The Paleoecology and Geomorphology of Holocene Deposits of the Southern Malad River, Box Elder County, Utah

Ann Schaffer Elder
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THE PALEOECOLOGY AND GEOMORPHOLOGY OF HOLOCENE DEPOSITS
OF THE SOUTHERN MALAD RIVER, BOX ELDER COUNTY, UTAH

by

Ann Schaffer Elder

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
GEOLOGY

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
1992
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Ann S. Elder
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ABSTRACT

The Paleoecology and Geomorphology of Holocene Deposits of the Southern Malad River, Box Elder County, Utah

by

Ann Schaffer Elder, Master of Science

Utah State University, 1992

Major Professor: Dr. David Liddell
Department: Geology

Widespread Lake Bonneville sediments have been modified by river aggradation and degradation associated with Holocene fluctuations in the Great Salt Lake. Exposures of exceptionally abundant and well-preserved molluscan deposits in the Bear River Valley, Utah, allow detailed paleoenvironmental reconstruction of Holocene environments. The exposed basal unit consists of largely unfossiliferous deltaic silts and clays deposited during Lake Bonneville time (roughly 11,000 - 13,000 yr B. P.). An unconformity representing at least 2000 yr separates the deltaic material from overlying highly fossiliferous stream sands. Eight species of molluscs, comprising a single community, occupied this low energy stream environment at 7690 ± 270 \(^{14}\)C yr B. P. A second unconformity separates these sands from a dark brown silt unit deposited by a river-associated environment, most likely an over-bank marsh, at 2420 ± 135 \(^{14}\)C yr B. P. Nine species of molluscs, comprising 3 communities, were present in this environment. Analysis of size-frequency distributions, percentage of
pelecypod valves, preservation, and orientation of the shells that were present in each environment suggests that the 7690 ± 270 14C yr B. P. fossil assemblage has been only slightly altered by biostratinomic processes. The younger assemblage has also been altered, with the size-frequency curves of the smallest gastropods displaying normal distributions.

Geomorphic and stratigraphic data from the Malad River show that water levels in the Great Salt Lake twice rose and fell significantly during the Holocene epoch. The oldest rise, to an altitude of at least 1288 m, occurred before 7690 ± 270 yr B. P., perhaps in response to a worldwide period of climatic cooling. This high-stand was followed by a fall of lake level roughly corresponding to the classic Hypsithermal Interval, about 7000 - 5000 yr B. P. A second rise occurred by 2420 ± 135 yr B. P., when the Great Salt Lake rose to approximately 1286 m. During this second rise, the Malad River overflowed its levees and later, as the Great Salt Lake receded for a second time, the river was captured by a headward-cutting tributary of the Bear River.

The regional distribution of the fossiliferous deposits was controlled by the time at which capture occurred. Capture of the Malad channel by the Bear River occurred after the last fossiliferous sediments were deposited; thus no fossils are found downstream from the point of capture.
INTRODUCTION

Lake Bonneville sediments have been modified by widespread river aggradation and degradation associated with Holocene fluctuations in the Great Salt Lake. The result is a complex conglomeration of overlapping geomorphic features that are difficult to sort chronologically.

The Bear River Valley is a north-south trending valley in north-central Utah (Fig. 1). It extends from the Bear River Bay of the Great Salt Lake northward to the Malad Range and spurs of the Blue Spring Hills, where it meets the Malad Valley. The northern boundary of the Malad Valley is at approximately the same latitude as Red Rock Pass to the east; therefore, the valleys represent one of the northern-most arms of Lake Bonneville.

The Bear River Valley contains lake bottom deposits from three Lake Bonneville levels (Gilbert, Provo and Bonneville) (Currey, 1980). The last regression of Lake Bonneville occurred approximately 11,000 years ago (Scott et al., 1983) and, since that time, the lacustrine deposits have been downcut by streams, exposing many vertical meters of Pleistocene lake deposits and Holocene sediments. The Malad River is one such stream which exposes highly fossiliferous deposits at a number of locations along part of its course. Though other nearby drainages cut through lake and river-associated deposits at the same elevation, only a small number of individual shells have been found elsewhere in the Bear River Valley.

The purpose of this study was to evaluate the taphonomy and age relationships of the molluscan communities found along the Malad River, and the geomorphology and stratigraphy of the surrounding lake and river sediments in order to better understand the paleoecology and depositional environments of the molluscan fauna and explain its limited extent. This was accomplished by determining the taxonomic composition of the assemblages, analyzing population and community structures and evaluating possible biostratigraphic influences. Sediment analyses were used to
Fig. 1. Map showing study area (Bear River Quad., T.10N., R.3W., Secs. 10, 11, 14; Tremonton Quad., T.10N., R.3W., Sec.3; T.11N., R.3W., Sec.34). Inset (Morrison, 1966) shows maximum extent of Lake Bonneville.
identify environmental controls on the distribution and composition of the fossil communities. Stratigraphic relationships were correlated using geomorphic, $^{14}$C and amino acid dating techniques. Geomorphic interpretations were based on aerial photograph interpretation, field mapping and soil analysis.
METHODS

Field Methods

The areal extent of the mollusc-rich deposits was determined by sampling a representative selection of exposures along north-south and east-west transects. The north-south transect was centered along the Malad River to utilize river-cut exposures into Pleistocene and Holocene sediments. The east-west transect extended approximately 6 km from each bank of the Malad River, not exceeding the northern or southern extent of the mollusc-rich deposits. The fossiliferous part of the study area was systematically sampled by dividing it into four 1 km sections from north to south. Samples were taken at each section boundary (or as near as possible, depending upon exposure and accessibility) (Fig. 2). At each sampling location the deposit was described and the surface elevation of the exposure determined from a topographic map. Field observations included vertical extent of the exposure, sediment color, approximate grain size, sedimentary structures and abundance and type of fossils and their orientations. East-west transect samples were taken at each location where river and road cuts exposed sediments of the same elevation as the fossiliferous north-south samples. The same field observations were made on these samples.

