained orange to brown. This sand contains an assemblage of gastropods in the upper portion of the unit, similar to that of the West Public Shooting Grounds locality. Above the green sand unit is a 4- to 6-in (10- to 15-cm) wave-rippled bed of well sorted, carbonate sands of coarse to medium texture, which are interlaminated with clays and silts. These rippled beds are interpreted as Gilbert regressive facies.

The sand unit that overlies the Gilbert regressive rippled beds is composed of fine to medium grains and lacks well defined bedding. The thickness (6 ft or 1.8 m), texture, and relatively low ripple index, suggests that these sands were deposited as a dune complex after the Gilbert regression. Transgressive pebbles and cobbles overlie the dune sands, at altitudes of 4225 to 4228 ft (1287.7 to 1288.6 m) and grade into cemented sands lakeward. This complex is interpreted as a post-Gilbert transgression to the 4230 ft (1289.3 m) level, seen as beach crests and berms in many localities around the lake.

<u>White Rock Bay</u> (37)

White Rock Bay, located on the northwestern end of Antelope Island, straddles a boundary of the Great Salt Lake State Park. The author found Gilbert age features in the form of a ridge at 4276 ft (1303.2 m) and a wave cut terrace at 4257 ft (1297.6 m). A large ridge at 4250 ft (1295.4 m) and a smaller ridge at 4243 ft (1293.4 m) were also observed. Another possible Gilbert age beach crest is located between 4236 ft and 4232 ft (1291.2 m to 1290.1 m).

<u>Hooper</u> (38)

Rubin and Alexander (1958) analyzed woody material in a sand unit at 4232 ft (1291 m). This material provided an age estimate of 9730 ± 350 yr B.P. (W-386; no ^{13}C adjustment), which Currey and James (1982) interpret as a late phase of the Gilbert episode.

Archeologic Site Descriptions

Danger Cave (18)

The stratigraphy in Danger Cave helps support the geomorphic evidence of late Pleistocene and Early Holocene chronologies. Danger Cave was excavated between 1949 and 1953 by a number of scientists under the direction and supervision of Jesse D. Jennings (Jennings, 1957). It is located 1 mi (1.6 km) northeast of Wendover, in Tooele County, at an elevation of 4310 ft (1313.6 m).

The first human occupation was sometime around 10,500 yr B.P. This age is an average of seven radiocarbon age estimates on materials from the surface of sand I (stratum 2), unit DI, and the lower part of unit DII (Madsen, written communication, 1987). It is inferred by Jennings (1957) that the site was occupied by paleo-Indians from late summer to early fall. There is radiometric evidence that both bats and mountain sheep were present either in alternating seasons or when humans were absent. Layers of bat guano in the lower cultural strata have been linked to moderately wet conditions and increased insect populations (Jennings, 1957). Ostracod shells, gastropod shells, and ooids are also found in these lower strata.

From the earliest major occupational horizons of humans, there are eolian bands of dust and sand believed to be derived from Gilbert beaches (Jennings, 1957). The Gilbert shore was probably not far from the mouth of Danger Cave. Coprolite research by Fry (1976) suggests that the inhabitants ate mostly halophytic vegetal foods such as Artemisia tridentata (sagebrush), Atriplex confertifolia (shadscale), Sacobatus vermiculatus (greasewood), Scirpus americanus (bulrush), and Juniperus osteosperma (Juniper nuts). Their diets were meagerly supplemented by harvesting fauna and flora from other ecological zones to the west. Fresh water is found in the forms of runoff and springs (Simms, 1977) as indicated by marsh sediment above Gilbert transgressive gravels found in Juke Box trench.

Juke Box Cave (19)

Juke Box Cave is located 2.2 miles (3.5 km) north of Wendover. The stratigraphy of Juke Box Cave is similar to that of Danger Cave, although radiometric data are non-existent.

Lake Bonneville sediments, including marl, are found 14 feet (4.2 meters) below the surface. Overlying this material unconformably is a calcareous silt layer that is oxidized near the top. This stratum is void of cultural artifacts and ostracods but contains a fossil phalange of Equus sp. (Jennings, 1957).

Disconformably overlying sediments contain alternating layers of rockfall material, vegetable matter, and loessal beds. In a comparison of both Danger and Juke Box Caves, Jennings (1957) concluded that the paleoenvironmental and archeologic histories were similar.

Hogup Cave (16)

Hogup Cave was excavated during 1967 and 1968 by teams of archeologists from the University of Utah (Aikens, 1970). This cave faces the Great Salt Lake Desert flats on the western flank of the Hogup Mountains. Aikens estimates the elevation of the mouth of the cave at 4700 ft (1432.5 m), 1 mi (1.6 km) east of a spring (Cresent Spring) that probably served as the water source.

The earliest cultural stratum has estimated ages of 8800 ± 200 yr B.P. (GaK 2083) and 8350 ± 160 yr B.P. (GaK 1569) (^{13}C adjustments unknown), suggesting that humans entered this cave relatively late compared to Danger and Juke Box caves. These age estimates are from the first strata (Stratum 1), which overlies bedrock.

Aikens (1970) infers that during stratum 1 time, water was still covering portions of the Great Salt Lake Desert. This assertion is partially based on human dietary content, which is indicated by coprolites with 50 percent halophytes in strata 1 through 3 (Fry, 1976).

Summary

The author's inferred chronology of Great Salt Lake between the period of 12,000 and 8000 yr ago is summarized in Figure 20. At the conclusion of the post-Provo

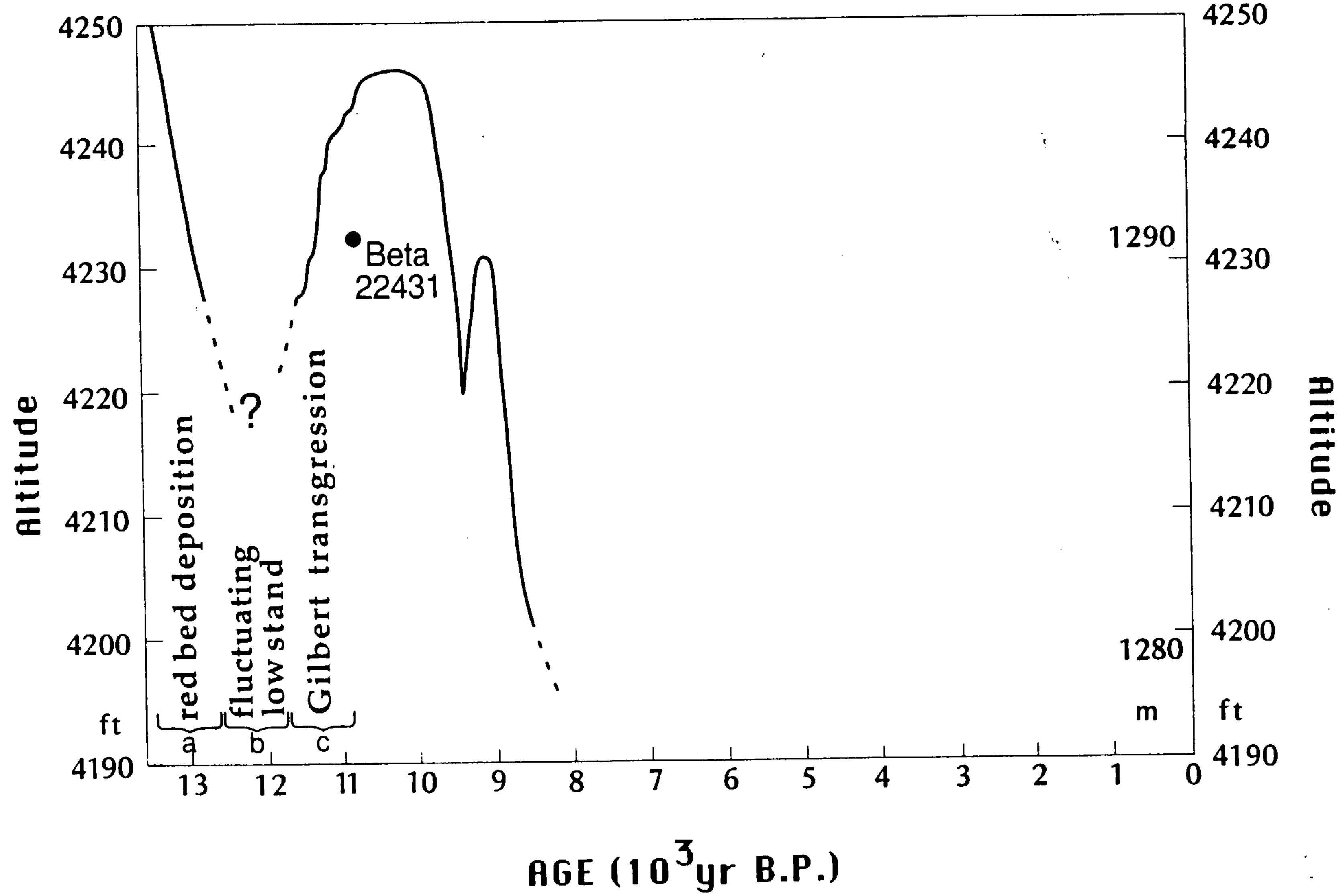


Figure 20. Fluctuation hydrograph (12,000 to 8,000 yr B.P.)

regression, about 13,000 yr B.P., the lake had regressed to a level below 4220 ft (1286.2 m) (Scott et al., 1983; Spencer et al., 1984; Oviatt, 1984; Currey et al., 1988a). This interlacustral episode provided the subaerial exposure for oxidizing and hence reddening sediments from the exposed lakebed and washing them into the nearshore zone of the diminishing lake. These pre-Gilbert red beds have been examined at Little Mountain, West Public Shooting Grounds, 1300 South borings, Goggin borings, 3 Flags borings, USGS borings, Jordan River paleodelta II, and Seagull Point.

The pre-Gilbert red beds conformably overlie Bonneville alloformation units around the periphery of the northern Bonneville basin and Great Salt Lake. The beds range in thickness from 0.3 to 6.5 ft (0.1 to 2.0 m) and in color from 5 YR to 10 YR (Currey et al., 1988a). They texturally range from friable sands and sandy clay loams to calcareous muds and clays.

In the majority of sites where pre-Gilbert red beds are found, 1 to 5 sand partings of 0.4-1.0 in (0.7-2.5 cm) were discovered. The sand partings suggest periodic fluctuations during red bed deposition. Red oxidized sand partings with ostracod assemblages, as seen at Goggin, Danger Cave, and Seagull Point, further indicate possible complex oscillations during deposition.

As seen in Figure 1, first-order fluctuations are represented by annual high frequency wave amplitudes. Second-order fluctuations would be represented by 100 yr low frequency waves. Third-order fluctuations described by Dearing and Foster (1986) are represented by very low frequency waves (1000 year waves) similar to Currey et al. (1984) and Currey and Oviatt's (1985, p. 1091) hydrograph diagrams. The sand partings and ostracod assemblages were likely deposited as a result of low lake stand first- and second-order fluctuations. Spencer et al. (1984) suggest that the lake further regressed to very near dessication levels, leading to the precipitation of Glauber's salt ($Na_2SO_4 \bullet 10H_2O$) at the deepest portion of the present Great Salt Lake.

Currey et al. (1988a) discuss the subaerial surface at the top of the pre-Gilbert red beds that resulted in desiccation cracks, ostracod assemblages, erosional relief, and desert pavement best shown at Little Mountain and West Public Shooting grounds. Juke Box Cave contains oxidized silts above the last Provo stage lacustral sediments (Jennings, 1957). From similar evidence, Miller (1980) and Currey et al. (1983) postulate a low stand prior to the Gilbert transgression with an upper limiting elevation of 4220 ft (1286.2 m) and minimum age estimate of 12,000 yr B.P.

Overlying the pre-Gilbert red bed unit is the Gilbert transgressive (green sand) unit. The transgressive facies consist of beach gravels at high energy shore locations, coarse to fine green sands in medium shore and deltaic areas, and gastropod-rich muds in marshy coastal flats, near fresh water sources. Radiocarbon age estimates of the Gilbert transgression are found in Table 10. Based on these estimates and the geomorphic evidence, the Gilbert transgression probably began approximately 12,000 yr B.P.

Anthropologic data at Danger, Juke Box, and Hogup caves suggest that the Gilbert transgression did not reach elevations greater than 4310 ft (1313 m). The Gilbert beach elevations and the number of beach building events are partially masked by isostatic rebounding. The highest Gilbert facies at Juke Box trench are found at 4247 ft (1294.4 m) and the lakeward pair of spits at Magna are found at an elevation of 4245 ft (1293.8). At Mills Junction the crest of the Gilbert age spit is 4260 ft (1298.3 m). The remaining 15 localities have a number of beach berms at different elevations (Figure 21).

Table 10. Radiocarbon age estimates for the Gilbert transgression.

Radiocarbon age	Lab No.	Site	Reference
*11,453 ± 600	C-609	Danger (18)	Jennings (1957)
*11,151 ± 570	C-610	Danger	Jennings (1957)
*10,270 ± 650	M-204	Danger	Jennings (1957)
*10,920 ± 150	W-4395	WPSG (3)	Miller (1980)
11,990 ± 100	Beta-16912	WPSG	Currey (unpub.
11,570 ± 100	Beta-16913	WPSG	Currey data)
10,990 ± 110	Beta-22431	WPSG	Murchison (1989)
*10,300 ± 310	GX-6949	Magna (26)	Currey (1983)
*10,285 ± 265	GX-6614	Magna	Currey (1983)

* ^{13}C adjustments unknown

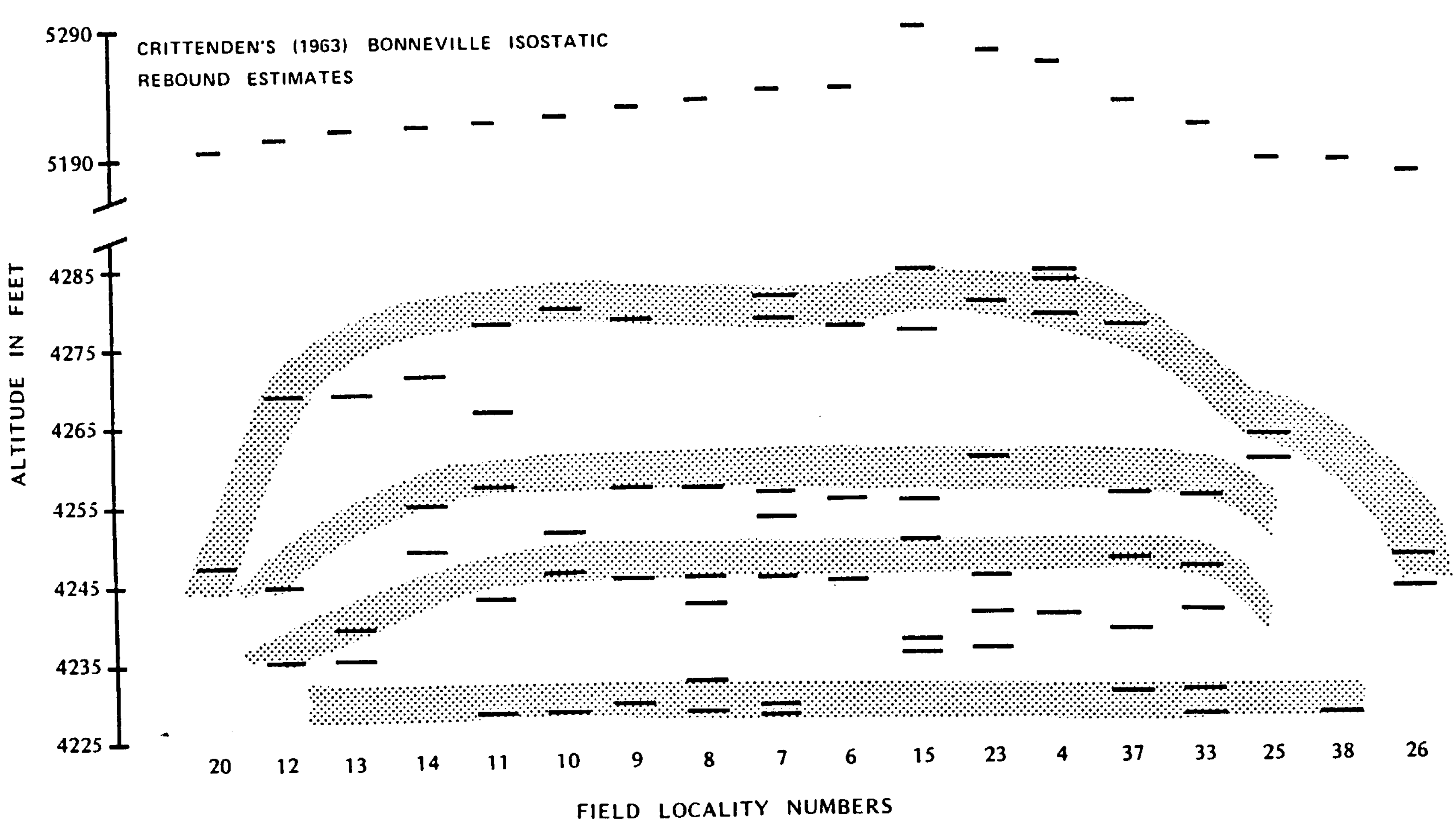


Figure 21. Surveyed beaches of very late Pleistocene to Holocene age compared to the Lake Bonneville isostatic rebound estimates of Crittenden; the numbers at the bottom refer to localities on Table 1 and the stippling highlights major beaches.

To unravel the Gilbert transgression and regression history, three techniques were utilized. The first technique was to observe the qualitatively selected properties of the surface vegetation, which is now established as dominant at each locality since the last saline inundation. The second technique was to observe and measure selected properties of the surficial sediments on berms. The third technique was to use the Kruskal-Wallis H test to statistically evaluate surficial sediment data inferring which beaches were from similar populations.

The first technique is very subjective, due to the fact that it was carried out visually. The oldest of the observed beaches have a cover of nonhalophytic shrub and/or grass communities and are devoid of halophytes. The younger beaches have a cover of only grasses and/or halophytes or are devoid of all vegetation. The preliminary identification of Gilbert age beaches was based on the above criteria as well as altitude and position.

The second technique involved observing the presence or absence of ooids, and sampling sediment at the crests of berms at 10 and 30 cm depths. Ooids were not observed above elevations of 4225 ft (1287.7 m) but were increasingly abundant below that level. Laboratory analysis of 10 and 30 cm sediment samples provided a measure of silt+clay accumulation as a percentage of the total sediment. This silt+clay percentage is used to infer relative age since deposition.

Soils formed on older lacustral geomorphic features should have accumulated nominal amounts of silts and clays through pedogenesis. Since pedogenesis is usually a temporally dependent occurrence, younger lacustral features should have considerably less silt and clay accumulation. The nonparametric Kruskal-Wallis H test was applied to the textural samples to infer whether the samples were taken from identical populations (Ebdon, 1985). The samples, listed in Table 10, show the sampled beaches and their respective silt+clay percentages.

A two-tailed difference of population test ($H = 23.17$) at a 0.10 significance level (after Isgreen, 1985) indicates that all altitudinal sample populations are significantly different from each other. To test whether the Gilbert beaches belong to the same population, the three Gilbert beach samples were subjected to the same test resulting in a $H = 0.71$ at the 0.10 significance level. The $H = 0.71$ at the 0.10 significance level statistically infers that the Gilbert beaches belong to the identical population. The lake level geomorphically expressed at 4230 ft (1289 m) (see Table 10) was tested with the Gilbert shoreline; a H statistic of 0.42 at the 0.10 significance level implies that the 4230 ft (1289 m) shoreline is within the same population as the Gilbert shorelines.

West Public Shooting Grounds deposits indicate up to four transgressive saline inundations. A series of marsh

Table 11. Silt+clay percentages from Great Salt Lake sites. The numbers in the parenthesis are the overall rankings of the sample values.