The north-south transect was sampled using bulk techniques. One meter vertical sampling intervals were used to obtain representative samples of the section. For each sample, a vertical face was shoveled out of the exposure to a depth of 8 - 10 cm with the last centimeter of sediment carefully removed to minimize damage to the fossils. A 25 x 25 cm square was outlined on the vertical face and observations were made within this square using a 5 cm grid system. Observations included pelecypod articulation, shell abrasion (amount of original shell material remaining) and any unique features.
Fig. 2. Map of study area (Bear River Quad., T.10N., R.3W., Secs. 10, 11, 14; Tremonton Quad., T.10N., R.3W., Sec. 3; T.11N., R.3W., Sec. 34) showing sample locations; soil distribution (from Soil Survey of Box Elder County, Utah) and abandoned Malad River channel. Ru - Rosh Springs Silt Loam, Fv - Fridlo Silt Loam, Gr - Greenon Silt Loam, Fe - Fielding Silt Loam.
Shell orientation data were collected on 2 randomly selected 25 x 25 cm squares. Measurements were taken at sample location 14C-2 at an elevation of 1288 m and at 8-83 at an elevation of 1296 m.

After all field observations for a sample were completed, a hammer and shovel were used to dig out the top and sides of the square to a depth of 25 cm. This 25 x 25 x 25 cm block was removed from the bank in large chunks and placed in a labeled plastic bag and protective box.

Intermediate sample locations were selected based on elevation of exposure and accessibility. Sampling was considered complete when the entire study area could be tied together with overlapping exposures and samples.

Eighteen samples were collected representing 3 horizontal km and 12 vertical m of sediment. Three depositional units, separated by unconformities, were sampled. The basal silty clay unit appeared to extend throughout the entire sampling area, though northern exposure was limited. The overlying unit, a highly fossiliferous sand deposit, extends from the northern limit of Bear River City, Utah, south to location XX (Fig. 2). The uppermost unit, a brown fossiliferous silt deposit, extends from sample location 2-83 southward to location XX.

Additional time was spent in the field excavating for shell and wood to be used for $^{14}$C dating (samples 14C-1, 14C-2). This material was removed with gloves and immediately placed in plastic bags. Aluminum foil was wrapped around the samples and labeled as to location and elevation.

Samples along the east-west transect were selected so that their elevations would coincide with the elevations of the fossiliferous deposits along the north-south transect. This allowed comparisons between potentially contemporaneous physical environments that were favorable for molluscan life and/or preservation and environments which were not. These six nonfossiliferous localities were sampled using bulk techniques. Because all of the east-west samples were nonfossiliferous, only 70 gm of sediment were needed for analysis. Field observations such as sediment color, sedimentary features and homogeneity of the exposure were noted.
Sample 5-83 was collected south of location XX along the Bear River. The sample was taken at a location where sediment of the same elevation as the fossiliferous deposits was easily accessible.

Though samples were not collected, field observations were made along the abandoned Malad River channel. All observations were made at the surface due to a lack of exposed cuts. Because the surface sediment had been disturbed by agricultural machinery, the only field observation made was the presence or absence of fossils.

Laboratory Methods

Rarefaction analysis was used to determine the adequacy of sample size with regard to species representation (Sanders, 1968). Subsamples of equal size were disaggregated and the total number of species present was graphed on a cumulative plot. As additional subsamples were disaggregated, the number of new species was added to the previous total and graphed. The sample size was considered adequate when no new species were found in two consecutive subsamples, thus leveling-off the cumulative plot. Three thousand cm$^3$ of sediment (or approximately 20% of the original 25 x 25 x 25 cm block) was found to be an adequate sample size for all of the fossiliferous samples. The number of individual pelecypod and gastropod shells within this amount of sediment varied from 427 to 1500 individuals.

Seventy grams of each fossiliferous sample were removed for sediment analysis. The remaining material from the 3000 cm$^3$ sample was carefully disaggregated with dissecting needles, and the fossils were sorted into taxa. The number of articulated and nonarticulated pelecypods was noted wherever applicable, as were any unique features.

The sorted shells were identified to the species level. Each individual of the species was then measured as follows:

1) gastropods - diameter of the largest whorl and height in mm,
2) pelecypods - length of bisection from hinge to ventral margin and anterior to posterior margin in mm.
This information was then plotted to determine the population size-frequency distribution. The mean, median and 95% confidence interval for the mean were calculated for each species population.

Samples 2-83 (1297 m), 3-83 (1293 m), 7-83 (1295 m), and 10-83 (1233 m) (Fig. 2), chosen by elevation, location and presence of gastropods, were dated using amino-acid deterioration. Five to ten shells of Physa gyrina (Physidae) were selected and sent to the Department of Geology and Geography at the University of Massachusetts, Amherst, Massachusetts for analysis.

Two additional samples, 14C-1 and 14C-2 (Fig. 2), were collected specifically for $^{14}$C analysis. 14C-1 was collected from the upper dark brown silt unit at an elevation of 1289.5 m. Sixty-eight gm of carbonized wood were disaggregated from this sample with tweezers and sent to Geochron Laboratories, Cambridge, Massachusetts for analysis (sample Number GX-9773). Sample 14C-2 was collected from the highly fossiliferous sand unit at an elevation of 1288 m. The sample was disaggregated and 200 gm of Sphaerium striatinum shells were collected. Care was taken to select only those shells which were well-preserved and showed little abrasion. The pelecypod shells were prepared using an ultrasonic cleaner and sent to Geochron Laboratories for analysis (sample Number GX-10015).

A grain size analysis was performed on approximately 70 gm of each fossiliferous and nonfossiliferous sample. Samples were wet-sieved through a 4.0 $\Omega$ mesh screen to break up aggregates. Samples containing a large percentage of clay were soaked in distilled water for a 24 hr period before wet sieving. Those grains larger than 4.0 $\Omega$ were dried and sieved through 1/2 $\Omega$ interval screens. The remaining grains were separated into 1/2 $\Omega$ intervals, using pipette analysis, from 4.0 - 8.0 $\Omega$. The sand/silt ratio (percentage of sand size grains divided by the percentage of silt size grains) and mean grain size were calculated for each sample and plotted against number of individuals per species. All procedures were in accord with Folk (1974).
Statistical tests were used to evaluate possible biostratinomic effects on the assemblages. The equation

\[ f/N \pm 1.96 \sqrt{[f/N(1-f/N)]/N}, \]

(Reyment, 1971), where \( f \) is the frequency and \( N \) is sample size for any binary distribution, was used to compare the proportions of right and left pelecypod valves. The null hypothesis tested states that there was a random distribution of right and left valves and, therefore, no selective transport had occurred. The hypothesis was rejected if the mean value did not fall within the calculated range at a significance level of 0.05.

The chi-square test

\[ x^2 = \frac{N(|ad-bc|-N/2)^2}{(a+b)(c+d)(a+c)(b+d)} \]

(Reyment, 1971), for comparing bimodal parameters from two sites, where \( a \) and \( b \) are parameters from one site and \( c \) and \( d \) are parameters from a second, was used to evaluate articulation frequency within the pelecypod-rich samples. If the test showed that different sites had similar articulation frequencies, the deposits were considered to have been nondisturbed.

A chi-square test was used to compare species size-frequency distributions between samples. The measurements were divided into size intervals, determined by the sample size and range, then tested and compared to a standard \( \chi^2 \) table. Size-frequency distributions were not considered significantly different if the \( \chi^2 \) calculation was larger than the \( \chi^2 \) table value at a significance level of 0.05.

The dominance diversity index for each assemblage was calculated using the Shannon-Weaver equation (Shannon and Weaver, 1948), where \( P_i \) equals the number of individuals in a species divided by the total number of individuals in the sample and \( \log P_i \) equals the natural log of \( P_i \). By definition, the value of \( H' \) is greatest when all species are equally abundant (Dodd and Stanton, 1981) and a large number of species are present. This value was then used to evaluate the equitability of each assemblage \( (J' = H'/H'_{\text{max}}) \) (Pielou, 1969), where \( H'_{\text{max}} \) equals the natural log of the number of species in the assemblage. The values of \( J' \) range
from 1.0, where all the species are equally abundant and thus have a high dominance diversity, to 0.0, a single species assemblage, as the dominance of one or more species increases.

Cluster analysis was used to group samples with similar faunas. Q-mode analysis was utilized so that the samples were clustered in terms of the percent of species present, with Euclidean distance as the coefficient of dissimilarity. The unweighted pair-groups method of arithmetic averages was used to form the tree (Henderson and Davis, 1980).

All molluscan specimens collected are deposited in the collections of the Department of Geology, Utah State University, Logan, Utah.
DESCRIPTION OF STUDY AREA AND STRATIGRAPHY

Geomorphology

The Bear River flows through the eastern part of the Bear River Valley. It has cut deeply into the valley floor (up to 10 m), and its nearly vertical walls expose many meters of Pleistocene lake strata. One of the largest tributaries of the Bear River is the Malad River, which parallels the Bear through much of the valley before joining it just south of Bear River City. Though the Malad is much smaller, it too is responsible for deep-cut banks with good exposures of Pleistocene and Holocene sediments.

One such exposure extends north from the southern boundary of Bear River City, Utah, a horizontal distance of approximately 4 km (Bear River Quad. T. 10 N., R. 3 W., secs. 10, 11, 14; Tremonton Quad., T. 10 N., R. 3 W., sec. 3; T. 11 N., R. 3 W., sec. 34). This cut has a maximum vertical exposure of 7 m and periodically intersects deposits of extraordinarily abundant fossil molluscs, synonomies of which follow in a later subsection.

Based on geomorphic characteristics, the Malad River study area can be divided into two sections. To the north of location XX (Fig. 2), the river channel forms tight meanders. Channel terraces lying 1 - 2 m below the surrounding farm fields are present on both sides of the river. Bowl-shaped landslide scars are abundant along the outside of meanders produced by active mass wasting.

To the south of location XX (Fig. 2), the meanders are much broader and more gentle. Terraces are absent as are landslide scars. All of the exposed sediment is nonfossiliferous and has a stratigraphy similar to that of the basal grey silty clay unit found in the northern section.
Stratigraphy

The stratigraphy along the Malad River north of location XX can be divided into two categories. Those river cuts which do not intersect a terrace expose a fairly homogeneous column made up of a grey silty clay with a maximum exposed thickness of 11 m. The stratigraphy of the terrace deposits is somewhat more complicated (Figs. 3 and 4) with an exposed basal deposit of grey, silty clay containing interspersed, well-sorted, fine sand lenses which gradually thicken and become more abundant with increasing elevation. The maximum vertical exposure of this unit is 4 m. Silt-covered ripples are visible as are thin, dark-red clay bands (Fig. 5). Small, well-formed gypsum crystals are occasionally found. No fossils are present.

An unconformity separates the silty clay unit from an overlying sand deposit. The sand is moderately well-sorted and brown in color. A small clay lens, 2 cm thick, is present at the top of this unit. Sedimentary features include cross bedding, wavy laminations and linear ripples.

The most notable characteristic of the sandy unit is the unusually dense population of molluscs (Fig. 6). Species present include the gastropods Lithoglyphus hindsii, Valvata humeralis, Gyranlus parvus, Helisoma subcrenatum, Physa gyrina, Lymnaea palustris, and the pelecypods Anodonta californiensis and Sphaerium striatum, which is the dominant species.

Approximately 65% of the pelecypod and gastropod shells within the sand unit are coated with CaCO₃. The thickness of the coating varies, with a maximum thickness of 5.0 mm. CaCO₃ casts of reeds are also very abundant. They average 5.0 cm in length and 8.0 mm in diameter. A few CaCO₃-covered, blue-green algal stomatolites were also found within the fossiliferous layer.

The upper boundary of the sandy fossiliferous unit is also an unconformity. Above the unconformity lies a dark brown predominantly massive silt unit (Fig. 7). The distribution of fossils varies, with shells being scarce at low elevations but gradually increasing up through
Fig. 3. Fence diagram showing correlation between sections.
Fig. 4. Stratigraphy of the fossiliferous deposits. Stratigraphic information was compiled from samples 10-83 - 18-83 and 2-83.
Fig. 5. Grey, silty clay, with interspersed, well-sorted, fine sand lenses (A), silt-covered ripples (B) and dark red clay bands (C) (8-83).
Fig. 6. Sandy unit showing a dense population of molluscs. Shells are very abundant throughout the entire unit (8-83).
Fig. 7. Fossiliferous dark brown silt unit. Shells are scarce at low elevations, but increase in number up through the unit. Note abundance of articulated pelecypods (8–83).
the section. Species include the gastropods *Lymnaea palustris*, *Physa gyrina*, *Helisoma subcrenatum*, *Lymnaea stagnalis*, *Lithoglyphus hindsii*, *Gyranlus parvus*, *Valvata humeralis* and the pelecypods *Sphaerium striatun* and *Anodonta californiensis*.