* Loc.	Gil. High	Gil. Med.	Gil. Low	4230
4	.195 (46) .107 (36)	.039 (26) .009 (6.5)	.015 (16.3) .005 (3.5)	.017 (19.5) .051 (27)
6			.404 (53) .145 (43)	
11	.110 (36.3) .146 (44)	.377 (51) .392 (52)	.628 (55) .483 (54)	.196 (47) .236 (49)
26	.076 (34) .116 (39.5) .074 (30.3) .116 (39.5)			
33				.134 (42) .162 (45)

* Numbers refer to localities listed on Table 1.
Source: Author's original data collected between 1987-1988.

deposits overlie the red beds at several sites, implying several intervals of moist conditions. A species specific radiocarbon age estimate on Lymnaea stagnalis shells suggest a transgression about 10,990 ± 110 yr B.P. (Beta 22431) followed by a minor regression. At Magna spit, gastropod shells suggest a multiple spit formation at 4245 ft (1293 m) between 10,300 ± 310 yr B.P. (GX-6949) and 10,285 ± 265 yr B.P. (GX-6614) (Currey and Oviatt, 1985). If an estimated 60 ft or 18 m (Currey, 1980) of isostatic rebounding is taken into account, at least three major beach building oscillations, after the four smaller transgressions, are thought by the author to comprise the Gilbert episode.

The first and second transgression are probably responsible for the two associated beaches below the 4250 ft (1295.3 m) level. The third oscillation is estimated to have formed the highest level, which is altitudinally consistent throughout the sites, if isostatic rebound is taken into account. The lake probably began to regress sometime after 10,000 yr B.P. The H statistic of 0.42 (see above) and associated radiocarbon age estimations of 9450 ± 150 yr B.P. (Beta-21807; no ^{13}C adjustment) and 9730 ± 350 yr B.P. (W-386; no ^{13}C adjustment) suggest that the 4230 ft (1289 m) level may have formed between 9700 and 9400 yr B.P. (Currey and James, 1982). The 4230 ft (1289.2 m) beaches are discussed at most of the localities in this chapter (see Figure 21).

Mehringer's (1985) pollen record in the Great Basin suggests that after 9000 yr B.P. rising temperatures contrasted sharply with the previous cool-moist conditions. Fry (1976) infers the same warming trend, at Hogup Cave around 8300 yr B.P., from human coprolites that exhibit the ingestion of halophytic vegetal foods and high sodium excretion. Based on the above data, it can be assumed that the lake lowered gradually through the next 1000 years. In contrast to my interpretation, data by Isgreen (1986) suggests high effective moisture, following the post-Gilbert warming, in the eastern Great Basin between 8490-7740 yr B.P. Currey and James (1982) report that Sevier Lake and Great Salt Lake went through a slight lake rise around 8000 yr B.P., based on stratigraphic records from areas outside the basin. This higher moisture could be responsible for the post-Gilbert marshes at 8360 ± 140 yr B.P. (-26.4 0/00 ^{13}C; Beta-18804) from Juke Box Trench, although no other sites exhibit a comparable high effective moisture regime at this time.

CHAPTER 3

MID-HOLOCENE (8000 TO 4000 YR B.P.)

Introduction

Previous Concepts

The mid-Holocene has been described as a period of low lake levels in many areas in the west and southwest (Antevs, 1952; Morrison, 1966; Harper and Alder, 1972; Currey, 1980; Madsen, 1980; Currey and James, 1982; Mehringer, 1985). Sometimes refered to as the Altithermal, this period was characterized by warmth and drought-like conditions (Smith and Street-Perrott, 1983). Morrison (1966) believes that gypsum-ooid dunes formed in the Great Salt Lake Desert during this time.

There is debate whether the lake actually dried up periodically during this period. Morrison (1966) referred to the interlacustrine unconformity, coeval eolian deposits, and the Midvale soil near modern lake margins as evidence of complete dessication. Currey (1980) infers that dessication polygons formed above the water table during one or more mid-Holocene intervals, as evidenced by polygonal fissures that are now submerged. Arnow (1984) recognizes lake levels lower than 4200 ft (1280 m) but believes the lake never completely dried up. Cores studied by Grey and Bennett (1972) revealed no evidence of complete dessication in post-Gilbert time.

Author's Research Strategy

Previous studies suggest that this time period is typified by warmer and drier climate. Potential geomorphic and archeologic lake evidence, if existing, will probably be found at mean or lower than mean altitudes. The interpretation of subaerial and subaqueous deposits with special emphisis on obtaining radiocarbon age estimates is the research design method utilized in this 4000 yr period.

Chapter Overview

The small body of evidence, obtained from previous reports and the author's field and laboratory work, suggests that the lake fluctuated between 4212 and 4180 ft (1284 and 1274 m) for 4000 yr. It is thought that networks of polygonal fissures indicate a very low lake between 6900 and 6000 yr B.P. (Currey, 1980). Localities exhibiting information from this time period are shown in Figure 22.

Geomorphic Site Descriptions

Stansbury Island (23)

The west shore of Stansbury Island is almost completely lined with ooids due to the shallowness of the lake floor to

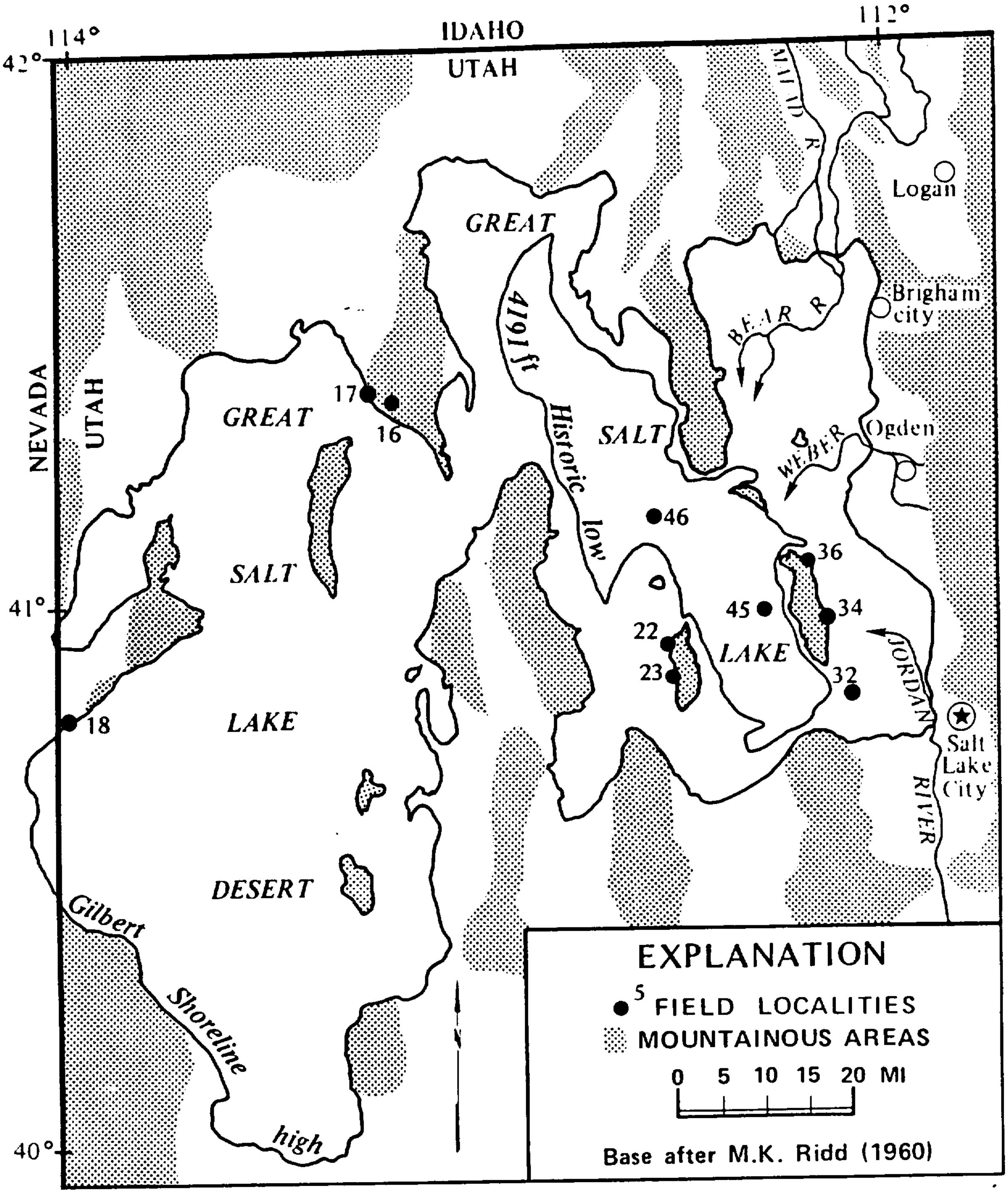


Figure 22. Map of localities mentioned for the period between 8000 and 4000 yr B.P.

the southwest. On the western shore, ooids cemented to oolite were sampled from a plainar bed that overlies shore pebbles and is unconformably overlain by foreset beds of ooids. The ooids were excavated from a quarry 30.5 in (77.4 cm) below the surface. These sample was found at an altitude of 4212 ft (1284.0 m) and has a radiocarbon age of 7070 ± 100 yr B.P. (+4.7 0/00 ^{13}C; Beta-22432) (Figure 23). This cemented ooid layer is probably a beach that was buried by ooid sands of a later Holocene transgression.

<u>Jordan River Paleodelta II</u> (32)

The distributary levees of the Jordan paleodelta II channel, overlying Gilbert transgressive facies, were probably formed sometime after 8000 yr ago. The paleochannel cut through what is now a typic Natrustalf. This alfisol is a member of the Lasil series and the fine-silty, mixed, mesic family (Soil Survey Staff, 1974). The description of this series is listed on Table 11. The parent material of this series is composed of mixed lake sediments with additional loessal material in the A and B horizons.

The differences in texture, mineralogy, color, and pH between the channel and the Lasil series suggest different parent material, age, and fluvial or lacustral histories (Table 12). The Lasil soil has developed in lacustrine sediments with ground water fluctuations that represent the typic Natrustalfs. The finer texture (clay loams and silty

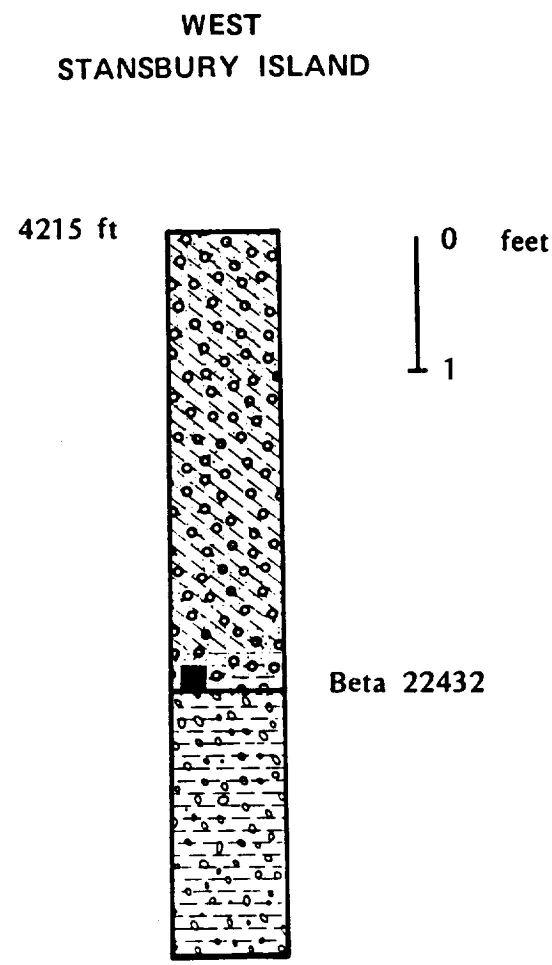


Figure 23. Stratigraphy of Stansbury Island locality (23); radiocarbon age on horizontally bedded ooids. See Table 3 for an explanation of symbols and patterns.

Table 12. Lasil Series soil near Jordan paleodelta II (32).

A2 -	0 to 5 in, light brownish-gray (10YR 6/2) silt loam, medium, platy structure; slightly hard, friable, slightly plastic; common very fine roots and very fine pores; strongly alkaline (pH 8.8).
A3 -	5 to 9 in, light brownish-gray (10YR 6/2) silt loam, medium, prismatic structure; hard, friable, slightly plastic; few very fine roots; many very fine pores; calcareous, strong alkaline (pH 8.9).
B2t -	9 to 14 in, light-gray (10YR 7/2) clay loam, medium, prismatic structure; extremely hard, firm, sticky, and very plastic; few very fine roots; many very fine pores; organic and clay films on ped faces; calcareous, very strongly alkaline (pH 9.2).
B3ca -	14 to 19 in, light-gray (2.5Y 7/2) silty clay loam, medium, platy structure; extremely hard and sticky and very plastic; few very fine roots; many very fine and fine pores; organic and clay films on ped faces; calcareous, strongly alkaline (pH 9.2).
C1ca -	19 to 29 in, light-gray (5Y 7/2) silty clay loam yellowish-brown (10YR 5/4) mottles; massive; extreme ly hard, friable, sticky and very plastic; many very fine and fine pores; calcareous, very alkaline (pH 9.6).
C2 -	29 to 48 in, light-gray (5Y 7/2) silt loam, dark yellowish-brown (10YR 4/4) mottles; massive; friable, slightly sticky and plastic; many very fine pores; calcareous, strongly alkaline (pH 9.2).
IIC3 -	48 to 78 in, light-gray (2.5Y 7/2) fine sand, coarse, brown (10YR 4/3) and yellowish-brown (10YR 5/4) mottles; massive, very friable, nonsticky and nonplastic; few fine interstitial pores; calcareous, alkaline (pH 9.0).

Source: Soil Survey Staff, 1974

Table 13. Soil horizon comparasion between the Lasil soil and Jordan paleochannel soils.

Lasil Series	Trench 1	Trench 2
A2-A3 Silt loam 10YR 6/6 Lt. brownish-gray pH - 8.8	A Sandy loam 10YR 4/4 Dk. yellowish brown pH - 8.1	A Sandy loam 10YR 5/4 Yellowish brown pH - 8.9
B2t Clay loam 10YR 7/2 Dk. grayish brown pH - 9.2	B Sandy loam 5Y 7/3 Pale yellow pH - 8.1	AB Sandy clay loam 5Y 7/2 Light gray pH - 8.4
B3ca Clay loam 2.5Y 7/2 Lt. olive brown pH - 9.2		B Sandy clay loam 2.5Y 8/2 White pH - 7.9
C1ca Silty clay loam 5Y 7/2 Light gray pH - 9.6	C1 Sandy loam 2.5Y 5/2 Grayish brown pH - 8.2	C1 Sandy loam 2.5Y 8/4 Pale yellow pH - 8.1
C2 Silt loam 5Y 7/2 Light gray pH - 9.2	IIC2 Sand 5Y 5/4 Olive pH - 8.4	C2 Loamy sand 5Y 6/3 Pale olive pH - 8.2
IIC3 Fine sand 2.5Y 7/2 Olive gray pH - 9.0		IIC3 Loamy sand 5Y 6/4 Pale Olive pH - 8.0

clay loams) suggests that the Lasil soil has undergone clay synthesis and is relatively older than the channel material. As the Lasil soil was undergoing pedogenesis, the channel and floodplain areas were collecting new layers of coarser sands from the Jordan River paleodelta. Sediment load and water discharge fluctuations, after Gates (1984), are believed to be responsible for sequential layering of fluvial sands toward the south bend of the river channel. Modern A and lower B horizons probably developed from eolian sources after abandonment and subsequent eastward migration of the Jordan River sometime after 2000 yr ago.

Seagull Point (34)

On the eastern end of Seagull Point, Holocene marsh sediments are seen in outcrop as wedge-shaped bodies of organic sediment. These organic deposits appear to have accumulated behind berms or some other barrier beaches. These marsh sediments probably continue laterally along strike throughout the length of the spits.

The oldest and most organic sample (8 gm of humate extract) was taken from a 2-in (5-cm) thick wedge-shaped bed at 4210.2 ft (1283.2 m). The sample was overlain by a 6 in (15.2 cm) iron-stained sand unit and 2-ft (60-cm) white-gray calcareous sand unit. The exposure was capped by a 1.1 ft (32.5 cm) modern soil, with saltgrass (Distichlis stricta) and greasewood (Sarcobatus vermiculatus) vegetation at the surface (Figure 24a). The sample has a radiocarbon age of 7650 ± 90 yr B.P. (-26.4 0/00 ^{13}C; Beta 25290). The high organic content in this marsh bed suggests accumulatiom on a lagoon floor during a protracted lake rise and stabilization level.

Farther west (Figure 24b), a 6-in (15-cm) wedge shaped organic bed is found at 4211.2 ft (1283.5 m). A radiocarbon age of a sample (2.5 gm of humate extract) of the organic marshy material is reported at 5890 ± 120 yr B.P. (-26.1 0/00 ^{13}C; Beta 26629). This marsh material overlies a coarse sand unit of 10 in (25 cm) and is overlain by a white to gray, medium clean sand unit of 4 in (10 cm).

Conformably overlying the clean sand unit, is another marshy calcareous organic soil (Figure 25b). The overlying organic marshy soil was formed 2000 yr later (Beta-25289), suggesting very slight lake fluctuations during this period.

<u>Tin Lambing Shed Basin</u> (36)

A 0.43-in (1-cm) thick calcareous lacustrine mud was removed from an inclined lens in a sequence of foreset gravels for radiocarbon age estimation. This sample was taken from coastal bluffs 5 ft (1.5 m) below a 4218 ft(1285.6 m) beach crest. The radiocarbon age of 7260 ± 130 yr B.P. (-4.5 0/00 ^{13}C; Beta-23353) is based on carbonate carbon only. This sample is thought to contain secondary carbonate, but is sequentially and altitudinally analogous to the Stansbury Island (23) ooid age estimate.

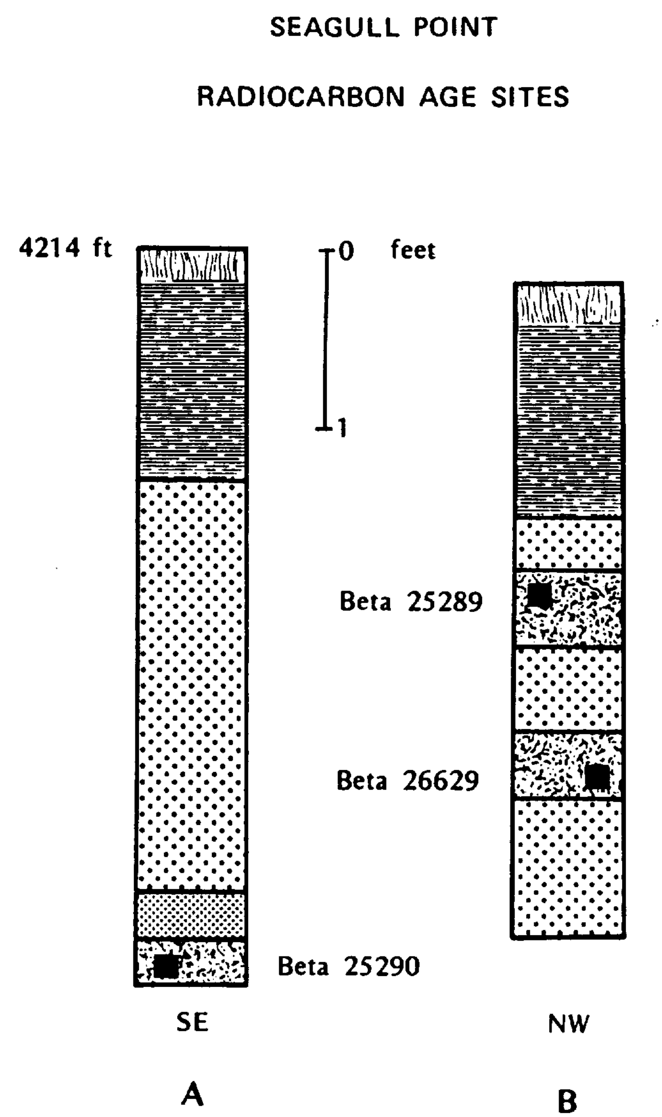


Figure 24. Stratigraphic columns on the eastern part of the Seagull Point (34) exposure (see Figure 19). See Table 3 for an explanation of symbols and patterns.