Along the northern section of the Malad River all of the fossiliferous terrace deposits are characterized by the same soil profile. The United States Department of Agriculture Soil Survey of Box Elder County classifies the soil as the Roshe Springs silt loam (Ru) of the Roshe Springs Series. The Roshe Springs silt loam has an Ap Horizon of 0 - 25 cm, an Al horizon of 50 - 68 cm, a Clcag horizon of 50 - 68 cm and a C2g horizon of 68 - 152 cm. No B horizon is present. The soils of the surrounding fields are classified as the Greenson silt loam (Gr), Fielding silt loam (Fe) and Fridlo silt loam (Fv) (Fig. 2). Each of the surrounding soils has at least 22 cm of B horizon.

The Roshe Springs silt loam is not found along the southern section of the Malad River. It is, however, found west of the river channel with a distribution that looks like a drainage pattern. Figure 2 shows the location of the Roshe Springs soil within the study area.

**Fauna**

A description of each molluscan taxon and its synonymies is listed below.

**GASTROPODA**

**LYMNAEIDAE**

*Lymnaea stagnalis*, Say 1818 (Fig. 8a)

*Limnaea*

Whorls flatly rounded; shell elongate, narrow and thin; spire acutely pointed, occupying over half the length of the shell.
Fig. 8. Molluscs present along the Malad River: a. Lymnaea stagnalis (2X)(USU 88-1); b. Lymnaea palustris (2X)(USU 88-2); c. Physa gyrina (2X)(USU 88-3); d. Lithoglyphus hindsii (2X)(USU 88-4); e. Anodonta californiensis (IX)(USU 88-5).
Lymnaea palustris, Muller 1774 (Fig. 8b)

Stagnicola
Galba
Limnophysa

Spire short; sutures impressed; shell ovate, thinly striated, robust; aperture more than 1/2 the length of the shell.

PHYSIDAE

Physa gyrina, Say 1821 (Fig. 8c)

Physella

Spire usually shorter than aperture; aperture contracted at the top and rounded at the bottom; shell sinistral, elongate or oblong.

AMNCOLIDAE

Lithoglyphys hindsii, (Fig. 8d)

Amnicola
Leptaxis
Pluminicola fusca

Whorls subangular; aperture rounded posteriorly; shell smooth, conic and subglobose.

PLANORBIDAE

Helisoma subcrenatum, Carpenter 1856 (Fig. 9a)

Planorbella
Planorbis
subcrenata

Large ultra-sinistral shell; whorls enlarge very quickly; spire is generally sunken.

Gyranlus parvus, Say 1817 (Fig. 9d)

Anisus
Planorbis
Segmenting

Very small ultra-dextral shell; rapidly increasing whorls; spire sunken.
Fig. 9. Molluscs present along the Malad River: a. Helisoma suberetatum (2X)(USU 88-6); b. Valvata humeralis (6X)(USU 88-7); c. Sphaerium striatum (2X)(USU 88-5); d. Cyranus parvus (6X) (USU 88-9).
VALVATIDAE

Valvata humeralis, (Fig. 9b)

Humerosa

Very small shell; whorls rounded; circular aperture; lip is sharp and operculum is orbicular.

PELECYPODA

ANODONTIDAE

Anodonta californiensis, Lea 1852 (Fig. 8e)

Margaron
californica

Shell long, elliptical with a low beak; dorsal side is nearly straight.

SPHAERIIDAE

Sphaerium striatinum, Lamark 1818 (Fig. 9c)

Cyclas
striatum
dentatum

Shell small, thin, oval to suborbicular.
AGE AND DEPOSITIONAL ENVIRONMENTS

The stratigraphy of the fossiliferous deposits is a product of three different depositional environments separated by periods of erosion. The grey, silty clay basal deposit represents a deltaic environment characterized by ripple marks, scour-and-fill features, small scale cross-bedding and planar beds (Davis, 1978). The proportion of silt and clay (32.03% and 61.07%, respectively, with a mean of 7.4 Ø) suggests that the study area lay between a delta front and a prodelta (Davis, 1978). This interpretation is supported by low sediment size variation and high lateral continuity within the 3 m of exposed sediment. The delta was deposited during Lake Bonneville, approximately 11,000 - 13,000 yr B. P. (Currey and Oviatt, 1985), evident by the elevation of the deposit (1284 - 1288 m) and by the presence of gypsum crystals in the sediment. The crystals formed because high amounts of calcium sulfate were present in the lake and, consequently, in the lake sediments. The calcium sulfate then precipitated as gypsum crystals (C.A. Oviatt, personal communication).

The sandy middle unit represents a shallow, low-energy stream environment. Evidence for this interpretation includes: 1) well-sorted, subrounded sandy sediment with 83.2% sand size grains (mean of 3.4 Ø); 2) cross-bedded sand layers, suggesting that current direction shifted a number of times during deposition with interspersed periods of erosion; 3) CaCO₃ casts of reed and shell material, which characteristically form as organic material is rolled along a chemically conducive stream channel (D.R. Currey, personal communication); and 4) the presence of wavy laminations and ripples, which suggest water movement. Further evidence includes the dominant presence of *Sphaerium striatum*, which prefers streams and non-stagnant lakes (Hornbach et al., 1982), the presence of *Anodonta californiensis*, which is generally found in stable sand substrates in rivers (Stern, 1983), and the absence of *Lymnaea stagnalis*,
which prefers stagnant water (Boubjerg, 1975; Scheerboon and Elk, 1978). This unit dips slightly to the southeast, suggesting that the Malad River has exposed the shoreline of the ancient stream where reeds and blue-green algae were present. A date of 7690 ± 270 14C yr B. P. (GX-10015) for *Sphaerium striatum* shells found in this unit (Fig. 4) indicates that the underlying unconformity represents at least 2000 years of time.

The environmental conditions during the period of deposition of the upper dark brown silt unit fluctuated frequently. Generally, the environment was river-associated, possibly an overbank marsh, with a low flow component. This is evident from the grain size distribution, with 45.39% - 58.25% of the sediment falling in the silt size range and 35.41% - 42.66% being clay size (means range from 5.7 φ - 7.0 φ), suggesting a very low energy environment (Folk, 1974). Other evidence includes: 1) the absence of sedimentary features characteristic of moving water, such as ripples, cross-bedding, lenticular deposits and wavy laminations and 2) the presence of *Lymnaea stagnalis*, which prefers slow to stagnant water (Boubjerg, 1975; Scheerboon and Elk, 1978). An analysis of the ostracod fauna by R. M. Forester of the USGS (Denver) found six species present, including *Candono acuminata*, *C. caudata*, *C. rawdoni*, *C. distincta*, *Cypridopsos vidua* and *Cyprideis beaconensis*. This assemblage supports the low-energy hypothesis and suggests that Ca-Mg-HCO3 and Na-Cl were codominant solutes, with a salinity of less than 3000 ppm, probably fluctuating between 300 ppm and 1500 ppm throughout the year. The water temperature was generally cold (below 20 - 25° C) (R.M. Forester, personal communication).

The age of this upper deposit is somewhat uncertain. A date of 2420 ± 135 14C yr B. P. (GX-9773) was obtained for carbonized wood collected at an elevation of 1290 m. Amino acid dating techniques were used to evaluate four samples of gastropods collected from 1293, 1294 and 1297 m (Fig. 4). Amino acid dates ranged from 1200 - 2300 yr B. P., with an average of 1700 ± 400 yr B. P.
From the youngest and oldest possible dates above, it is concluded that the age of this deposit is between 1200 and 2555 yr B. P. Due to the greater accuracy associated with $^{14}$C dates on carbonized wood, it is suggested that the actual age is closer to $2420 \pm 135$ $^{14}$C yr B. P. Amino acid dating techniques rely on the assumed effective temperature for the depth at which the sample was taken, which reduces the reliability of the results (W.D. McCoy, personal communication). Other sources of uncertainty include the kinetics of epimerization in Physa and the variance in the alloisoleucine/isoleucine ratio. Therefore, the confidence in the approximate amino acid age should be $\pm 50\%$ (W.D. McCoy, personal communication).

The regional distribution of the mollusc-rich deposits was controlled by the geomorphic processes which altered the course of the Malad River channel. Analysis of aerial photographs reveals a shallow, abandoned channel which coincides with the characteristic soil type of the fossiliferous deposit (Rw on Figure 2). Broken shell material is present at the surface along this channel, including a few identifiable Physa gyrina shells. The channel appears to have once been connected with the Malad River at location XX (Fig. 2), suggesting an explanation for the difference in geomorphology and stratigraphy of the northern exposures and southern exposures of the river channel. Sampling locations and reconnaissance mapping showed that each of the fossiliferous terraces along the Malad River were formed by cut-and-fill processes. No terraces, and therefore no fossils, were present south of location XX. It is suggested that the Malad River flowed along a now-abandoned channel south of XX when the fossils were deposited prior to $2420 \pm 135$ $^{14}$C yr B. P. Therefore, the lateral distribution of the fossiliferous deposits is controlled by the geomorphic processes which altered the course of the Malad River after the deposition of the most recent fossiliferous sediment at $2420 \pm 124$ $^{14}$C yr B. P.
BIOSTRATINOMY

Low-Energy Stream Environment

Analysis of the fossil assemblage present in the sand unit, which was deposited at 7690 ± 270 14C yr B. P., suggests that the fauna has undergone a minimal amount of disturbance from biostratinomic processes. The disturbance represents only minimal effects since two of the six tests and observations used to detect biostratinomic influence indicate that the fauna has been disturbed while the remaining four do not. Evidence supporting a relatively undisturbed fauna includes the presence of six articulated *Anodonta californiensis* shells, which are very large and fragile and which separate and abrade very rapidly if transported or disturbed (D. R. Currey, personal communication) and a statistical analysis of right and left *Sphaerium striaturn* valve distributions. Out of a sample size of 84, 41 right valves and 43 left valves were present, which indicates that no selective transport of the valves has occurred, since the calculated values encompass the random distribution of 50% right valves and 50% left valves with a 95% confidence interval. Other evidence includes the well-preserved state of the gastropod and pelecypod shells, with approximately 80% of a sample of 200 gastropods exhibiting unbroken spires and apertures and 65% retaining the periostracum and original color.

Orientations of 150 *Sphaerium striaturn* shells were taken from two randomly selected sites and the data plotted in 5° intervals on two rose diagrams (Figs. 10 and 11). Statistical analysis indicates that the orientations are random and, therefore, also suggests that the shells have not been disturbed by post mortem process.

Evidence supporting at least minor disturbance includes the fact that only 24% of the *S. striaturn* shells were articulated and the observation that approximately 30% of the disarticulated *S. striaturn*
Fig. 10. Rose diagram showing orientations of 150 *Sphaerium striatinum* pelecypods plotted in 5° intervals. Measurements were made along the bisection line from umbo to ventral margin (14C-2, 1288 m).
Fig. 11. Rose diagram showing orientations of 100 *Sphaerium striatum* pelecypods plotted in 5° intervals. Measurements were made along the bisection line from umbo to ventral margin (8-83, 1296 m).
were found in a hydrodynamically stable position, stacked in piles of 3 - 6 shells, thus suggesting that the position of the shells had been affected by fluid dynamics.

It is therefore concluded that the fauna contained in the sand unit has been only slightly disturbed by biostratinomic processes.

River-Associated Environment

As in the low-energy environment, biostratinomic processes only slightly altered the fossil assemblage deposited at 2420 ± 135 \(^{14}\)C yr B. P. As before, a few lines of evidence support disturbance while most do not. Evidence supporting an undisturbed assemblage includes: 1) the presence of 4 articulated *Anodonta californiensis* shells, 2) the statistical analysis of the distribution of right and left *Sphaerium striatinum* shells, with a sample size of 256 shells and a right valve occurrence of 127, and 3) the preservational state of the fossils, with 92% of the gastropods exhibiting unbroken spires and apertures and 75% retaining the periostracum and original color.