It is theorized that these materials were deposited and then buried by a later Holocene transgression.

Archeologic Site Descriptions

Danger Cave (18)

Jennings (1957) believes human presence at Danger Cave dwindled sometime around 7000 yr B.P. and was rare or even absent until 3819 ± 160 yr B.P. (C-636, ^{13}C adjustment unknown). Loessal accumulation, formation of salts from runoff, and intermittent guano bands overlie earlier human occupational zones, implying infrequent occupation or abandonment during this period.

It is probable that since the Gilbert regression, sustained human occupation at Danger Cave became logistically uneconomical. This partial occupation lends support to the theory of Simms (1977) and Madsen (1982) that later Great Salt Lake Desert inundations positively influences human reoccupation of cave sites due to increases of marshland habitat.

Hogup Cave (16)

Hogup Cave human occupational zones are divided into units that are characterized by recognizable cultural patterns. Unit 1 is divided into 8 strata, and is estimated to date from 8400 to 3250 radiocarbon yr B.P. Strata 4 through 8 exhibit a possible shift in cultural and ecological patterns based on the distribution of flora and fauna remains. It has been suggested by Aikens (1970) that a drying trend, in the latter half of Unit 1, was responsible for Great Salt Lake Desert desiccation and increased halophytic vegetation. Aikens also suggests that humans were utilizing the site more intensely, exploiting new tool technologies, and harvesting more diverse species later in Unit 1. It seems that these traits were probably adapted in response to a lake level that was absent from this site during all of the early human occupation.

<u>Sandwich Shelter</u> (22)

Located on the northeast side of Stansbury island, Sandwich Shelter lies at approximentally 4269 ft (1301.1 m) (Marwitt et al., 1971, p. 27). A radiocarbon age of 7040 ± 280 yr B.P. (RL-55, ^{13}C adjustment unknown) was obtained from charcoal at the lowest human occupation stratum. Mehringer (1986) states that a land bridge or the shoal at 4206 ft (1281 m) was required for human migration to the island. Currey and James (1982) and Isgreen (1986) recognize the temporal significance of a land bridge between Stansbury Island and the mainland. Assuming that the lake was at 4212 ft (1283 m), as the Stansbury ooid age implies, humans could still walk across the shallow expanse to the island (Jameson, 1958).

C-2

Isotopic and Palynologic Site Descriptions

Cresent Springs (17), Great Salt Lake core (45), and Core site I (46)

Studies by Grey and Bennett (1972) estimate lake level fluctuations using isotopic data gathered at localities (17) and (45). Grey and Bennett (1972) report carbon and oxygen-isotope values from a core taken at Cresent Springs (17). This spring is located near the salt flats below the Hogup Cave at an altitude of approximately 4252 ft (1296 m). Oolitic sand is found at the bottom of the core 12.9 ft (4 m) from the surface and was age estimated at 25,000 yr old. Overlying the oolitic sands is a 6.5- ft (2-m) unit of silts and clays. Grey and Bennett (1972) interpret these silts and clays as deep water deposition associated with Late Wisconsin glaciation. An organic marsh deposit unconformably overlies the silts and clays, and is estimated at 4500 yr B.P. The author believes that the silts and clays were Lake Bonneville sediments and that the marsh deposit is a product of a lacustrine-free environment. Grey and Bennett's (1972) assessment of a core from the lake bottom, about 5 mi north of Bird Island (locality 45), indicates a general trend towards desiccation after the deposition of the Mazama ash (6900) to 4000 yr ago. Ross (1973) and Rudy (1973) infer that, from 7500 to 4000 yr ago, the area was dry with little or no inundation of the Great Salt Lake Desert.

McKenzie and Eberli (1987) utilized carbonate content and mineralogy as well as oxygen-isotope stratigraphies in their assessment of mid-Holocene lake fluctuations from an offshore locality west of Antelope Island (46). The appearance of authigenic dolomite above the Mazama ash layer at 1.83 m to 4.38 m, led McKenzie and Eberli to concur with Currey and James' (1982) mid-Holocene playa stage from 7000 to 5500 yr B.P. According to McKenzie and Eberli (1987) a cooling period and a higher lake level is thought to have begun about 5000 yr ago. A xeric period is believed to have followed the cooler period and lasted well past 4000 yr ago. This chronology is based on a very approximate estimation of the time that authigenic dolomite appeared (5500 yr B.P.), but very little evidence to the contrary exists from this period.

Mehringer (1985, 1986) has correlated ratios of halophytes and shadscale to sagebrush and conifer pollen, indicating lake level trends by vegetation changes. By 7000 yr ago pollen sequences indicate a warming trend in the eastern Great Basin. After 7000 yr B.P., pollen ratios at Cresent Springs (17) and Great Salt Lake (45), indicate that relatively low effective moisture produced shrinking lakes, expanding shadscale and sagebrush communities, and the reduction of grasslands and forests (Mehringer, 1985). Silty sediment, probably derived from both accelerated eolian and slopewash activity, overlying the Mazama ash at Jukebox trench (20) seems to support this conclusion. Mehringer (1985, p. 179) does however illustrate that the warming trend had slowed by 5400 yr ago and even reversed by 4000 yr ago.

Summary

Little radiometric, geomorphic, or anthropologic data exists from the period between 8000 to 4000 yr ago, as compared to the previous 4000 yr interval. Much of the inferrential information, such as isotopic and palynologic data, must therefore be correlated to the meager stratigraphic and geomorphic data reviewed in this chapter. It has been demonstrated that xeric conditions were prevailent during the latter half of this period (Morrison, 1966; Currey and James, 1982; Mehringer, 1985, 1986). These xeric conditions would have produced lake levels that ranged from slightly above or well below the historic mean of 4200 ft (1280.8 m) (McKenzie and Eberli, 1987). Geomorphic lake level features are not prominent, which suggests that they were poorly developed, reworked, obliterated, or submerged by later Holocene fluctuations. Figure 25 summarizes the 4000 yr lake level chronology discussed in this chapter.

It is apparent that the warming trend from 9000 to 8000 yr ago continued, lowering the lake level at least 15 ft (4.5 m), well into the period around 7700 yr ago. The lake

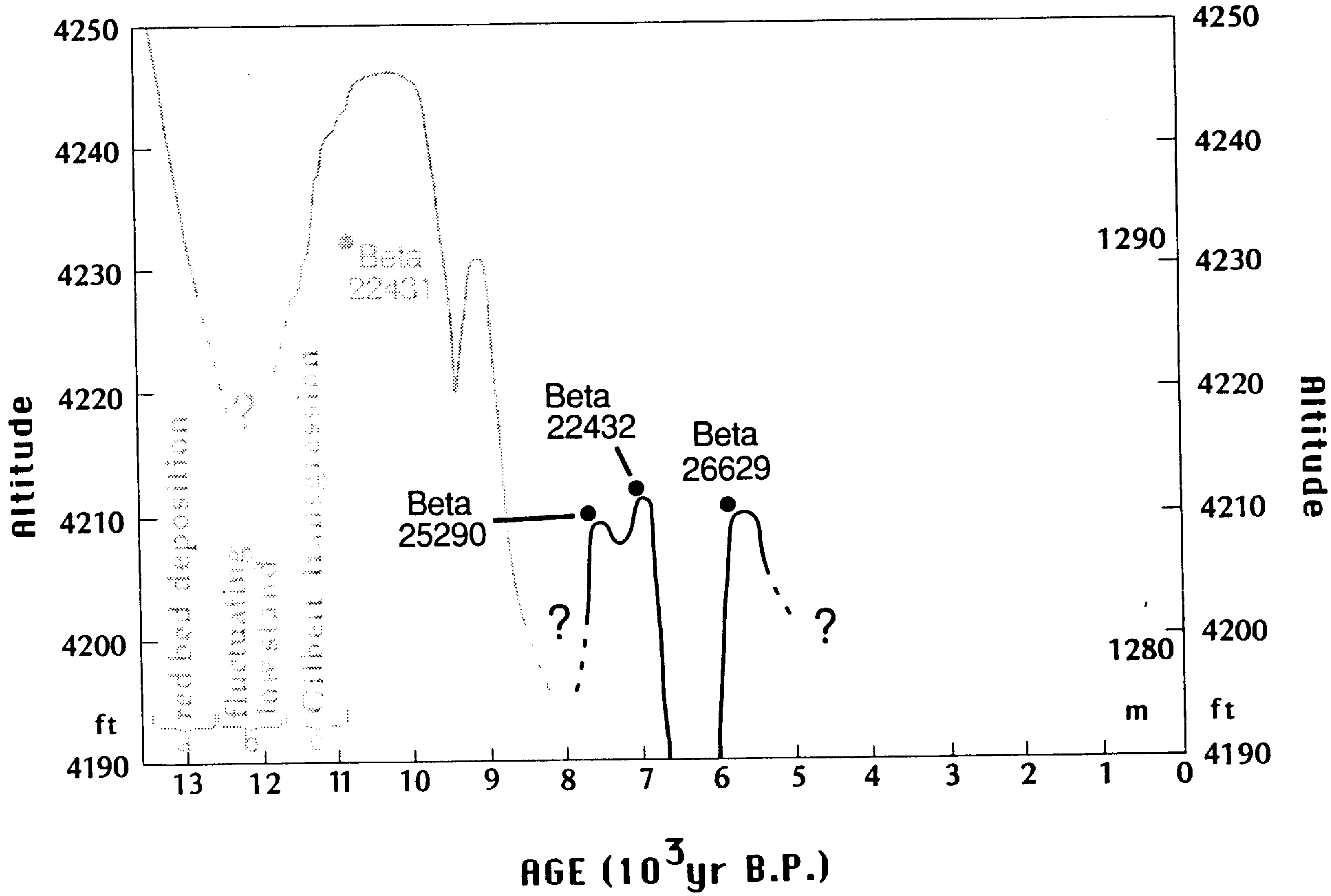


Figure 25. Fluctuation hydrograph (8,000 to 4,000 yr B.P.)

is thought to have risen to 4210 ft (1283.2 m) 7650 ± 90 yr B.P. (Beta-25290) depositing a back bar or barrier marsh sediment at Seagull Point. This organic material (Beta-25290) is overlain by oxidized coarse sand, inferring subaerial exposure after deposition. The lake probably regressed to an unknown level shortly thereafter. Radiocarbon age estimates of 7260 ± 130 yr B.P. (Beta-23353) and 7070 ± 100 yr B.P. (Beta-22432) indicate a possible small lake rise to between 4212 ft (1284.1 m) and 4213 ft (1284.1 m) that were buried by sediment during later Holocene transgressions.

After this small lake rise immediatly prior to 7000 yr ago, the lake lowered sufficiently to produce networks of polygon fissures as low as 4180 ft (1274.1 m) (Currey, 1980). The data summarized here indicate these fissures probably formed between 6900 to 6000 yr ago. It is uncertain whether the lake actually desiccated completely, because no conclusive evidence of total desiccation has been demonstrated.

Currey and James (1982) suggest that Great Salt Lake reached a level higher than 4200 ft (1280.2 m) about 6000 yr ago, based on stratigraphy from a core. The lake began to rise slightly to a 4211 ft (1283.5 m) level around 5890 ± 120 yr B.P. (Beta 26629), based on the radiocarbon age estimate at Seagull Point. This organic sample is overlain by a clean medium sand, indicating eolian conditions after initial deposition. This feature implies that the lake regressed after 5800 yr ago (Mehringer, 1985) to at least as low as the 4200 ft (1280.1 m) mean and possibly significantly lower.

McKenzie and Eberli (1987) speculate that a dry climatic period followed this short transgression of 5890 yr ago. Although the author can offer no insights between 5890 and 4000 yr ago, it is thought that the warming trend continued until 4000 yr B.P.

CHAPTER 4

LATE HOLOCENE TO PRESENT (4000 YR B.P. TO PRESENT)

Introduction

Previous Concepts

The last 4000 yrs of Great Salt Lake fluctuations are deducible at a higher resolution, due to fresher geomorphic exposures, more abundant archeologic sites, and correlative pollen and isotopic data. This period is thought to have been under xeric conditions between 4000 and 3500 yr ago (Antevs, 1948, 1955; Currey and James, 1982; Ross, 1973; Rudy, 1973; Mehringer, 1985; McKenzie and Eberli, 1985, 1986).

Many names have been attached to the rebirth of lakes and glaciers during an increased effective moisture stage at the end of the xeric conditions. This rebirth is referred to by Antevs (1948) as the Medithermal, while Currey and James (1982) prefer the terms Neopluvial and Neolacustral. This moister period probably began shortly after 3,500 years ago (Grey and Bennett, 1972; Mehringer, 1985; McKenzie and Eberli, 1987). After the initial lake rise to the pluvial late Holocene High of 4221 ft (1286.5 m) (Currey et al., 1988b), the level of the lake has fluctuated between the highest "Little Ice Age" level of 4217 ft (1285.2 m) and the known lowest level of 4191 ft (1277.3 m) (Madsen, 1982).

Author's Research Strategy

In most places, the late Holocene geomorphic features are associated with the late Pleistocene and early Holocene features discussed in Chapter 2. The strategy for this chapter mirrors the second chapter with added emphasis on archeologic, isotopic, and palynologic data. Radiocarbon age estimates for the late Holocene high are needed to help support the isotopic data.

Chapter Overview

The evidence obtained by the author suggests a mean lake level of 4200 ft (1280 m) or lower from 4000 yr B.P. until the late Holocene high of between 3400 and 1400 yr B.P. After a short drop the lake rose to 4217 ft (1285.7 m) between 400 and 300 yr B.P. In the mid to late 1700s, the lake had stabilized at 4214 ft (1284.4 m) forming two possible 4214 ft levels. After 1750 A.D. lake levels have remained near a mean level of 4200 ft (1280 m). Localities discussed in this chapter are shown on Figure 27.

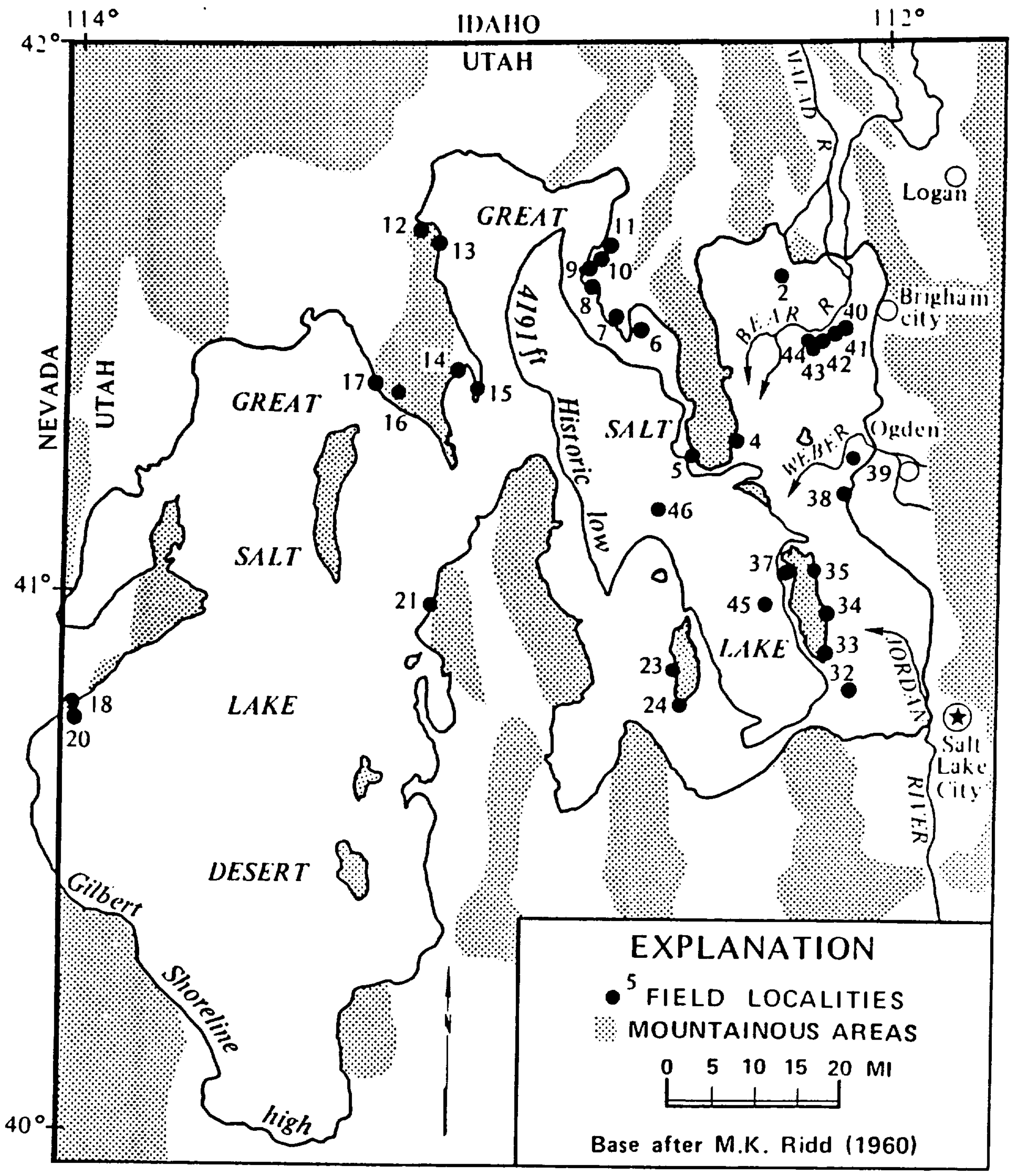


Figure 26. Map of localities mentioned for the period between 4000 yr B.P. and the present.

Geomorphic Site Descriptions

Mollys Stocking (2)

Mollys Stocking is a remnant birdfoot delta of Gilbert age (Currey et al., 1988b). Late Holocene beach strands were surveyed that range in elevation from 4222 to 4217 ft (1286.8 to 1285.3 m) along the periphery of Mollys Stocking (Table 14). These beach strands probably represent at least two lake rise episodes, although Atwood and Mabey (1988) contend ranges of this magnitude are not uncommon compared to their single year (1987) Great Salt Lake rise study.

Promontory East (4)

The author identified late Holocene beaches at this site to be hummocky ridges facing northeast. Six beach

Table 14. Measured beach ridge elevations at Mollys Stocking (2).

Traverse No. 1			
Beach site	1	4222.0 ft	(1286.7 m)
	2	4221.3 ft	(1286.5 m)
	3	4217.0 ft	(1285.3 m)
	4	4218.5 ft	(1285.7 m)
	5	4220.2 ft	(1286.2 m)
Traverse No. 2			
Beach site	6	4220.3 ft	(1286.2 m)
	7	4221.4 ft	(1286.5 m)
	8	4221.5 ft	(1286.6 m)
	9	4220.7 ft	(1286.3 m)
	10	4219.7 ft	(1286.0 m)
	11	4219.0 ft	(1285.8 m)

Source: Author's original data collected in 1987.

ridges (see Figure 8) with their surficial silt+clay percentages and altitudes are listed on Table 15. The beach ridges might have been formed during stillstands which may have been subjected to isostatic rebound during or just after deposition. Alternatively, Atwood and Mabey (1988) suggest that these fluctuating elevations are normal.

Promontory Point (5)

Silty ooid beach ridges were measured by the author at Promontory Point. Three ridges at altitudes 4222 ft (1287 m), 4218 ft (1285.8 m), and 4211 ft (1283.6 m) were the only late Holocene shore features at this site (Figure 27). Surficial sediment analysis in Table 16 is in sequential and

Table 15. Measured beach ridges at Promontory East (4).