Seven size-frequency curves from 7 samples of *Physa gyrina* with varying sand/silt ratios were visually compared (Figs. 12 and 13). Generally, all of the distributions were similar to Olsen's (1957) predicted right-skewed curve, with high juvenile mortality and slow growth, suggesting that *P. gyrina* was well-adapted to all of the environments it inhabited (Dodd and Stanton, 1981). Fourteen size-frequency curves from 7 samples of *Lymnaea palustris* (Figs. 14 and 15) and *Lymnaea stagnalis* (Figs. 16 and 17) were also compared. Curve shape was generally the same for all 3 species. It is concluded the *P. gyrina*, *L. palustris* and *L. stagnalis* were well-adapted to a number of environments, having recurred in 7 of 9 fossiliferous samples with varying sand/silt ratios.

The general shape of 10 size-frequency curves from 5 samples of *Gyranulus parvus* were compared (Fig. 18 and 19). Approximately 25% of the
Fig. 12. Size-frequency distribution curves for Physa gyrina (sample numbers indicated) showing generally right-skewed shapes.
Fig. 13. Size-frequency distribution curves for *Physa gyrina* (sample numbers indicated) showing generally right-skewed shapes.
Fig. 14. Size-frequency distribution curves for Lymnaea palustris (sample numbers indicated) showing generally right-skewed shapes.
Fig. 15. Size-frequency distribution curves for *Lymnaea palustris* (sample numbers indicated) showing generally right skewed-shapes.
Fig. 16. Size-frequency distribution curves for *Lymnaea stagnalis* (sample numbers indicated) showing generally right-skewed shapes.
Fig. 17. Size-frequency distribution curves for Lymnaea stagnalis (sample numbers indicated) showing generally right-skewed shapes.
Fig. 18. Size-frequency distribution curves for Gyranlus parvus (sample numbers indicated). Note normal shape of curves from samples 9-83 and 7-83.
Fig. 19. Size-frequency distribution curves for Gyranlus parvus (sample numbers indicated). Note normal shape of curve from sample 3-83.
curves were normally distributed while the rest were right-skewed, with high juvenile mortality. A normally distributed size-frequency histogram suggests biostratinomic disturbance (Olsen, 1957; Dodd and Stanton, 1981) and, therefore, it is concluded that approximately 25% of the *G. parvus* population deposited within the upper dark brown silt unit had been disturbed. The same was found to be true for *V. humeralis*.

Thus, a small percentage of *G. parvus* and *V. humeralis* shells were affected by biostratinomic processes while populations of *P. gyrina*, *L. palustris* and *L. stagnalis* in the same samples were not. Both *G. parvus* and *V. humeralis* are minute species of gastropod, roughly averaging 2.0 mm in height and 2.3 mm in diameter of largest whorl. *P. gyrina*, *L. palustris* and *L. stagnalis* are all much larger, averaging roughly 7.0 mm in height and 4.0 mm in diameter of largest whorl. It is therefore suggested that biostratinomic processes were only strong enough to affect the small *G. parvus* and *V. humeralis*, causing 25% of the size-frequency curves to be normally distributed. Biostratinomic processes were never strong enough to affect the larger gastropod species and, therefore, all of their size frequency curves are right-skewed.
COMMUNITY STRUCTURE

Newell et al. (1959) suggested that three different community types exist. They are: (1) communities controlled entirely by habitat, where members only exist in a specific environment; (2) communities controlled totally by recurring members; (3) communities controlled by intimately associated biotic interactions. Types 1 and 2 are easily defined since they are statistical evaluations and not based on member interactions. They are also most applicable to the fossil record (Newell et al., 1959).

For the purposes of this research, a community will be defined as an assemblage of recurring members with consistent dominant species. This combines type 2 and 3 of Newell et al. (1959) classification by recognizing the importance of both recurrence and trophic interactions of the dominant and subdominant species.

Taxonomic Composition

Table 1 lists the percentage of each species present in each sample. Based on the above criterion, three communities were present within the study area. The most common community was present in 66% of the fossiliferous samples and contained six species of gastropods including Valvata humeralis, Lymnaea palustris, Physa gyrina, Helisoma subcrenatum, Lymnaea stagnalis and Gyranlus parvus, with V. humeralis as the dominant species. Sample 18-83 contains only four of the six species, but it has been placed in this community due to the abundance of V. humeralis.

The second most common community occurred in 22% of the fossiliferous samples. It is characterized by the presence of five species of gastropods, including Lymnaea palustris, Physa gyrina, Helisoma subcrenatum, Lymnaea stagnalis and Gyranlus parvus, with L. palustris being dominant.

The third community contains three species of molluscs that do not appear in the two previous communities. Four species of gastropods (Lymnaea palustris, Physa gyrina, Helisoma subcrenatum and
Table 1. Percentage of each species present in samples.

<table>
<thead>
<tr>
<th>SPECIES (%)</th>
<th>SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-83 2-83 3-83 4-83 7-83 9-83 10-83 17-83 18-83 140-2</td>
</tr>
<tr>
<td>H. subcrenatum</td>
<td>0.05 0.13 10.3 2.63 1.40 0.66 0.44 2.20 0.0 0.08</td>
</tr>
<tr>
<td>L. palustris</td>
<td>2.56 1.90 72.5 61.6 3.74 6.13 13.3 34.8 0.82 6.54</td>
</tr>
<tr>
<td>P. gyrina</td>
<td>4.60 3.08 11.1 24.4 25.2 22.6 13.7 0.73 1.24 0.40</td>
</tr>
<tr>
<td>L. stagnalis</td>
<td>1.25 0.45 3.00 4.63 13.5 1.26 2.53 1.17 0.0 0.49</td>
</tr>
<tr>
<td>G. parvus</td>
<td>4.39 0.0 3.03 3.63 14.2 16.0 6.44 8.08 13.2 0.0</td>
</tr>
<tr>
<td>L. hindaii</td>
<td>0.0 5.36 0.0 0.0 0.0 0.0 0.0 0.0 0.0 14.4</td>
</tr>
<tr>
<td>V. humeralis</td>
<td>87.1 0.0 0.0 2.63 41.6 53.3 63.4 52.7 84.6 0.0</td>
</tr>
<tr>
<td>S. striatinum</td>
<td>0.0 88.9 0.0 0.0 0.0 0.0 0.0 0.14 0.0 77.0</td>
</tr>
<tr>
<td>A. californiensis</td>
<td>0.0 0.07 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.90</td>
</tr>
</tbody>
</table>
Lithoglyphus hindsii), and two species of pelecypods (Anadonta californiensis and Sphaerium striatinum) are present in community three, with S. striatinum being the dominant species.