Site	Alt.(ft)	% Gravel	% Sand	% Silt+clay
1 10cm	4225	6.9	83.0	9.9
30cm		66.5	31.9	1.4
2 10cm	4219	74.4	24.5	1.1
30cm		93.0	6.5	0.4
3 10cm	4221	49.3	49.4	1.3
30cm		40.5	58.5	0.3
4 10cm	4217	44.2	54.3	1.4
30cm		15.3	83.3	1.3
5 10cm	4214	43.6	55.1	1.4
30cm		55.2	44.8	0.0
6 10cm	4210	32.2	67.0	0.2
30cm		39.5	59.7	0.8

Source: Author's original data collected in 1988.

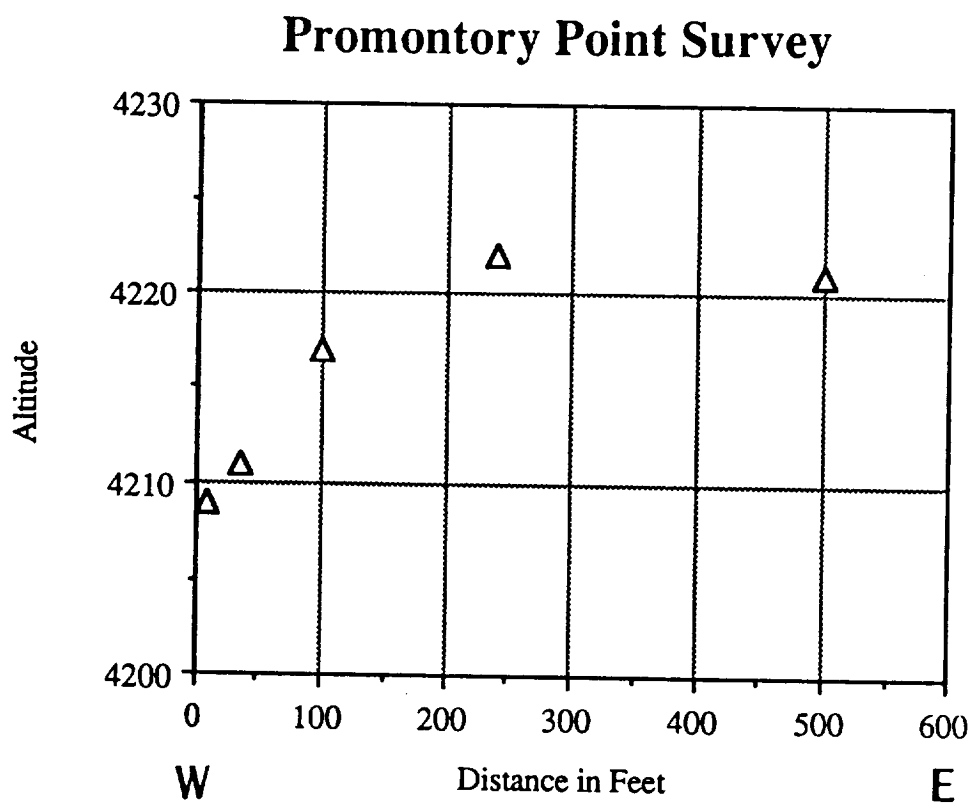


Figure 27. Profile of ridge sites at Promontory Point (5) locality; altitudes and distances are in feet.

altitudinal order. There is an abrupt descent between site 2 and site 3 that is void of accreted beach material. A beach, if formed at 4214 ft (1284.4 m), was probably eroded due to wave action or slope failure.

Rozel Point (6)

Holocene geomorphic features at Rozel Point were probably formed from ooids deposited in a longshore barrier beach and spit construction regime. Numerous berms were surveyed by the author as far inland as 2 miles (3.2 km) from the April 1988 (4208 ft, 1282.7 m) shoreline (Figure 28). The complex morphology of Rozel Flat is interpreted using surficial sediment analysis and the beach surveys. Surficial sediment analysis for beach ridges comprising the beach ridge complex (spit) closest to the lake on the west end of the dominant lakeward spit are shown in Table 17. Figure 29 shows the location of the transect at the Rozel

Table 16. Measured beach ridges at Promontory Point (5).

Site	Alt(ft.)	% Gravel	% Sand	% Silt+clay
1 10cm	4222	0.0	93.1	6.89
30cm		5.1	93.0	1.81
2 10cm	4218	11.3	82.9	5.78
30cm		10.4	88.1	1.45
3 10cm	4211	4.7	94.1	1.31
30cm		0.0	98.5	1.51

Source: Author's original data collected in 1988.

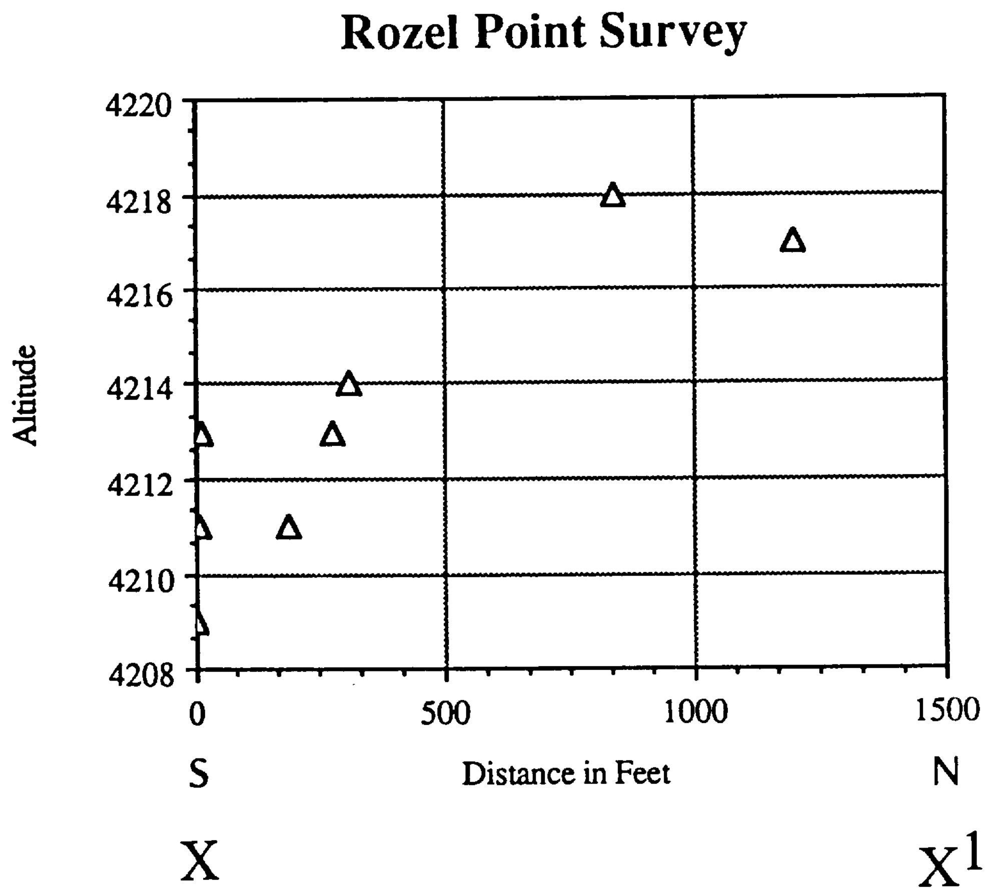
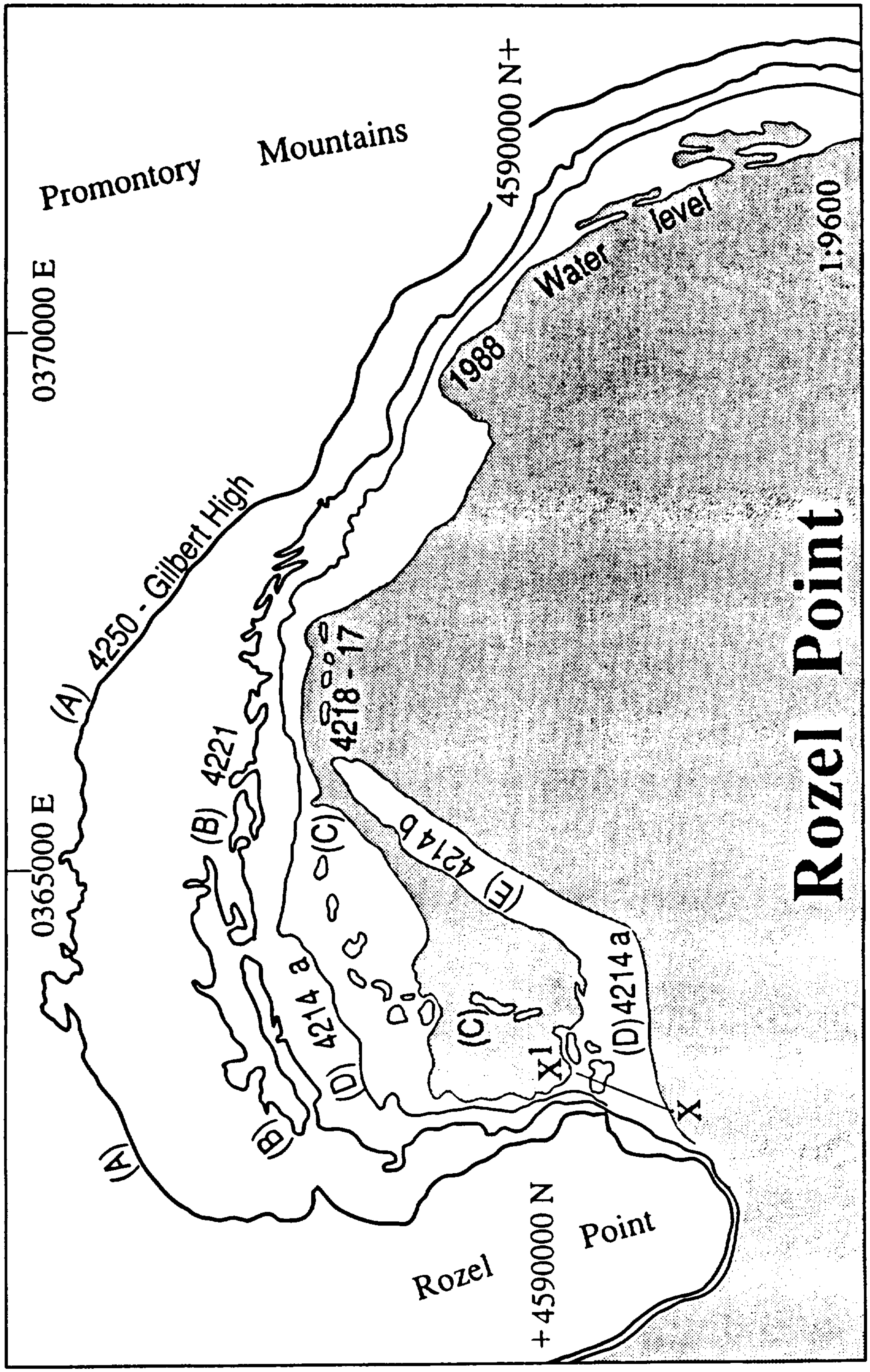


Figure 28. Profile of Rozel Point (6) locality; altitudes and distances are in feet. The line from X to X1 shows the location of the transect on Figure 29.

Figure 29. Map of Rozel Point showing the 4250 ft Gilbert high shoreline (A), late Holocene high stand of 4221 ft (B), late Holocene 4217 ft level (C), late Holocene 4214 ft levels (D) and the later (E). The X - X1 transect is shown on Figure 28.



Promontory
Mountains
0370000 E
0365000 E
4590000 N+
(A) 4250 - Gilbert High
(A)
(B) 4221
(B)
(C) 4218 - 17
(C)
(C)
(E) 4214 b
(D) 4214 a
(D) 4214 a
1988 Water level
1:9600
X
X'
+4590000 N
Rozel Point
Rozel Point

Point locality.

A major barrier bar with a crest of 4223 ft (1287.1 m) stretches across Rozel Flat at about 4593000 N (Figure 29, B). This late Holocene high berm is composed of medium sand and is devoid of ooids. It has formed a back bar marsh and several small spits including zetaform curves (Davies, 1972). The next highest bar/spit morphometric couplet is expressed at the 4218-4217 ft (1285.6-1285.3 m) level (Figure 29, C). The spit that is east trending from the abutment of the Rozel Mountains, probably started to build

Table 17. Measured beach ridges at Rozel Point (6).

Site	Alt.(ft)	% Gravel	% Sand	% Silt+clay
1 10cm	4221	0.0	77.7	22.3
2 10cm	4218	0.0	93.1	6.9
3 10cm	4217	0.0	92.6	7.4
30cm		0.0	99.5	0.5
4 10cm	4213	0.0	99.6	0.4
30cm		0.0	97.9	2.1
5 10cm	4211	3.2	95.6	1.2
6 10cm	4210	1.1	97.5	1.3
7 10cm	4213	0.0	100.0	0.0
8 30cm	4212	0.0	99.0	1.0
9 10cm	4211	0.0	100.0	0.0

Source: Author's original data collected in 1988.

during this episode. There seem to be two beach building events near the 4214 ft (1284.4 m) level (Figure 29, D and E). The Rozel Mountains spit was extended eastward due tolongshore currents, based on an ooid spit crest at 4213 ft (1284.1 m) (Figure 29, D). The second 4214 ft (1284.4 m) lake level fluctuation probably redirected the Rozel Mountain spit (Figure 29, E) northeastward. Portions of the 4218-4217 ft (1285.6-1285.3 m) (Figure 29, C) bar were breached by lake current possibly during these two 4214 ft (1284.4 n) lake levels. Two more late Holocene ooid berm crests are found at altitudes of 4212 ft (1283.6 m) and 4210 ft (1283.3 m).

Ross (1973) reports ooid berms between 4207 ft (1282.2 m) and 4205 ft (1281.5 m) and a large spit with a 4205 ft (1281.5 m) crest, which are now under water. This low spit extends eastward from Rozel Point, supporting the previous spit formation theories at this locality.

Horseshoe Bay (7)

This sheltered bay contains geomorphic features produced by longshore currents. The crest of the highest Holocene barrier, which spans the entire bay, is reported by Ross (1973) at 4223 ft (1287.1 m). A terrace below the baymouth crest at 4219 ft (1285.9 m) is prominant throughout the site, but is breached by an ephemeral stream. Ross (1973) also reported ooid berms at 4208 ft (1282.6 m) and 4202 ft (1280.6 m) with a low driftwood storm beach at a 4201 ft (1280.3 m) elevation.

Coyote Bay (8)

Ross (1973) reports two Holocene bars with associated marshes at elevations of 4225 ft (1287.7 m) and 4223 ft (1287.1 m). An ooid berm at 4214 ft (1284.4 m) is the next highest lake feature. Two younger ooid berms at 4211 ft (1283.5 m) and 4206 ft (1281.9 m) are reported by Ross (1973) as historic beaches.

Desolation Bay (9)

Ross (1973) reports a Holocene baymouth ridge crest at 4223 ft (1287.1 m) and a wave cut terrace at 4220 ft (1286.2 m). Partially vegetated ooid berms are reported at 4209 ft (1282.9 m) and 4207 ft (1282.3 m).

Black Mountain Bay (10)

Black Mountain Bay has a berm crest at 4224 ft (1287.4 m) and a smaller berm at 4219 ft (1285.9 m) (Ross, 1973). Below these berms, dunal activity has been the predominant beach building process. The oldest Holocene dune is found at 4214 ft (1284.4 m) and is intersected by the historic high (1873 A.D.) stand of 4212 ft (1283.8 m). The youngest foredune has a crest of 4208 ft (1282.6 m).

Windmill Bay (11)

Holocene age beach berms at Windmill Bay are hummocky mounds due in part to the gentle slope of this wide bay (Figure 9). The highest berm identified by the author has a crest of 4223 ft (1287.2 m). The next berm is approximately

2,000 ft (609.5 m) lakeward and has a crest altitude of 4218 ft (1285.6 m). Two ooid berms at 4214 ft (1284.5 m) and 4214 ft (1284.4 m) are located within 130 ft of each other and 160 and 30 ft (48.7 and 9.1 m) respectively, from the lake margin. The last berm, 10 ft (3 m) inland from the 1988 water level of 4208 ft (1282.7 m), has a crest altitude of 4211 ft (1283.6 m). Surficial sediment analysis, in Table 18, is in sequential and altitudinal order. The two berms at 4214 ft (1284.4 m) seem to be of different beach building events based on texture.

<u>Peplin Bar</u> (12)

The first and only discernible beach berm reported by Rudy (1973) is located at 4222 ft (1286.8 m) and is

Table 18. Measured beach ridges at Windmill Bay (11).

Site	Alt.(ft)	% Gravel	% Sand	% Silt+clay
1 10cm	4223	4.4	81.7	13.7
30cm		14.5	75.4	9.9
1m		26.9	72.1	1.1
2 10cm	4218	0.0	94.6	5.4
30cm		0.0	98.4	1.2
3 10cm	4214	0.0	97.5	2.4
4 10cm	4214	0.0	99.1	0.9
5 10cm	4211	2.8	97.0	0.2

Source: Author's original data collected in 1988.

identified by a vegetation change of saltgrass. Only barren salt flats stand between this berm and the present lake margin.

Hogup Bar (13)

The only late Holocene lacustral feature Rudy (1973) found is a vegetation change from barren salt flat expanses to a saltgrass ecotone at 4223 ft (1287.1 m).

Big Wash Bar (14)

Rudy (1973) observed an ecotone between salt flats and grassy vegetation at 4223 ft (1287.1 m), as typified in the two previous sites.

Fingerpoint Spit (15)

Holocene beaches are well-exposed on the east side of Fingerpoint Spit. Rudy (1973) describes a vegetated hummock, with subsurface gravels, at 4223 ft (1287.1 m) with a 3-ft (0.9-m) deep marshy depression behind. More recent investigations have measured the highest Holocene beaches at 4225 ft (1287.7 m) and 4226 ft (1287.9 m). Rudy measured a minor beach berm at 4219 ft (1285.9 m) with a small marshy depression toward the west. The next lowest sand and gravel berm Rudy encountered was observed at 4215 ft (1284.7 m) and is void of vegetation. Ooid beaches are dominant at the lower beach features. Rudy (1973) identified ooid beach berms at 4211 ft (1283.5 m), 4207 ft (1282.2 m), 4205 ft (1281.5 m), and 4201 ft (1280.3 m). The only Holocene geomorphic feature on the west side of the spit is the abrupt contact of the salt flats at 4205 ft (1281.5 m).

Juke Box Trench (20)

Clay-rich muds, sands, and calcareous silts overlie the post-Mazama tephra layer (see Figure 10). The first layer overlying the post-Mazama marsh is a calcareous mud with bioturbated silts and lithic clasts. It appears that a period of xeric conditions prevailed until the deposition of a 6 inch (15 cm) pinkish-gray mud. Another xeric period followed based on a 2.4 inch (6 cm) calcium carbonate cemented granular mud layer. Overlying this mud layer is a sandy unstratified clay-rich and friable muddy soil. It appears that this layer was weathered after deposition because of the platey structure of the muds. A final 2-in (5-cm) peaty layer overlies the previous stratum with an age estimate of 1310 ± 230 yr B.P. (Beta-23645, ^{13}C adjustment unknown). This peaty organic layer is interpreted as a marsh layer fed from upslope mountain drainage at the end of a high moisture regime.

Grassy Mountain dunes (21)

Currey (1987) reports Holocene hydroeolian planation west of the Grassy Mountains. The dunes were deposited by materials from older desiccated surfaces, probably during the Altithermal. Currey (1987) believes that lake rise water basally eroded the dunes, leaving behind a record of late Holocene lacustral activity. Currey (1987) identified levels at 4221 ft (1286.7 m) and 4217 ft (1285.2 m).