Cluster analysis was used to group samples based on their species content. Samples were clustered using Euclidean distance as the coefficient of dissimilarity. Those samples representing similar biofacies clustered together and were then considered to contain recurring communities of fossils. The dissimilarities between sample pairs are presented in Table 2.

Sedimentologic Relationships

The distribution of the number of individuals for each species as compared to the sand/silt ratio is presented in Figure 20. Generally, the highest number of individuals is found in the siltier sediment (sediment with a sand/silt ratio of approximately 0.2 - 0.4). Sphaerium striatinum is the only exception to this generalization and will be discussed in more detail later. Members of both the Valvata humeralis and Lymnaea palustris communities decrease in number in sediment with a sand/silt ratio greater than 1.0.

The members of the Sphaerium striatinum community are restricted to those substrates with a high sand/silt ratio. The preference of suspension feeders for sediments with low silt and clay fractions has been documented in various studies (Stump, 1975). It therefore seems likely that S. striatinum is restricted to sandy substrates due to its feeding habits, thus reflecting a different trophic structure than the other two communities.

Lythoglyphus hindsii is the second most dominant species in community 3, though it represents only 5.3% of the fossil assemblage as compared to 88.9% for Sphaerium striatinum. Unlike the other gastropods, L. hindsii is not present in any of the other communities. Walker (1971) states that the most dominant species in terms of biomass will be of a different feeding group than the second most abundant species. Applying
Table 2. Resemblance matrix for clustered distribution of samples. Similarity of samples decreases with increasing values.

<table>
<thead>
<tr>
<th>SAMPLES</th>
<th>1-83</th>
<th>2-83</th>
<th>3-83</th>
<th>4-83</th>
<th>7-83</th>
<th>9-83</th>
<th>10-83</th>
<th>17-83</th>
</tr>
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<tbody>
<tr>
<td>2-83</td>
<td></td>
<td>124</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-83</td>
<td>112</td>
<td></td>
<td>114</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>4-83</td>
<td>105</td>
<td>109</td>
<td></td>
<td>19</td>
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<td></td>
</tr>
<tr>
<td>7-83</td>
<td>52</td>
<td>102</td>
<td>83</td>
<td>71</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>9-83</td>
<td>40</td>
<td>106</td>
<td>87</td>
<td>76</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-83</td>
<td>27</td>
<td>110</td>
<td>87</td>
<td>78</td>
<td>29</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-83</td>
<td>47</td>
<td>108</td>
<td>66</td>
<td>61</td>
<td>43</td>
<td>36</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>18-83</td>
<td>10</td>
<td>123</td>
<td>112</td>
<td>105</td>
<td>51</td>
<td>38</td>
<td>28</td>
<td>46</td>
</tr>
</tbody>
</table>
Fig. 20. Distribution of the number of individuals for each species as compared to the sand/silt ratio.
this property to the *S. striatinum* community, *L. hindsii* is of a different group than *S. striatinum*, yet unlike most deposit feeders, it does not prefer finer-grained substrates. This could be due to physical parameters such as the amount of plant material and oxygen in the sediment or physiologic factors such as the size of the radula.

The stratigraphic distribution of the three communities can be seen in Figure 21. Samples taken from the same elevation (Samples 1-83, 7-83 and 10-83) contained the same community since these samples represented approximately the same period of time. However, differences of even 30 cm of elevation, or brief periods of time, correspond to drastic changes in community structure (Samples 2-83 and 4-83; Samples 3-83 and 8-83) and sediment. Therefore, during the deposition of the fossiliferous sediments, the environmental conditions fluctuated frequently, resulting in changes in the fossil assemblages.

**Diversity**

Shannon-Weaver values were grouped according to the community present (Table 3). Community 1, dominated by *Valvata humeralis*, and Community 2, dominated by *Lymnaea palustris* have generally higher values than Community 3. Therefore, the species in Communities 1 and 2 are more equally abundant than the species in Community 3.

The equitability of Community 3 is closer to 0 than the equitability of Communities 1 or 2, which have similar values. Therefore, as expected from the low dominance diversity index, one species is more dominant in Community 3 than in the other communities. In this case the dominant species is *Sphaerium striatium*. In both calculations the community dominated by *Valvata humeralis* fell between the *L. palustris* and *S. striatinum* communities.
Fig. 21. Stratigraphic distribution of the three communities.
Table 3. Dominance diversity ($H'$) and equitability values ($J'$).

<table>
<thead>
<tr>
<th>SAMPLES</th>
<th>DOMINANCE DIVERSITY</th>
<th>EQUITABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-83</td>
<td>0.541</td>
<td>0.302</td>
</tr>
<tr>
<td>7-83</td>
<td>1.433</td>
<td>0.800</td>
</tr>
<tr>
<td>9-83</td>
<td>1.216</td>
<td>0.678</td>
</tr>
<tr>
<td>10-83</td>
<td>1.113</td>
<td>0.259</td>
</tr>
<tr>
<td>17-83</td>
<td>1.075</td>
<td>0.552</td>
</tr>
<tr>
<td>18-83</td>
<td>0.512</td>
<td>0.369</td>
</tr>
<tr>
<td>Community 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-83</td>
<td>0.918</td>
<td>0.570</td>
</tr>
<tr>
<td>4-83</td>
<td>1.106</td>
<td>0.568</td>
</tr>
<tr>
<td>Community 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-83</td>
<td>0.464</td>
<td>0.238</td>
</tr>
</tbody>
</table>
GEOMORPHIC INTERPRETATIONS

As previously stated, the basal deltaic material was deposited while Lake Bonneville covered the study area from 11,000 - 32,000 yr B. P (Currey and Oviatt, 1985). The recession of the lake and concurrent drop in the base level, which occurred prior to 7690 ± 270 14C yr B. P., caused the Malad River to degrade its channel, creating the unconformity that overlies the deltaic deposit. Analyses of aerial photographs of the area reveal a shallow, abandoned channel west of the present-day course, south of XX (Fig. 2), which appears to have once been connected with the Malad River. It is suggested that the Malad River flowed down the now abandoned course during this lake recession. Further evidence for a change in channel location will be presented throughout the interpretation.