Stansbury Island (23,24)

Two sites on the western (23) and southern (24) margins were analyzed by the author for Holocene beach features. Geomorphic features such as spits, lagoons, and berms have been identified. A spit, with a crest of 4223 ft (1287.1 m), is composed of forset beds dipping at 23 degrees and has a maximum limiting date of 7070 ± 100 yr B.P. (+4.7 0/00 ^{13}C; Beta-22432) (Figure 24). On the western side of the spit are ooid berms at 4219 ft (1285.9 m), 4214 ft (1284.4 m), and 4211 ft (1283.5 m). On the southern tip of Stansbury Island (24), ooid and gravel beach berms are found at altitudes of 4222 ft (1286.8 m), 4219 ft (1285.9 m), 4214 ft (1284.4 m), and 4211 ft (1283.5 m). The highest 4222 ft (1286.8 m) berm has a large enclosed lagoon to the north that may have formed by the connection of two southern spits. Data reported by Rudy (1973) from locality (24) document berms at 4219 ft (1285.9 m) and 4211 ft (1283.5 m), a driftwood beach at 4208-4207 ft (1282.6-1282.2 m), and a minor beach at 4205 ft (1281.5 m).

Jordan River paleodelta II (32)

The late Holocene Jordan River paleodelta was inundated by a static water level of 4221 ft (1286.6 m) seen just west of Baileys Lake on the Saltair quadrangle (Currey et al., 1988b). The highest levees were isolated in a mini-birdfoot delta shape about 3000 ft (914.3 m) from the main channel (Figure 13). The Jordan river probably began to flow northward emptying into the area now occupied by the Salt

Lake International Airport and various duck clubs. The subsequent meandering of the Jordan River eastward to its present position, is thought to have been caused by isostatic rebound and/or block faulting at the base of the Wasatch mountains.

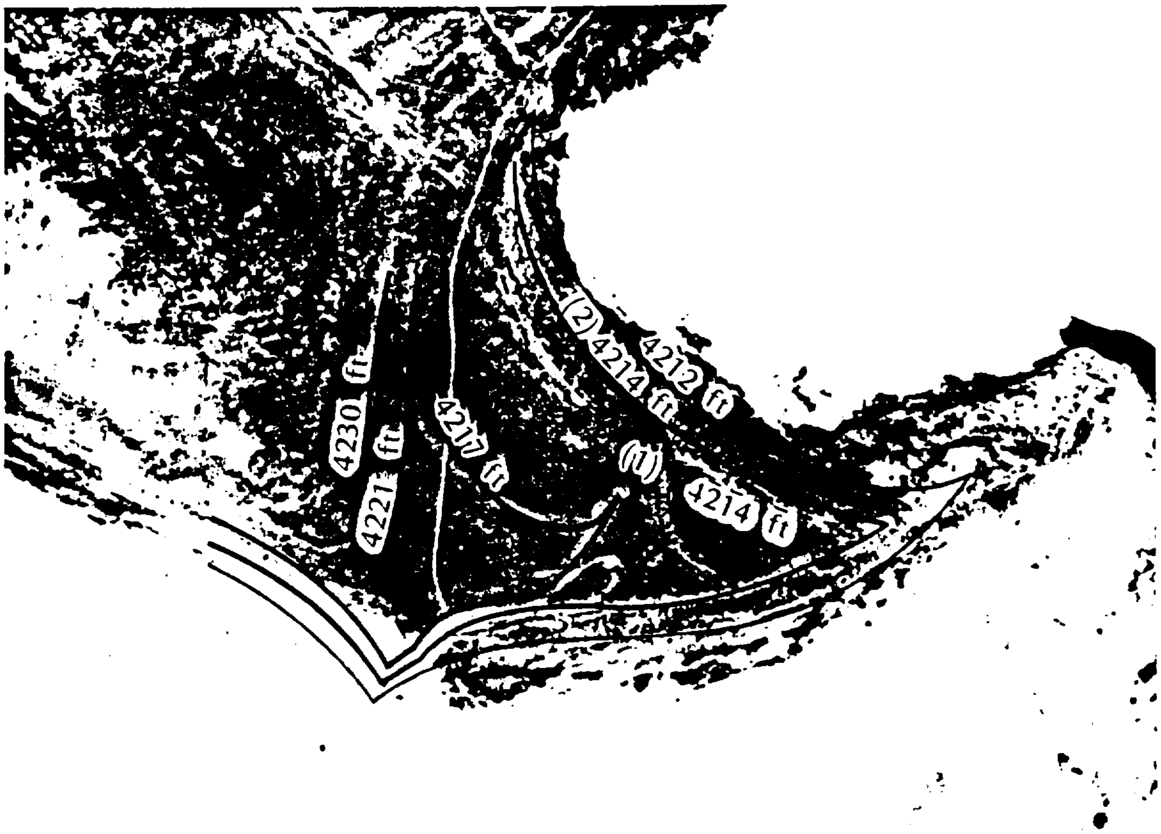
Unicorn Point (33)

Late Holocene beaches and spits are manifest in the shape of a unicorn's head at this southern Antelope Island locality. The author found prominent beach berms at 4223 ft (1287.1 m), 4217 ft (1285.3 m), 4214 ft (1284.5 m), 4214 ft (1284.4 m), and 4212 ft (1283.7 m). To reconstruct the beach building events, 50 survey points and corresponding elevations were recorded from a Gilbert shoreline bluff.

The survey and subsequent analysis of elevations revealed four to possibly five major events leading to the geomorphic expression seen today. The first late Holocene berm was deposited at an elevation of 4223 ft (1287.1 m) (Figure 30). This event is recorded by a beach berm that ranges from 4223 to 4219 ft (1287.3 to 1285.9 m). This lacustral event maintained the Gilbert age beach profile with no apparent spit development.

The next highest berm is found at 4217 ft (1284.5 m) and is composed of pebbles and ooids. This beach-building event was responsible for the first small spit development and possibly a small back lagoon (refer to Figure 30). The two 4214-ft (1284.5 and 1284.4-m) berms seem to have been

UNICORN POINT
SURVEYED BEACH RIDGES



SCALE APPROX. 1:48,000

Figure 30. Unicorn Point (33) surveyed beach ridges.

deposited at different times. The highest berms (1) added beach sediments (ooids) on the southeast shore while curving the previous spit tip toward the northwest, probably forming the unicorn's horn, much like King and McCullaghs' (1971) simulation model of spit recurvature. The next 4214 ft (1284.4 m) shoreline (2) encapsulated the older features with cobble and gravel beaches that can be seen today. This last depositional event is thought to be the last major lake rise of the 1700s. The high water debris line of 1987 (4212 ft or 1283.7 m) can be seen as a small ridge of gravel and debris hummocks.

<u>Seagull Point</u> (34)

Marsh sediment from a lagoon located 4 in (10 cm) above the 5890 ± 120 yr B.P. (Beta-26629) marsh sediment, indicates that the next identifiable lake rise at this site took place about 3450 ± 250 yr B.P. (-25.5 0/00 ^{13}C; Beta-25289) (see Figure 24). The sample (1.735 gm of humate extract) was dug from a 8 in (20 cm) thick wedge shaped bed exposed in a vertical beach bluff. This marshy sediment is probably the precursor and maximum limiting date of the lake rise to the 4221 ft (1286.5 m) static water level. The beach depositional evidence that suggests this lake rise episode is a cemented gravel layer at 4219 ft (1285.9 m) farther north and west in the exposure (Figure 19). A 4221 ft (1286.5 m) grassy berm can be identified on the surface of the Seagull Point, south of the exposed bluff.

Camera Flats (35)

A depression behind the 4221 ft (1286.5 m) berm is thought to be a washover marsh from the late Holocene high. A sample (1.92 gm of humate extract) was taken from a 16 in (40 cm) deep pit below the modern soil and vegetation. A Accelerator Mass Spectrometer age estimate of 1400 ± 75 yr B.P. (Beta-25580 and AMS ETH-3999, ^{13}C adjustment by Beta Analytic Inc.) was reported for this organic sample and is a minimum limiting date for the Late Holocene high.

White Rock Bay (37)

The author identified predominantly oolite dunes near the lower beach ridges from 4219 ft (1285.9 m) to just above the recent ooid and pebble beach at 4212 ft (1283.7 m). The dunes are partially stabilized by vegetation that grades into non-vegetated sand at lower altitudes. Ross (1973) reported ooid berms at 4207 ft (1282.2 m) and 4204 ft (1281.2 m).

Archeologic Site Descriptions

Danger Cave (18)

Jennings (1957) believes that human occupation at Danger Cave became cyclic or seasonal after 4000 yr B.P. This hypothesis is based on alternating bands of human debris and eolian deposits from the nearby salt flats. The Desert Culture is postulated to have either migrated out of the region, evolved into the Sevier/Fremont culture, or were absorbed into other unidentifiable cultures sometime around 1600 yr B.P. (Madsen, 1982). Sporadic human occupation continued by the Fremont culture at Danger Cave until about 1970 ± 240 yr B.P. (C-635, ^{13}C adjustment unknown) (Fry, 1976). More recent data by Madsen (written, comm., 1987) suggest that humans occupied Danger Cave until 330 ± 200 yr B.P. (Beta-23646, ^{13}C adjustment unknown).

Hogup Cave (16)

Aikens' (1970) Unit II ranges in time from 3200 ± 140 yr B.P. (GaK-1564) to 1530 ± 80 yr B.P. (GaK-1561) (^{13}C adjustments unknown). This period is marked by a greater reliance on big game hunting (mostly pronghorn), indicating an absence of marshland conditions west of the cave. Plant macrofossils, seeds in human coprolites, as well as population estimates seem to dwindle during this period. Aikens (1970) believes that these changes are a result of drying lake bed, even though an increase in sagebrush indicates more abundant moisture. It is now believed that the reverse occurred (Madsen, 1982). That these same changes could result from higher lake levels both forcing the inhabitants to search elsewhere for big game and shift from plant foods to meat. Ross (1973) supports higher lake levels by inferring shallow lake coverage of the salt flats from 4000 to 1800 yr B.P. from Hogup Cave inhabitants' diets.

Unit III spans from 1530 ± 80 yr B.P. (GaK-1561) to 620 ± 70 yr B.P. (GaK-2080) (^{13}C adjustments unknown) (Aikens, 1970). It is during this timespan that the Fremont culture is thought to have emerged (Madsen, 1982). Based on artifact counts, there seems to be a large increase of occupation at Hogup during this period. A sharp increase in hunting of big game herbivores implies a grassland cover west of the cave (Aikens, 1970; Ross, 1973).

Unit IV is believed to range from 480 ± 80 yr B.P. (GaK-1566, ^{13}C adjustment unknown) to A.D. 1850 (Aikens, 1970; Jennings, 1978). The occupation of Hogup Cave during this time span seems to have returned to a seasonal hunter-gather site by a culture known as the Shoshoni. Ross (1973) attributes this seasonal occupation by Shoshoni hunting parties to a dry desert with no lake inundation in the area. Aikens (1970) believes that these seasonal groups probably had some ties with horticultural settlements living near the eastern shore of Great Salt Lake.

Injun Creek (39)

Aikens (1966) documents a year around occupation site of horticulturist-hunters near Injun Creek. This Fremont lakeshore site lies at an altitude of between 4210 and 4205 ft (1283.2 and 1281.5 m) near the Weber River delta. Two radiocarbon age estimates of 585 ± 90 yr B.P. (GX-553) and 345 ± 100 yr B.P. (GX-552) (^{13}C adjustments unknown) from fire hearths imply permanent occupation until 345 yr B.P. It is believed that the lake transgressed over this site about 1600 A.D., based on an undated black sandy humus layer overlying the cultural remains.

Bear River 1 (40)

Lying at approximately 4210 ft (1282.2 m), Bear River 1 was probably a seasonal camp (Aikens, 1966). It is theorized that the ordinarily horticulturist Fremont peoples followed migrating herbivores and waterfowl to the edge of the lake. Due to the large amount of skeletal material found, this site was judged to be a butchering station (Aikens, 1966). A radiocarbon age estimate of 1065 ± 120 yr B.P. (unknown lab no. and ^{13}C adjustment) on a Bison bison scapula infers the time period of this site.

Bear River 2 (41)

This archeological site lies at an altitude of 4210 ft (1283.2 m), 1 mi (1.6 km) to the west of Bear River 1. Aikens (1967) suggests that this Fremont camp was a temporary station with repeated seasonal occupation. Aikens (1967) and Currey and James (1982) present evidence for a Great Salt Lake shoreline 2 ft (.6 m) below the slightly elevated site area. A piece of charcoal gives an age for this site of 995 ± 105 yr B.P. (GXO-732; ^{13}C adjustment unknown).

Bear River 3 (42)

Bear River 3 is similar to the previous Bear River sites except for the presence of storage and dwelling structures. This site is located farther southwest from Bear River 1, at an elevation of 4210 ft (1283.2 m). Shields and Dalley (1968), Jennings (1978), and Currey and

James (1982) mention a postoccupational flooding of the site by a 4211 ft (1283.5 m) or higher stillstand. The sediment that flooded this area is a gastropod-rich sand containing Lymnaea shells. Currey and James (1982) suggest that early low-lying cultivated land was also flooded, possibly by the rise of 1924. A radiocarbon estimate gives an occupational age of 1450 ± 110 yr B.P. (GaK-1562; ^{13}C adjustment unknown) for this site.

Knoll Site (43)

The Knoll site rests on an older sand bar which is overlain by a clay layer of 1 to 2 ft (0.3 to 0.6 m). The site is located at an elevation of 4220 ft (1286.5 m). A radiocarbon age determination of 640 ± 110 yr B.P. (RL-19; ^{13}C adjustment unknown) was obtained from a piece of charcoal from a fire hearth (Fry and Dalley, 1979). No other lacustrine sediment has been deposited at this site since 640 ± 110 yr B.P.

Levee Site (44)

The levee site is actually two sites separated by a ground distance of 300 yds (274 m) (Fry and Dalley, 1979). These sites lie at an altitude of 4210 ft (1283.2 m) along the bank of an abandoned channel of the Bear River. Several dwellings and trash/storage pits were excavated. Radiocarbon ages from fire hearths suggest two different phases of occupation. The first phase is contemporary with the Bear River sites. Two of these early age estimates are 1170

± 140 yr B.P. (RL-34) and 1250 ± 140 yr B.P. (RL-35) (^{13}C adjustments unknown). The second phase or Levee phase, which includes the Knoll site, has age determinations of 860 ± 110 yr B.P. (RL-20), 810 ± 120 yr B.P. (RL-21), and 710 ± 100 yr B.P. (RL-33) (^{13}C adjustments unknown) (Fry and Dalley, 1979).

Isotopic and Palynologic Site Descriptions

Cresent Springs (17), Great Salt Lake core (45), and Core site I (46)

Grey and Bennett (1972) report three small clay bands that were deposited on marshy organic materials around 2700 yr ago at Cresent Springs (17). They interpret these clay deposits as short term lake rises above the 4252 ft (1295.9 m) springs. It does not seem likely for any late Holocene lake inundations to have deposited the clay bands at that extremely high altitude. These clay bands are probably due to erosional runoff deposition from higher pre-Holocene clay formations. Their 7000-yr qualitative record of lake volume, from a core 5 mi north of Bird Island (45), indicates a lake rise trend beginning about 3500 yr B.P. The lake rise reaches a peak some 2000 yr later, then begins to lower (Figure 5c).

McKenzie and Eberli's (1985, 1987) age calibrations from oxygen isotope and carbonate stratigraphies at locality (46) suggest a "neolacustrine minimum episode" beginning around 4000 yr B.P. and lasting until 3000 yr B.P. A change from the dominant authigenic carbonate aragonite, to calcite, led McKenzie and Eberli (1985, 1987) to propose a maximum lacustrine episode that reached 4215 ft (1284.7 m) from 3000 to 1500 yr B.P. Currey et al. (1988a) recognized this predicted high as only being 6 ft (1.9 m) too low. After 1400 yr B.P., McKenzie and Eberli's data show a period of lower lake levels followed by another maximum episode from 600 yr B.P. to present (Figure 5a).

Pollen studies by Mehringer (1985) at Cresent Springs (17) have produced a 4350-yr chronology of relative abundance of halophytes and shadscale to sagebrush (Figure 5b). A high level of halophytes and shadscale pollen is seen after 3000 yr B.P. until around 1800 yr B.P. The noted high ratio of halophytes and shadscale pollen around 600 yr ago suggests a very late Holocene lake rise. A Great Basin dendrochronology reconstruction, reported in Mehringer (1986), indicates that 1620 A.D. was a cooler than normal year.

Summary

No evidence has been found to suggest any static lake level above 4212 ft (1283.8 m) from 4000 to 3440 ± 250 yr B.P. Lake levels probably fluctuated around the historic mean of 4200 ft (1280 m) or below during this period as seen in Figure 30.

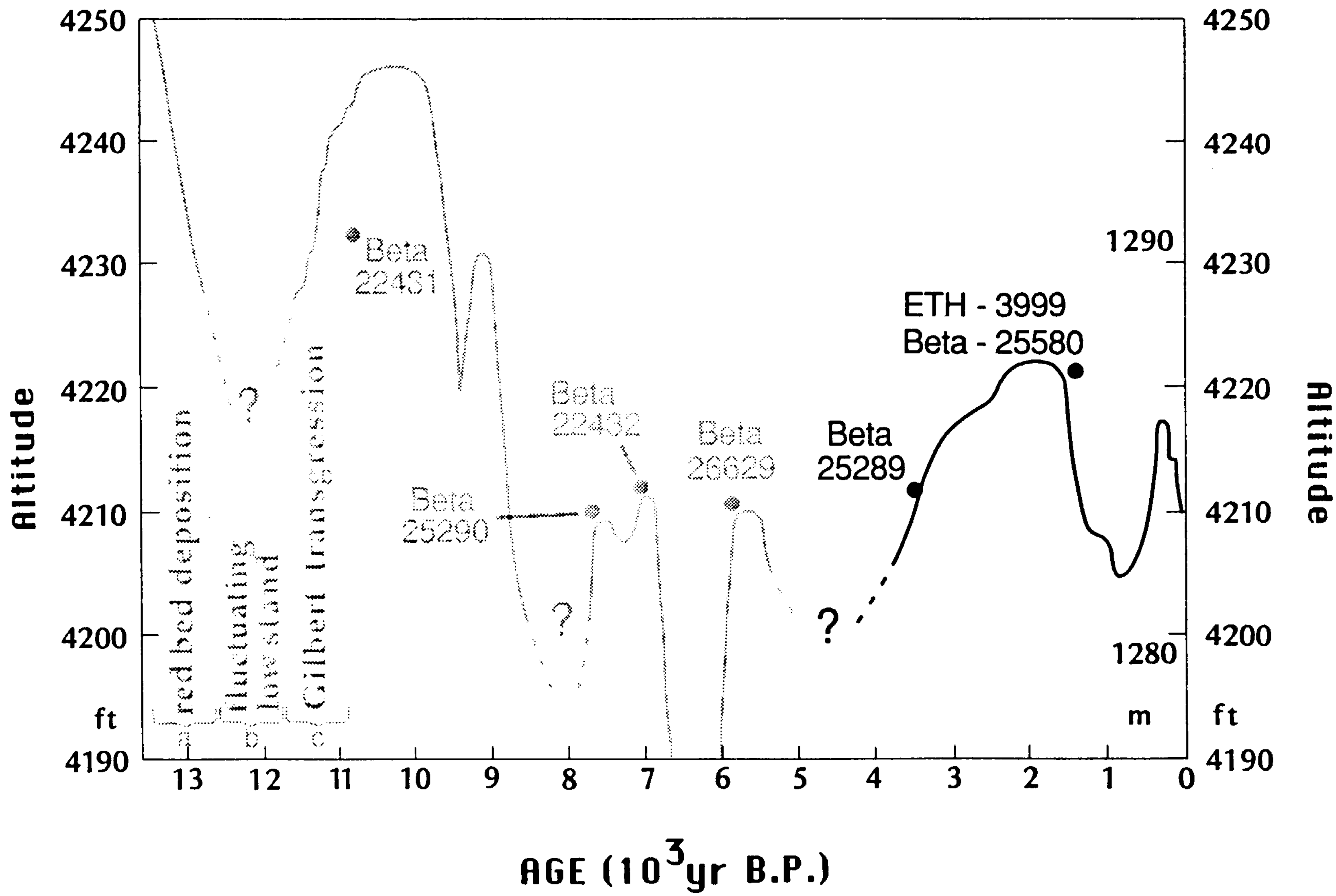


Figure 30. Fluctuation hydrograph (4,000 yr B.P. to present)

The late Holocene static lake levels discussed in this chapter are inferred to have come from different populations based on a Kruskal-Wallis anova test statistic of H = 10.42 at the .10 confidence level (Table 19). These levels of 4221 ft (1286.5 m), 4217 ft (1285.3 m), 4214 ft (1284.4 m), and 4211 ft (1283.5 m) are found at most of the geomorphic localities previously discussed (Figure 31).

The beginning of a neolacustrine lake rise is estimated to have begun near 3440 ± 250 yr B.P. (Beta-25289). This late Holocene high lake level probably regressed sometime near 1400 ± 75 yr B.P. (Beta-25580, ETH-3999). Isotopic, palynologic, and archeologic data support both the timing and altitude of this lake rise to an approximate static level of 4221 ft (1286.5 m). Geomorphic evidence of this water level is found at every site reported in this chapter (see Figure 31), with a complete suite of transgressive facies on Antelope Island (localities 34 and 35). Variance above the 4221 ft (1286.5 m) level is best explained by storm, seiche, and wind-blown wave deposition discussed by Currey (1987) and Atwood and Mabey (1988). Archeological site evidence suggests early humans had shifted to large game sustenance because previous marshland habitat ceased to be a productive food gathering endeavor.

The lake level is thought to have dropped from 4221 ft (1286.5 m) to just under 4210 ft (1283.2 m) between 1250 ± 140 yr B.P. (RL-35) and 1170 ± 140 yr B.P. (RL-34), based on radiocarbon estimates from the Levee site. This lake level,

Table 19. Textural Silt/clay percentages from Great Salt Lake localities. The numbers in the parenthesis are the overall rankings of the sample values.

Site	Holocene High	4217	4214	4211
5	.074 (30.3) .018 (22)	.061 (30) .015 (16.3)		.013 (11.5) .015 (16.3)
4	.110 (36.3) .014 (13.3)	.014 (13.3) .013 (11.5)	.014 (13.3)	.002 (1.5) .008 (6)
6	.287 (50)	.074 (30.3) .080 (35) .005 (3.5)	.004 (3) .021 (23)	.010 (9)
11	.110 (36.3) .011 (10)	.057 (29) .012 (11)	.024 (24) .009 (6.5)	.002 (1.5)
33	.202 (48) .017 (19.5)		.030 (25) .056 (28)	

* Numbers refer to localities listed on Table 1.
Source: Author's original data collected between 1987-1988.

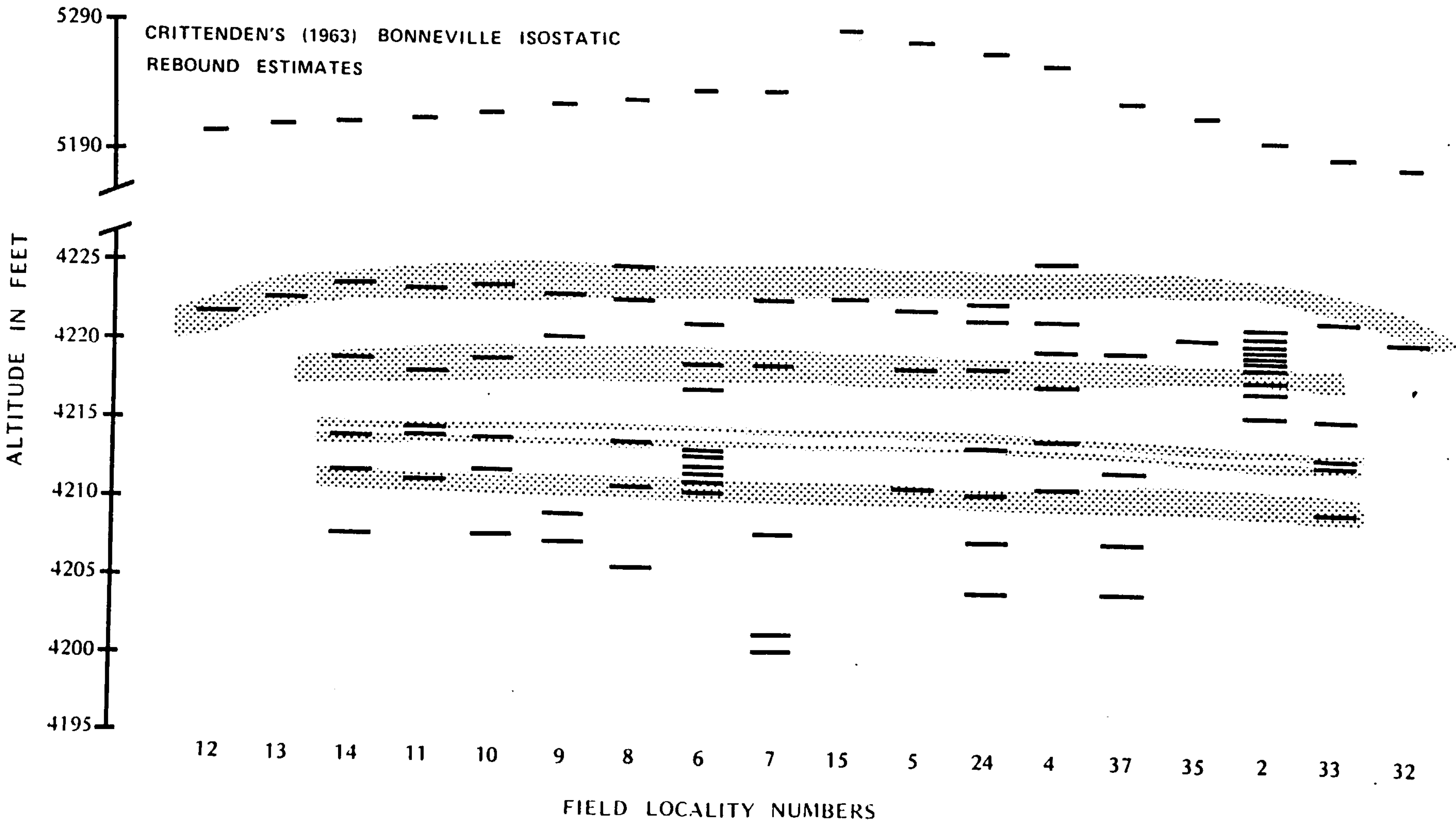


Figure 32. Surveyed beaches of late Holocene age compared to the Lake Bonneville isostatic rebound estimates of Crittenden; the numbers at the bottom refer to localities on Table 1 and tha stippling highlights major beaches.

fluctuating near 4210 ft (1283.2 m), is thought to have persisted for several years judging from an age estimate of 995 ± 105 yr B.P. (GXO-732) at the Bear River 2 site. A gradual lowering of lake levels to near 4205 ft (1281.6 m), during a second human occupational phase at the Levee and Injun Creek sites, occurred between 860 ± 110 yr B.P. (RL-20) and 345 ± 100 yr B.P. (GX-552).

A 4217 ft (1285.7 m) level, identified at Mollys Stocking, Promontory East, Promontory Point, Rozel Point, Windmill Bay, Grassy Mountain dunes, Stansbury Island, and Antelope Island localities, probably formed between 400 and 300 yr B.P. as suggested by Mehringer (1985). The Injun Creek and Bear River 3 sites are overlain by lacustrine sands and gastropod shells, probably by this lake rise. Currey and James (1982) suggest that a lake rise to a static level of 4217 ft (1285.2 m) would inundate the Great Salt Lake Desert, thus producing the lower geomorphic features best seen at Grassy Mountain dunes.

A late prehistoric lake rise of 4214 ft (1284.4 m) is estimated to have occurred as a dual beach-forming event, at the conclusion of the previous 4217 ft (1285.7 m) high. Beach crest elevations at Windmill bay, Rozel Point, and spit formations at Unicorn Point support this fluctuating stand at 4214 ft (1284.4 m) as do sediment analysis on silt+clay accumulations. McKenzie and Eberli's (1987) maximum-1 episode and gravity core graphs support this mid to late 1700's A.D. lake rise.

After circa 1750 A.D., lake levels have stabilized around a mean of 4200 ft (1280 m) as recorded by the hydrographs of Gilbert (1890) and Arnow (1984). Surveyed littoral beaches below altitudes of 4212 ft (1283.7 m) have been deposited between 1851 A.D. and the present (Mabey, 1986) (see Figure 1). A 4000-yr chronology of this period is shown in the hydrograph of Figure 30.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The Provo threshold-controlled shoreline stage reverted to closed-basin conditions after 14,200 yr B.P. (Currey and Burr, 1988). Much warmer climate probably influenced the continued regression from the post-Provo shoreline to well below 4220 ft (1286.2 m). Below levels of 4350 ft (1325.7 m), previously subaqueous and anoxic sediment was oxidizing then washing into the nearshore zones of the shrinking lake (Currey, pers. comm., 1989). These oxidized sediments, the pre-Gilbert red beds, conformably overlie Bonneville alloformation units around the Great Salt Lake basin. Spencer et al. (1984) suggest that the lake receded to a fluctuating level low enough to precipitate Glauber's salt at the deepest portions of the present lake sometime after 12,500 yr B.P. This low stand is probably responsible for oxidized sands overlying lacustrine sediments at Juke Box Cave; desiccation cracks, erosional relief, ostracod death assemblages, and desert pavement that overlie red beds at Little Mountain and West Public Shooting Grounds.

Sometime between 12,500 and 12,000 yr B.P., the lake began a fluctuating rise best shown by layers of nearshore sand inundating a deltaic marsh at West Public Shooting Grounds. This episode, the Gilbert transgression, continued to rise, depositing two major beach berms after 10,990 yr B.P., below the third and final high berm of approximately 4250 ft (1295.3 m) (Figure 33, in pocket). A post-Gilbert regression to a probable 4225 ft (1287.7 m) is thought to have occurred near 10,000 yr B.P. A minor lake rise to 4230 ft (1289.2 m) is believed to have occurred between 9730 and 9450 yr B.P.; followed by a period of lower lake levels.

The lake continued to lower during the beginning of the altithermal period. The level was probably near the historic mean (4200 ft or 1280.8 m) (Figure 34, in pocket) around 7650 yr B.P., when a minor transgression and regression left an organic deposit at 4210 ft (1283.2 m). Another minor rise to 4212 or 4213 ft (1283.7 or 1284.1 m) (Figure 35, in pocket) occurred between 7260 and 7070 yr B.P. Currey (1980) believes that the lake lowered to near dessication levels, sometime after 7000 yr B.P., based on polygonal fissures at very low lake depths around 4180 ft (1273.9 m). The lake began to rise to a 4211 ft (1283.5 m) level around 5890 yr B.P., based on an organic marsh sample at Seagull Point. After this lake rise event, climatic conditions were becoming favorable for lower lake levels.

The dry period continued until about 3400 yr B.P. A lake rise began near 3440 yr B.P. and lasted until just after 1400 yr B.P., based on radiocarbon samples from Antelope Island. This rise left several beach features at a

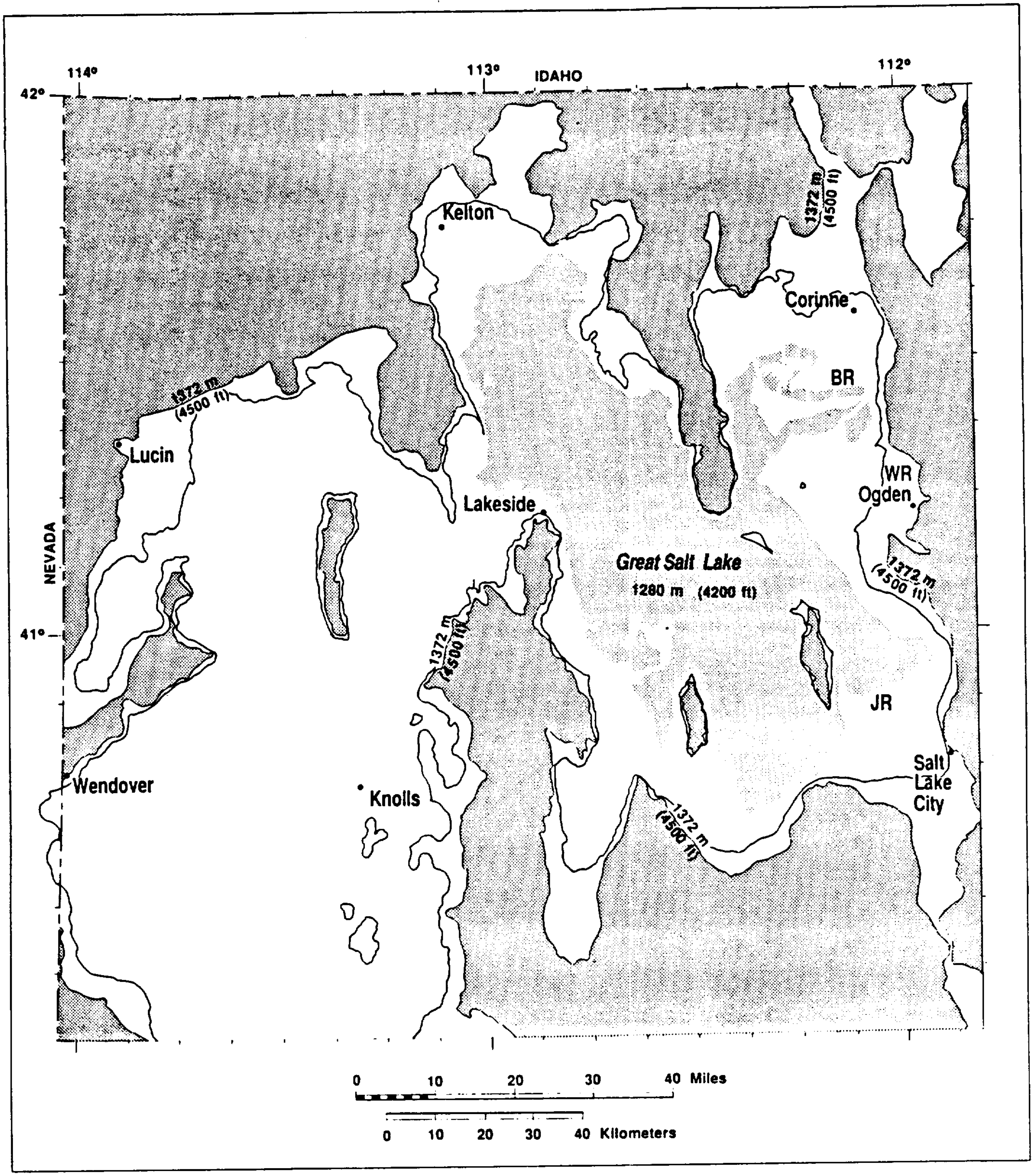


Figure 33. Map of the late Pleistocene Gilbert 4250 foot level.

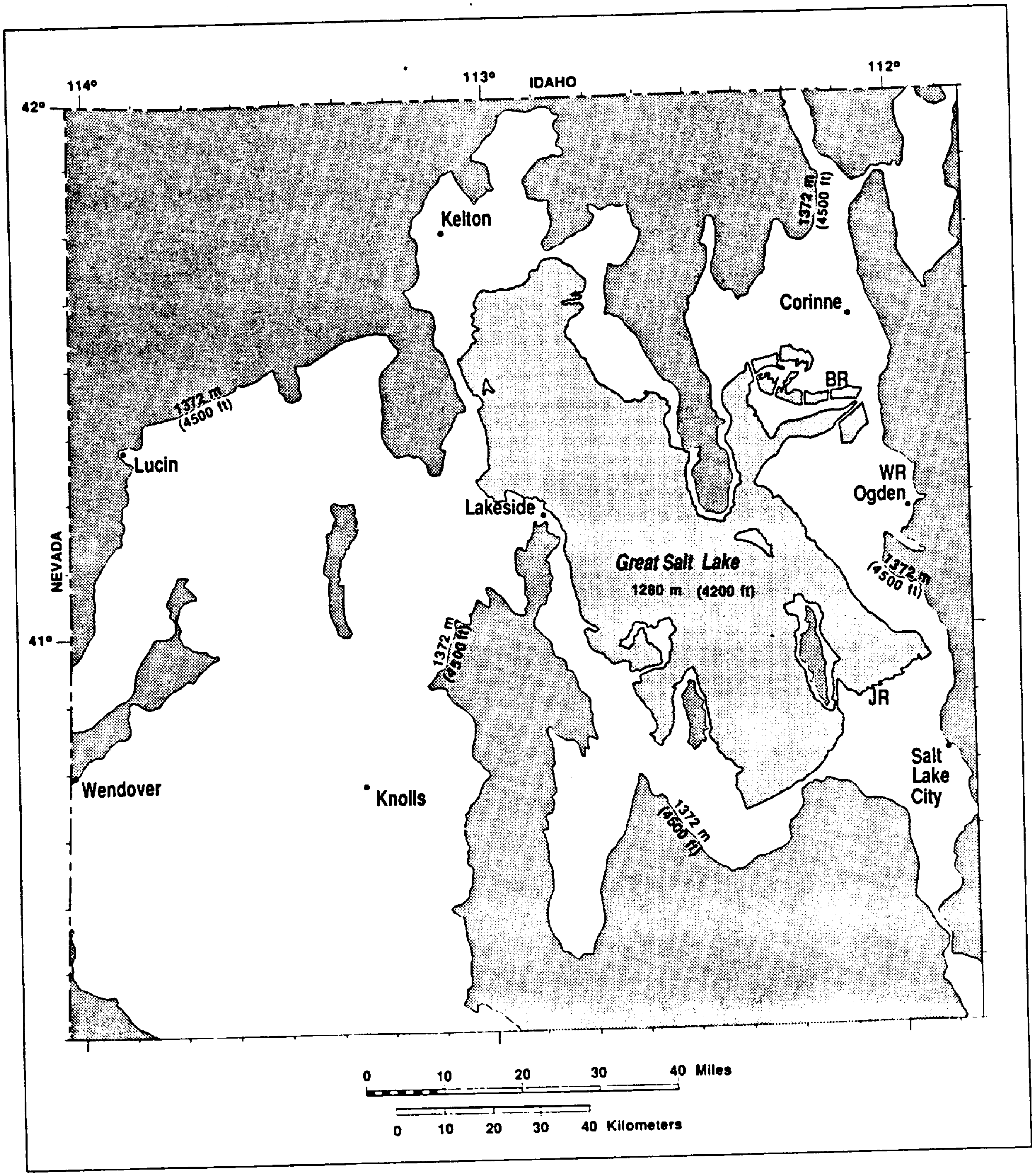


Figure 34. Map of the early Holocene 4200 foot level.

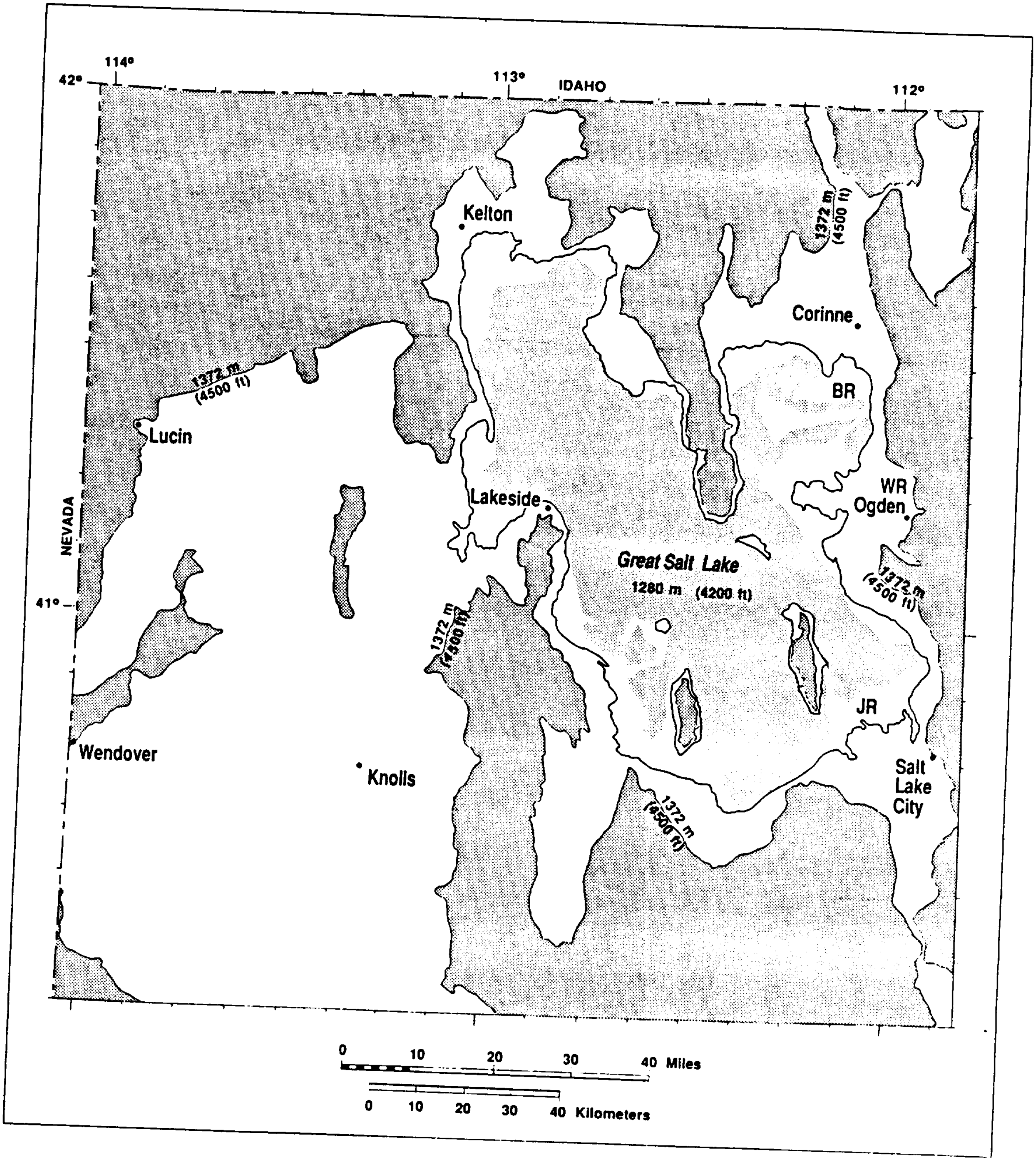


Figure 35. Map of the early Holocene 4212 foot lake rise.

static water level of 4221 ft (1286.5 m) (Figure 36, in pocket). The lake dropped from 4221 ft (1286.5 m) to just under 4210 ft (1283.2 m) between 1250 and 995 yr B.P., based on archeological evidence (Figure 37). Continued lowering of the lake to a 4205 ft (1281.6 m) level is believed to have occurred between 860 and 345 yr B.P. (Figure 38).

The "Little Ice Age" climatic influences caused the lake to rise to a static level of 4217 ft (1285.7 m) (Figure 39, in pocket) between 400 and 300 yr B.P. A rapid lowering to a static level of 4214 ft (1284.4 m) occurred 250 yr B.P. This 4214 ft (1284.4 m) stand is believed to be a dual beach forming event based on localities such as Rozel Point, Windmill Bay, and Unicorn Points. After 250 yr B.P., lake levels probably fluctuated near the historic mean of 4200 ft (1280 m) (Figure 34, in pocket). Historic records and hydrographs have documented the lake activity sine 1851 A.D., including the historic low of 4191 ft (1277.3 m).

Problems and Predictions

A very late Pleistocene and Holocene provisional chronology of Great Salt Lake was produced by the author through field investigations at localities summarized in Table 1, review of the pertinent literature, and extensive laboratory analysis of various sediments. Any Great Salt Lake chronology that employs the analysis of geomorphic features will undoubtedly omit lacustrine features below the

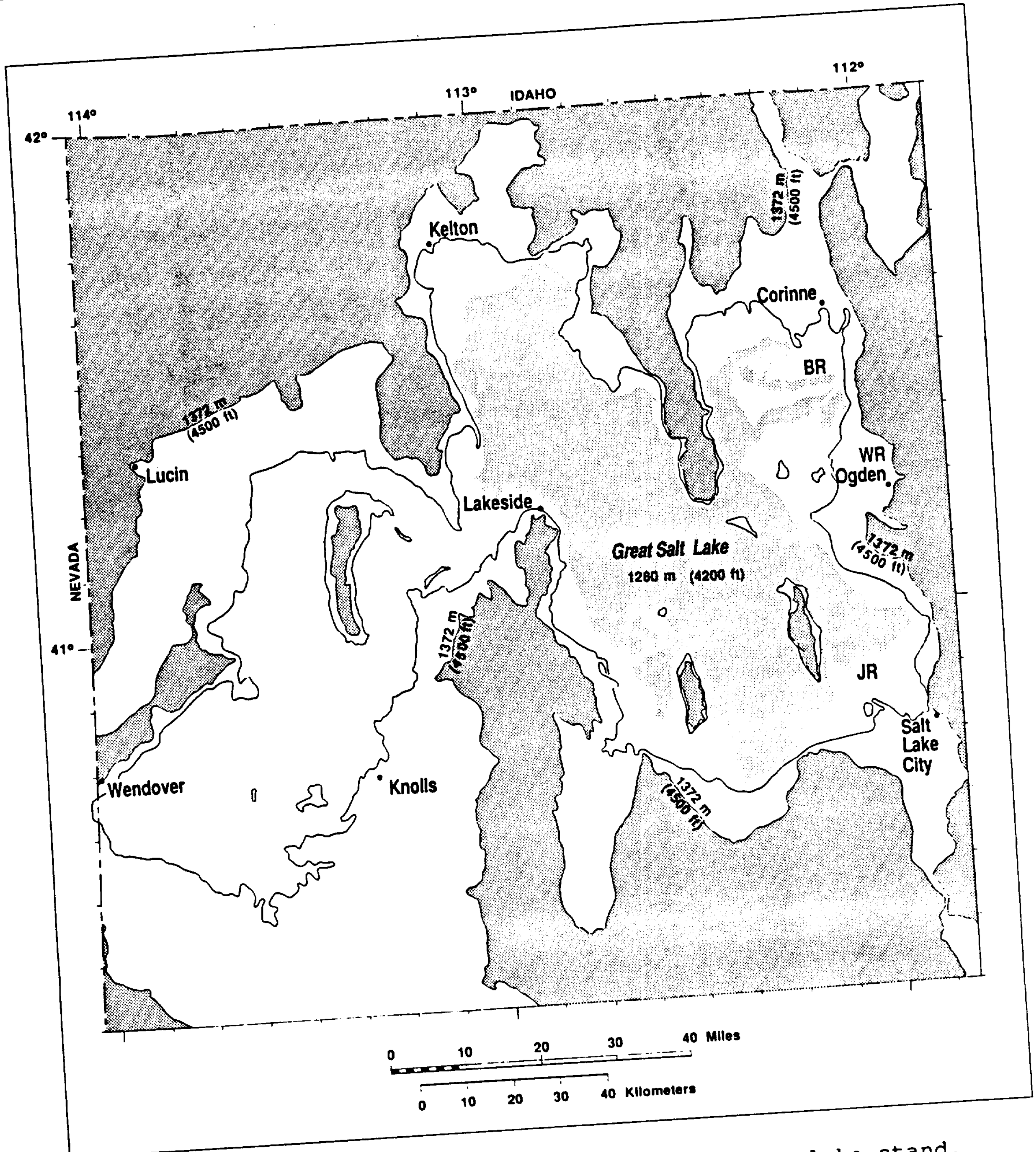


Figure 36. Map of the late Holocene 4221 foot lake stand.

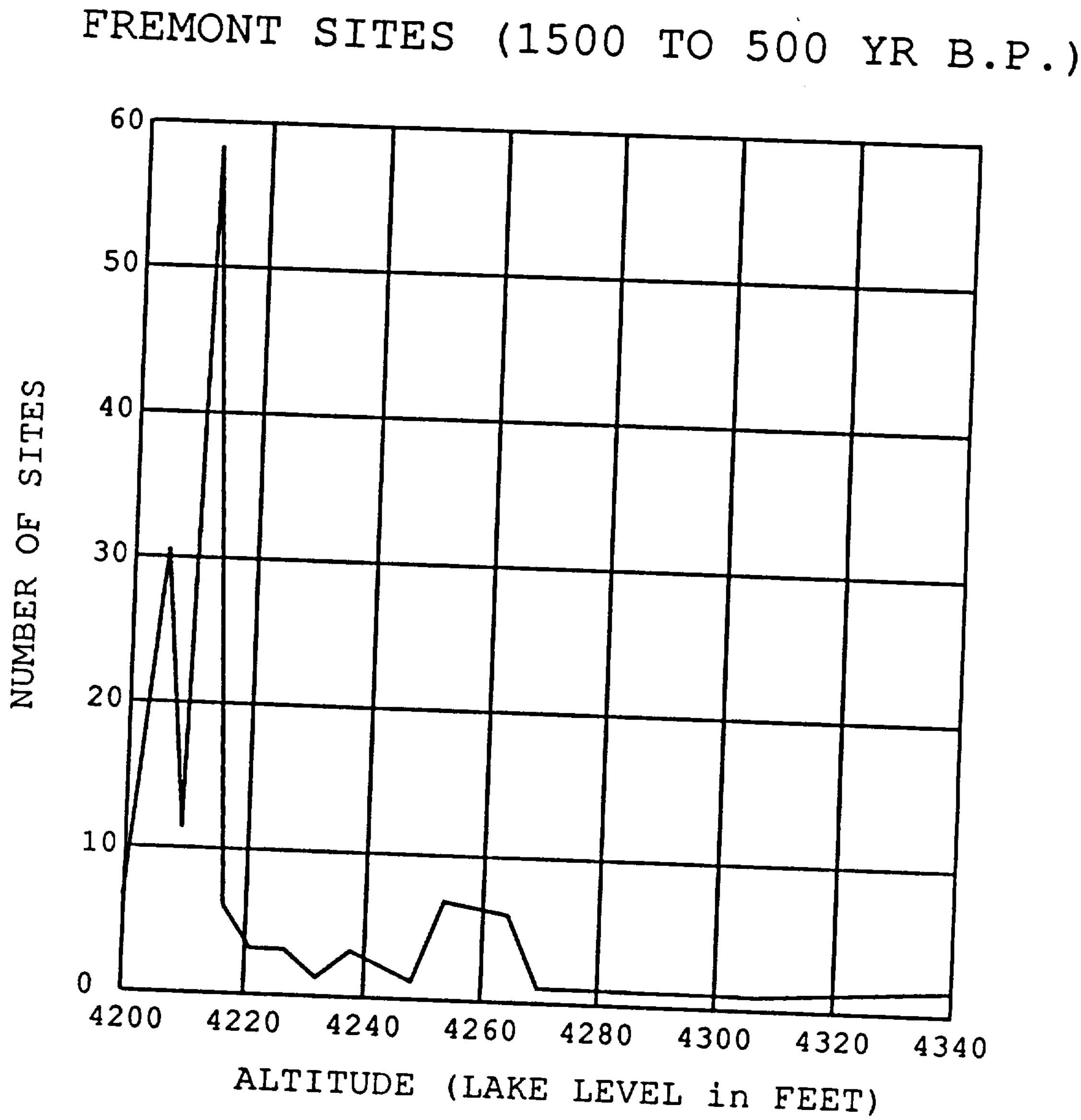


Figure 37. Graph of Fremont archeological sites to altitude.

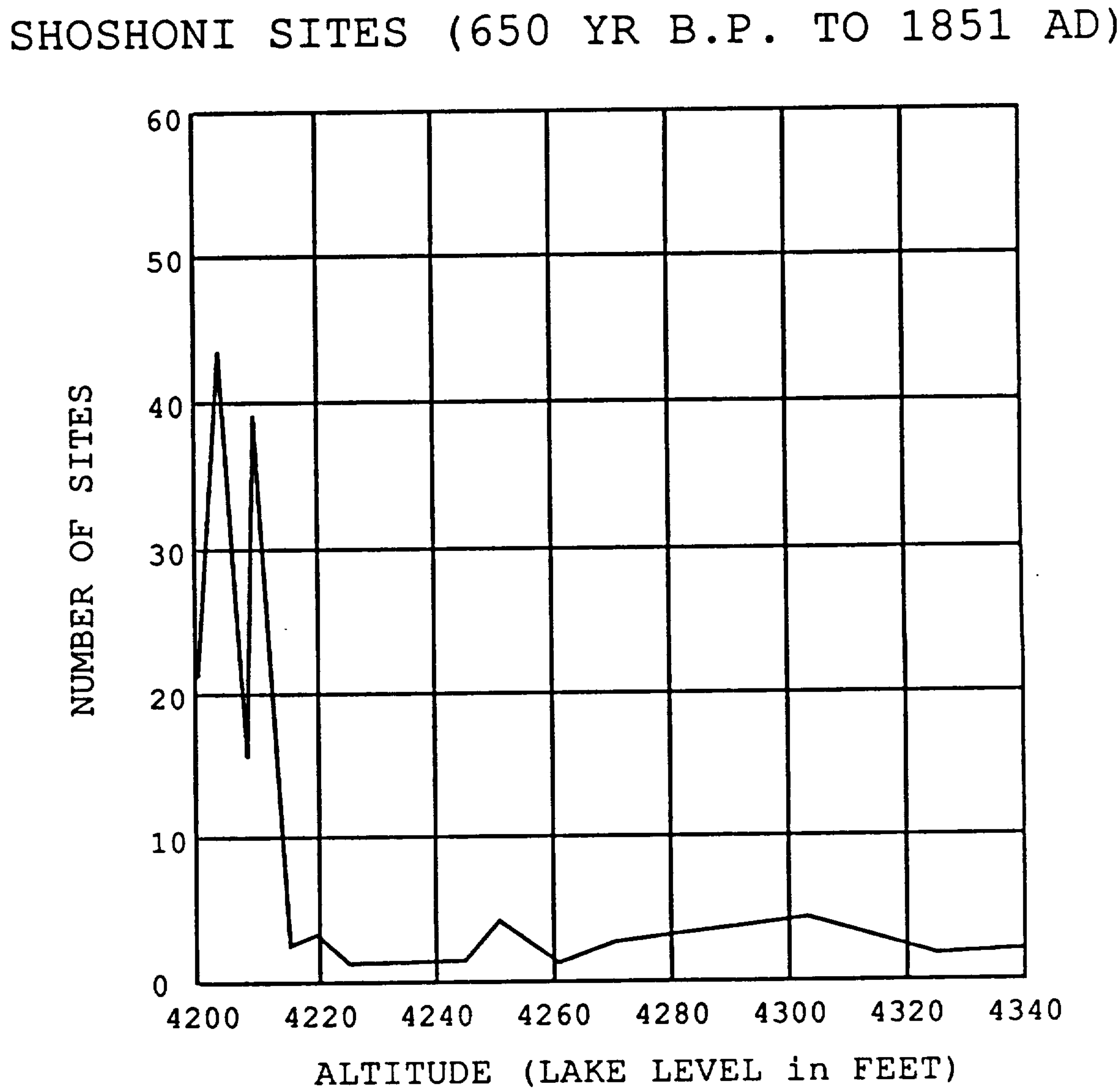


Figure 38. Graph of Shoshoni archeological sites to altitude.

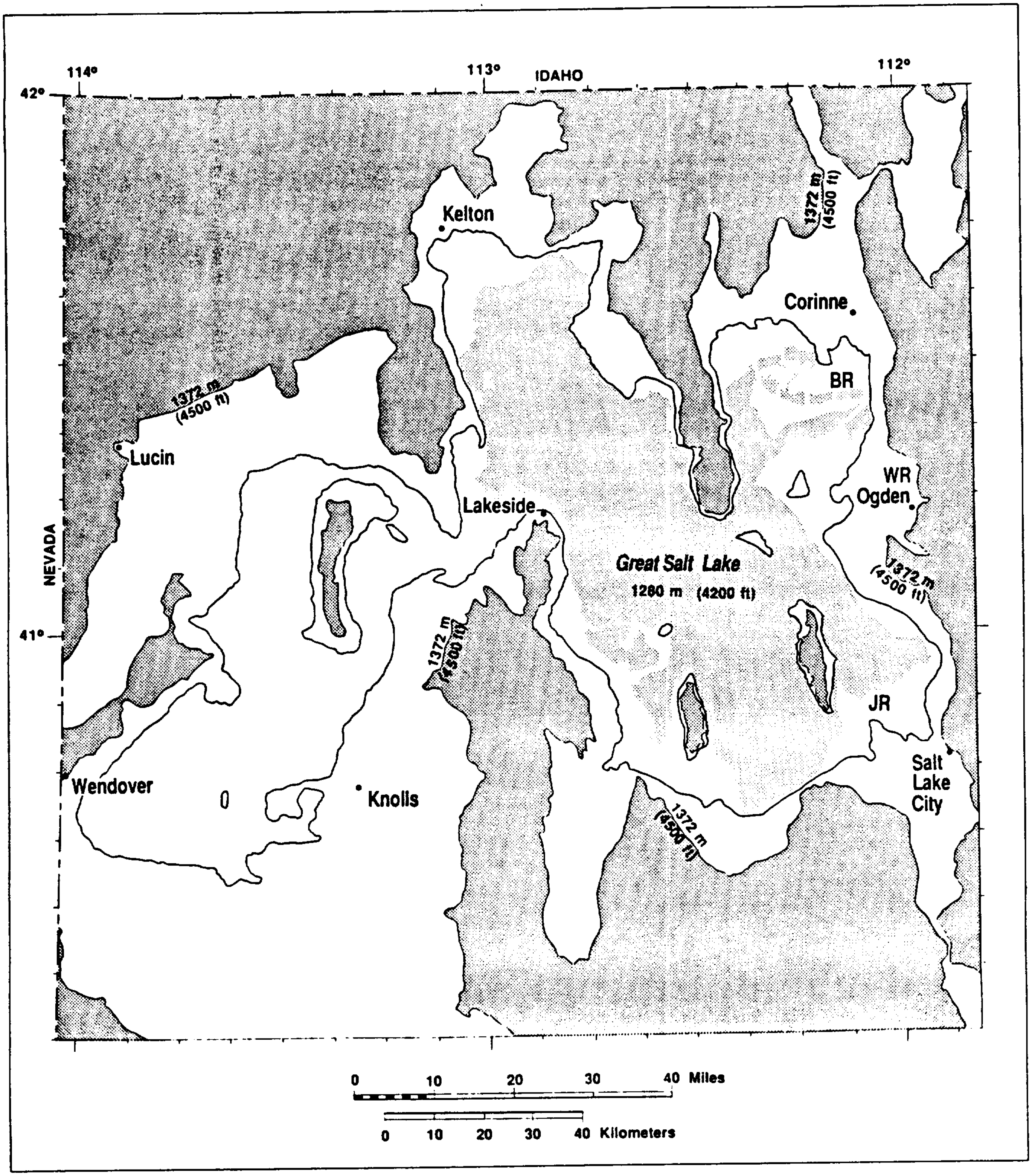


Figure 39. Map of the very late Holocene 4217 foot level.

then present surface of the static water level. Inference about lake levels below the present water surface must therefore, include additional interdisciplinary data. This dissertation attempted to interpret radiometric, stratigraphic, archeologic, isotopic, and palynologic data to support geomorphic interpretations that were based mostly on subaerial features.

Temporal determinations of radiocarbon estimates and the suitability of obtaining quality samples are prevalent throughout Holocene Great Salt Lake literature. Many of the early (i.e., pre-1975) radiocarbon reports show no corrections of ^{13}C and ^{12}C isotope ratios or no laboratory capability for isotopic adjustments. Often, age estimates are reported without stratigraphic interpretations, altitudes, exact locations, and sample preparations making inferences impossible. The procedures for determining suitability of samples varies from researcher to researcher due to a limited amount of dateable material in the Great Salt Lake and the basin area. Awareness of sample contamination variables such as humus illuviation, secondary carbonate leaching, and salinity externalities can reduce radiocarbon reporting errors.

A partial objective of this study was to provide a reliable chronology to aid private and governmental entities in determining a safe "planning level" which would reduce the probability of lake rise flooding. McKenzie (written comm., 1984) estimates that calcite is precipitated (high water indicator) about every 1500 yr based on isotopic stratigraphy. Very little interpretable third-order (1000 yr resolution) periodicity exists from the author's Holocene hydrograph (Figure 40). Although, if one could resolve first- and second-order periodicity, some interpretable pattern might exist. What does seem evident is that unless some extraordinary climatic factors occur, such as the late Pleistocene, late Holocene, or the "Little Ice Age" cold cycles, Great Salt Lake levels generally fluctuate between 4190 and 4212 ft (1277.1 and 1283.7 m) regardless of any human intervention (i.e., pumping project, irrigation, in-flow consumption).

The future challenge concerning Holocene Great Salt Lake fluctuations is:

1) resolution of isostatic deformation during the Holocene,
2) continued radiocarbon age determination of undated berms and other lacustrine features,
3) geochemical analysis of salinity changes through time and ooid evolution,
4) interpretation of the processes that drive the abrupt changes in climate (i.e., Milankovitch theory, global circulation perturbations, or a combination),
5) cooperation between government and academia as well as improved dissemination of Holocene lake data between disciplines.

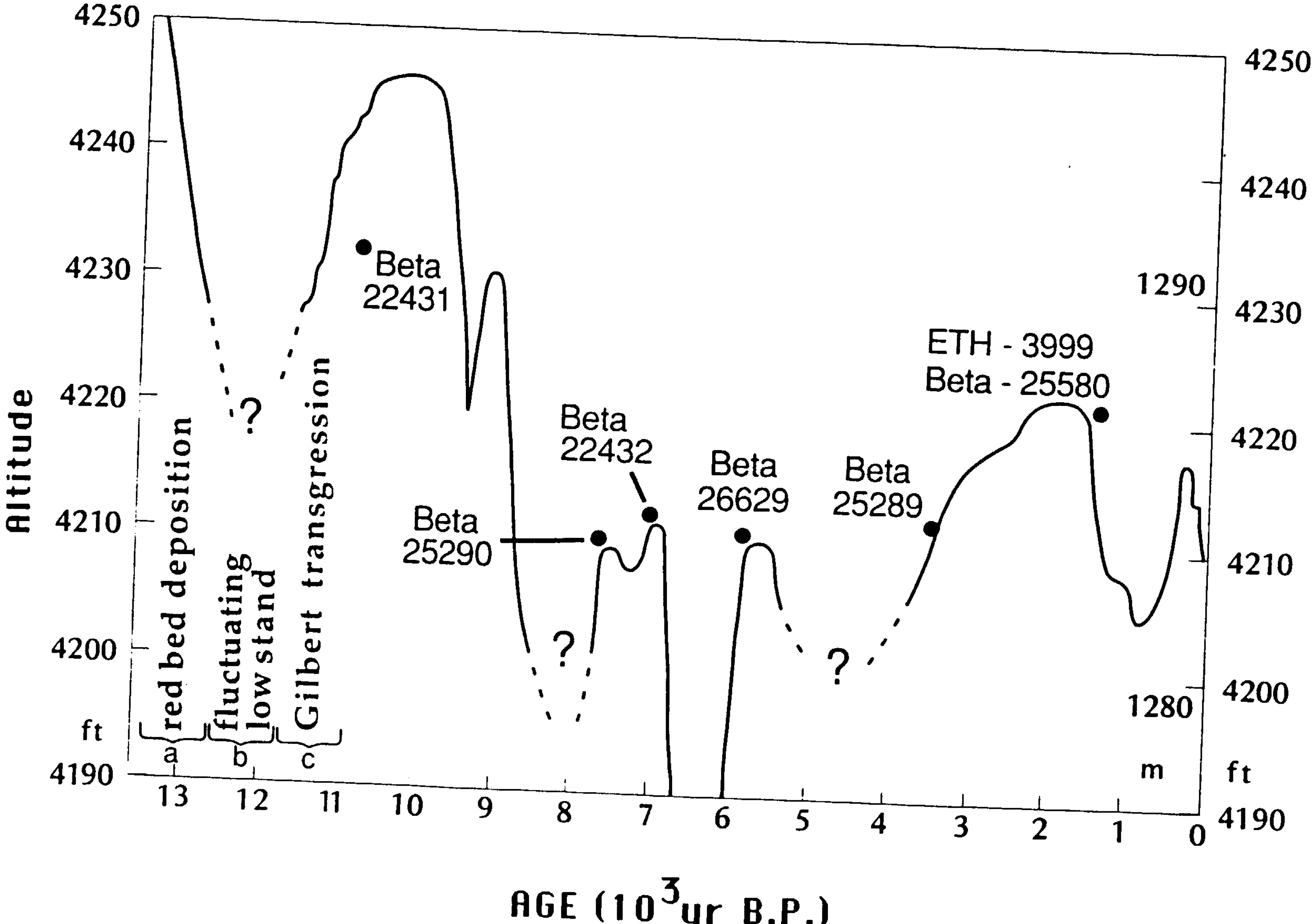


Figure 40. Fluctuation history of Great Salt Lake (13,000 yr B.P. to the present).

The Great Salt Lake may or may not rise high enough to flood cities, transportation arteries, or useable land, but complacency when the lake is low and panic when levels are high is a rather shortsighted planning method.

REFERENCES

Aikens, C.M. (1966). Freemont-Promontory-Plains relationships in northern Utah. Univ. of Utah Anthropological Papers 82, pp. 11-73.

________ (1967). Excavations at Snake Rock Village and the Bear River no. 2 site. Univ. of Utah Anthropological Papers 87, pp. 33-55.

________ (1970). Hogup Cave. Univ. of Utah Anthropological Papers 93, pp. 1-30.

Antevs, E. (1948). Climatic changes and pre-White Man. In "The Great Basin, with emphasis on glacial and post-glacial times." 38, 168-191. Univ. Utah Bull.

________ (1952). Cenozoic climates of the Great Basin. Geologische Rundschau 40,94-108.

________ (1955). Geologic-climate dating in the West U.S. Am. Antiquity 20, 317-335.

Arnow, T. (1984). Water-level and water-quality changes in Great Salt Lake Utah, 1847-1983. U.S.Geological Survey Circular 913, pp. 1-19.

Atwood, G. and D.R. Mabey (1988). Elevations of shoreline features produced by the 1986-87 high level of Great Salt Lake, Geol. Soc. of America Abstracts with Programs 20, 404.

Black, C.A. (ed) (1965). "Methods of soil analysis: part 2 chemical and microbiological properties." American Soc. of Agronomy, Inc., p. 1414-1420, Madison, Wisconsin.

Bowen, D.Q. (1978). "Quaternary geology." Pergamon Press, pp. 190-192, Oxford, England.

Chamberlin, R.V. and D.T. Jones (1929). A descriptive catalog of the Mollusca of Utah. Bull. of the Univ. of Utah, Biol. Series, 1.

Colman, S.M., K.L. Pierce, and P.W. Birkeland (1987). Suggested terminology for Quaternary dating methods. Quaternary Research 28, 314-319.

Crittenden, M.D., Jr. (1963). New data on the isostatic deformation of Lake Bonneville. U.S.G.S. Professional Paper 454-E, pp. E1-E31.

Currey, D.R. (1980). Coastal geomorphology of Great Salt Lake and vicinity. In, Gwynne, J.W., (ed), pp. 69-82, "The Great Salt Lake - A Scientific, Historical, and Economic Overview," Utah Geological and Mineral Survey Bulletin 116.

________ (1987). Great Salt Lake levels: Holocene geomorphic development and hydrographic history. In," Lab -oratory for Terrestrial Physics," Third Annual Landsat Workshop, pp. 129, NASA Goddard Space Flight Center, Greenbelt, Maryland.

Currey, D.R. and S.R. James (1982). Paleoenvironments of the Northeastern Great Basin and Mortheastern Basin rim region: A review of geological and biological evidence. In, Madsen D.B. and J.F. O'Connell, (eds), pp. 27-52, "Man and Environment in the Great Basin," Soc. for Amer. Archeol. Papers.

Currey, D.R. and C.G. Oviatt (1985). Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago. Geogr. Jour. Korea 10, 1085-1099.

Currey, D.R., C.G. Oviatt, and G.B. Plyer (1983). Lake Bonneville stratigraphy, geomorphology, and isostatic deformation in West-Central Utah. In, "Geologic Excursions in Neotectonics and Engineering Geology in Utah," pp. 63-82, Utah Geol. and Min. Survey Special Studies 62.

Currey, D.R., G. Atwood, and D.R. Mabey (1984a). Major levels of Great Salt Lake and Lake Bonneville. Utah Geol. and Mineral Survey Map 73.

Currey, D.R., C.G. Oviatt, and J.E. Czarnomski (1984b). Late Quaternary geology of Lake Bonneville and Lake Waring ,in, Kerns, G.J. and R.L. Kerns, Jr., (eds), pp. 227-237, "Geology of Northwest Utah, Southern Idaho, and Northeast Nevada," Utah Geol. Assoc., Pub. 13.

Currey, D.R., M.S. Berry, S.A. Green, and S.B. Murchison (1988a). Very Late Pleistocene red beds in the Bonneville Basin, Utah and Nevada. Geol. Soc. of America Abstracts with Programs 20, 55.

Currey, D.R., M.S. Berry, G.E. Douglass, J.A. Merola, S.B. Murchison, and M.K. Ridd (1988b). The Highest Holocene Stage of Great Salt Lake. Geol. Soc. of America Abstracts with Programs 20, 55.

Currey, D.R. and T.N. Burr (1988). Linear model of threshold controlled shorelines of Lake Bonneville, Utah. Geol. and Mineral Survey Misc. Pub. 88-1, pp. 104-110.

Davies, J.L. (1980). "Geographical variation in coastal development." pp. 76-188, Longman, New York.

Dearing, J.A. and I.D.L. Foster (1986). Lake sediment and palaeohydrological studies. In, Berglund, B.E., (ed), pp. 67-90, "Handbook of Holocene palaeoecology and palaeohydrology," John Wiley and Sons Ltd.

Eardley, A.J., V. Gvosdetsky, and R.E. Marsell (1957). Hydrology of Lake Bonneville and sediments and soils of its basin. Geol. Soc. of America Bulletin 68, 1141-1202.

Ebdon, D. (1985). "Statistics in Geography," pp. 128-163, Basil Blackwood Ltd., Oxford, England.

F.E.M.A. (1986). Closed-Basin lake flooding: Case studies and mitigation opportunities, F.E.M.A. Region VIII, Boulder, Colo.

Fry, G.F. (1976). Analysis of prehistoric coprolites from Utah. Univ. of Utah Anthropological Papers 97, pp. 4-25.

Fry, G.F. and G.F. Dalley (1979). The Levee site and the Knoll site. Univ. of Utah Anthropological Papers 100, pp. 3-68.

Gates, J.S. (1984). Hydrogeology of Northwestern Utah and adjacent parts of Idaho and Nevada. In, Kerns, G.J. and R.L. Kerns, Jr., (eds), pp. 239-248, "Geology of Northwestern Utah, Southern Idaho, and Northeast Nevada," Utah Geol. Assoc. Publication 13.

Gilbert, G.K. (1890). Lake Bonneville, U.S. Geol. Survey Monograph 1.

Grey, D.C. and R. Bennett (1972). A preliminary limnological history of Great Salt Lake, in, pp. 3-18, "The Great Salt Lake and Utah's Water Resources," Utah Section of the American Water Resources Association, Proceedings of the First Annual Conference, Salt Lake City.

Harper, K.T. and G.M. Alder. (1972). Paleoclimatic inferences concerning the last 10,000 years from a resampling of Danger Cave, Utah. in, Fowler, D.D., (ed), pp. 13-23, "Great Basin cultural ecology," Desert Research Institute Pub. in the Social Sciences, Reno, Vol. 8.

Head, K.H. (1980). "Manual of soil laboratory testing." pp. 143-237, Volume 1, John Wiley and Sons, New York.

Hopkins, D.M. (1975). Time-stratigraphic nomenclature for the Holocene Epoch. Geology 3, 10.

Hunt, C.B. (1980). G.K. Gilbert's Lake Bonneville studies. In, Yochelson, E.L., (ed), pp. 45-59, "The Scientific Ideas of G.K.Gilbert," Geol. Soc. of America, Special Paper 183.

Isgreen, M. (1985). Holocene environments in the Sevier and Escalante Desert basins, Utah: A synthesis of Holocene environments in the Great Basin. Univ. of Utah, M.S. thesis.

Jameson, S.J.S. (1958). Archeological notes on Stansbury Island. Univ. of Utah Anthropological Papers 34, pp. 7.

Jennings, J.D. (1957). Danger Cave. Univ. of Utah Anthropological Papers 27.

________ (1978). Prehistory of Utah and the Eastern Great Basin. Univ. of Utah Anthropological Papers 98, pp. 29-252.

Kay, P.A. and H.F. Diaz (eds) (1985). Problems of and prospects for predicting Great Salt Lake levels, Center for Public Affairs and Administration, Univ. of Utah.

King, C.A.M. and M.J. McCullagh (1971). A simulation model of a complex recurved spit. The Journal of Geology 79, 22-37.

Mabey, D.R. (1986). Notes on the historic high level of Great Salt Lake. Utah Geol. and Mineral Survey Notes, 20, 13-15.

Madsen, D.B. (1980). The human prehistory of the Great Salt Lake region. In, Gwynn, J.W., (ed), pp. 19-31, "Great Salt Lake - A Scientific, Historical, and Economic Overview," Utah Geol. and Mineral Survey Bulletin 116.

_________ (1982). Get it where the gettin's good: A variable model of Great Basin subsistence and settlement based on data from the Eastern Great Basin. In, Madsen, D.R. and J.F. O'Connell, (eds), pp. 207-226 "Man and Environment in the Great Basin," Society for American Archeology Papers,no. 2.

Marwitt, J.P., G.F. Fry, and J.M. Adovasio (1971). Sandwich Shelter. In, Aikens, C.M., (ed), pp. 27-36, Great Basin Anthropological Conference (1970) Selected Papers, Univ. of Oregon Anthropological Papers No. 1.

May, F.E. (1985). Hazard Mitigation Plan, Utah 1985. Comprehensive Emergency Management, Utah Dept. of Public Saftey.

Mehringer, P.J. (1985). Late-Quaternary pollen records from the interior Pacific Northwest and Northern Great Basin of the United States. In, Bryant, Jr, V.M. and R.G Holloway, (eds), pp. 167-189, "Pollen records of late-Quaternary North American sediments," Amer. Assoc. Strat. Palynol. Found., Dallas.

_________ (1986). Prehistoric environments. In, d'Azevedo, W. (ed), pp. 31-50, "Great Basin, Handbook of North American Indians."

McKenzie, J.A. and G.P. Eberli (1985). Late Holocene lake-level fluctuations of the Great Salt Lake (Utah) as deduced from oxygen-isotope and carbonate contents of cored sediments. In, Kay, P.A. and H.F. Diaz, (eds), pp. 25-39, "Problems of and Prospects for Predicting Great Salt Lake Levels," Univ. of Utah.

_________ (1987). Indications for abrupt Holocene climatic change: Late Holocene oxygen isotope stratigraphy of the Great Salt Lake, Utah. In, Berger, W.H. and L.D. Labeyrie, (eds), pp. 127-136, "Abrupt Climatic Change," D. Reidel Pub. Co.

Miller, R.D. (1980). Surficial geological map along part of the Wasatch Front, Salt Lake Valley, Utah. USGS Map MF-1198, two 1:100,000 maps and pamphlet, p. 13.

Miller, R.D., R. Van Horn, W.E. Scott, and R.M. Forester (1980). Radiocarbon date support concept of continuous low levels of Lake Bonneville since 11,000 Years B.P. Geol. Soc. of America Abstracts with Programs 12, 297-298.

Morrison, R.B. (1965). New evidence on Lake Bonneville stratigraphy and history from southern Promontory Point Utah. U.S. Geol. Survey Professional Paper 525-c, pp. 110-119.

Morrison, R.B. (1966). Predecessors of Great Salt Lake. In, Stokes, W.L.(ed), pp. 75-104, "The Great Salt Lake," Utah Geol. Soc.

Murchison, S.B. (1989). Utah chub (Gila atraria) from the latest Pleistocene Gilbert shoreline, west of Corrine, Utah. Great Basin Naturalist 49, 131-133.

North American commission on stratigraphic nomenclature, (1983). North American Stratigraphic Code, American Assoc. of Petroleum Geol. Bull. 67, 841-875.

Oviatt, C.G. (1984). Lake Bonneville stratigraphy at the Old River Bed and Leamington, Utah. Univ. of Utah, Ph.D. dissertation.

Reeves Jr., C.C. (1968). "Introduction to Paleolimnology." pp. 78, Elsevier Pub. Co., New York.

Ross, D.S. (1973). Holocene fluctuations of Great Salt Lake, with special reference to evidence from the Eastern Shore. Univ. of Utah, M.S. thesis.

Rubin, M. and C. Alexander (1958). U.S. Geological Survey dates IV. Science 127, 1476-1487.

Rudy, Jr., R.C. (1973). Holocene fluctuations of Great Salt Lake, with special reference to evidence from the Western Shore. Univ. of Utah, M.S. thesis.

Scott, W.E., W.D. McCoy, R.R. Shroba, and M. Rubin (1983). Reinterpretation of the exposed record of the last two cycles of Lake Bonneville, Western United States. Quaternary Research 20, 261-285.

Shields, W.F. and G.F. Dalley (1968). Excavations at Bear River No. 3. Univ. of Utah Anthropological Papers no. 22, pp. 60-65.

Simms, S.R. (1977). A mid-Archaic subsistence and settlement shift in the northeastern Great Basin. In, Fowler, D.D. (ed), pp. 195-210, "Models and Great Basin prehistory: a symposium," Desert Research Institute Publications in the Social Sciences, Reno, no. 12.

Smith, G.I. and F.A. Street-Perrott (1983). Pluvial lakes of the Western United States, in, Wright, H.E. and S.C. Porter, (eds), pp. 190-212, "Late-Quaternary Environments of the United States." Minneapolis, Univ. of Minn. Press.

Smith, G.R., W.L. Stokes, and K.F. Horn (1968). Some late Pleistocene fishes of Lake Bonneville. Copeia 4, 807-816.

Soil Conservation Service (1972). Soil Survey laboratory methods and procedures for collecting soil samples. USDA, Soil Survey Investigations Report Number 1, pp. 10-14.

Soil Survey Staff (1974). Soil survey of Salt Lake area, Utah USDA Handbook, pp. 1-128.

Soil Survey Staff (1975). "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys." SCS, USDA, pp. 140-141, Ag. Handbook 436, Washington.

Spencer, R.J., M.J. Baedecker, H.P. Eugster, R.M. Forester, M.B. Goldhaber, B.F. Jones, K. Kelts, J. McKenzie, D.B. Madsen, S.L. Retting, M. Rubin, and C. Bowser (1984). Great Salt Lake, and precursors, Utah: The last 30,000 years, Contributions to Mineralogy and Petrology 86, 321-334.

Stansbury, H. (1852). "Exploration and survey of the valley of the Great Salt Lake of Utah: For the U.S. Senate." Lippincott, Grambe, and Co., Philadelphia.

Stokes, W.L. (1966). "The Great Salt Lake." pp. 2-5, Utah Geological Society, Salt Lake City.

Stokes, W.L., G.R. Smith, and K.F. Horn (1964). Fossil fishes from the Stansbury level of Lake Bonneville, Utah, Proceedings: Utah Academy of Sci., Arts, and Letters 41, 87-88.

U.S.Army Corps of Engineers (1986). Great Salt Lake reconnaissance report. Dept. of the Army, Sacramento, Calif.

Utah Water Resources (1984). Great Salt Lake summary of technical investigations for water level control alternatives. Utah Dept. of Natural Resources, Jan. 1984, pp. 1-50.