Approximately 7690 ± 270 14C yr B. P. a major rise in the lake-level caused the Malad River to begin aggrading its channel. Possible causes for this rise will be discussed later. The sandy middle unit of the stratigraphic section was deposited during the aggradation phase. The shallow water, low-energy environment supported a variety of life, including numerous molluscs, reed plants and blue-green algae.

No evidence of the middle sandy, highly fossiliferous deposit is present along the present-day channel south of location XX (Fig. 2), which is the intersection of the present Malad River and the abandoned channel. The absence of fossils along the present-day channel south of XX suggests that the Malad River was still following its old channel during the rise in the lake level approximately 7690 ± 290 14C yr B. P.

At some point between 7690 ± 270 14C yr B. P. and 2420 ± 135 14C yr B. P. the Malad River began to degrade its channel, creating another unconformity. As with the sandy fossiliferous deposit, no evidence of the unconformity exists south of location XX, along the present Malad River channel.
The Malad River aggraded its channel again before 2420 ± 135 \(^{14}\text{C}\) yr B. P. This time, however, a low-energy stream environment existed. As much as 6.2 m of dark brown silt was deposited before the water level dropped and degradation resumed. Terraces and scarps, cut by previous erosional episodes, were back-filled to a level of 1 - 2 m below the surrounding lacustrine deposits. No terraces were formed south of location XX, along the present river channel, as the Malad River was still flowing along its old course at that time.

It is suggested that the Malad River overflowed its levees during the last episode of high water (2420 ± 135 \(^{14}\text{C}\) yr B. P.) and found a topographic low at location XX, east of its old course, which eventually led to the Bear River. The low became the present-day course of the Malad River. This theory is supported by the presence of gentle meanders and lack of terraces (which are characteristic of a young river) along the southern section, while the northern section exhibits more mature features, such as terraces, scarps, tight meanders and many generations of landslide scars. The sediment exposed along the southern section is a homogenous, reddish-brown silty clay which has not been interrupted by aggrading and degrading episodes as has the northern section.

Other evidence supporting the capture of the Malad River by the Bear River includes the presence of fossil mollusc shells found along the old course of the Malad River. Though many of the shells at the surface are fragmented, there are identifiable shells of *Physa gyrina*, a species that is found along the Malad River, north of location XX. No shells of any type are found along the present-day river course south of location XX, even though fossils are very abundant north of the inferred capture point.

The soil profile on the terraces of the last aggrading episode (Roshe Springs silt loam) does not contain a B horizon, as would be expected of a soil which has only been developing for 2420 ± 135 yr (C. G. Oviatt, personal communication). The surrounding soils, including those which are cut by the southern section of the river, have a well-developed B horizon, indicating a much older age (W. D. McCoy, personal
communication). The Roshe Springs silt loam coincides with the proposed old river channel, thus supporting a post 2420 ± 135 $^{14}$C yr B. P. date for the capture of the Malad River.
REGIONAL IMPLICATIONS

Periods of deposition and erosion, as seen along the Malad River, can be explained by four geomorphic hypotheses. Three of the four theories are not substantiated by field evidence, and therefore they will be briefly dealt with.

Tectonic uplift, tilting or isostatic rebound within the study area could have caused the Malad River to fluctuate between aggradation and degradation of its channel. These are, however, unlikely since geomorphic events took place rapidly based on dates from fossil material, and regional observations do not suggest rapid tectonic activity (W. D. McCoy, personal communication).

Capture of the Malad River by a tributary of the Bear River (similar to the event which led to the shifting of the Malad River channel after 2420 ± 135 14C yr B. P.) could have caused the Malad River to erode and aggrade the channel. This, too, is unlikely since both the Malad River channel north of location XX and the Bear River channel have high, untruncated levees, whereas levees are absent along the present-day Malad River channel south of location XX.

Headward erosion by the Malad River, leading to periodic capture of additional drainage, could have caused those events seen in the Malad River area. This theory is unlikely because of the brief time between events and the lack of supporting geomorphic evidence.

The fourth hypothesis suggests that climatic changes resulting in base level changes caused the Malad River to aggrade and degrade the channel. The base level of the Malad River, a tributary of the Bear River, is indirectly related to the elevation of the Great Salt Lake, into which the Bear River drains. The proposed periods of deposition and erosion by the Malad River may be the result of major fluctuations in the lake level of the Great Salt Lake during the Holocene Epoch. Numerous rises and falls have been proposed based on periods of climatic change.
within the region (Currey and Madsen, 1974; Currey, 1980; Currey and James, 1982), though estimates of the exact lake levels and times of occurrence vary greatly.

The oldest Holocene rise in lake level, as inferred by the stratigraphy of the Malad River, occurred before 7690 ± 270 \(^{14} \text{C} \) yr B. P. Beget (1983) defines a period of glacial advance between 7500 - 8500 B. P. as "Mesoglaciatiion," using radiocarbon-dated glacial deposits from various areas of the world. He cites evidence from the North Cascade Range of Washington as well as from the Rocky Mountains. Currey and James (1982) acknowledge the possibility of a rise in the Great Salt Lake at approximately 7500-8500 B. P., but suggest that more glacial and lacustrine evidence is needed.

The nature of the Malad River deposits at 7690 ± 270 \(^{14} \text{C} \) yr B. P. suggests that the Great Salt Lake did rise in response to climatic change that resulted in a period of Mesoglaciatiion. Shoreline features which would determine the exact level of the Great Salt Lake at about 7690 B. P. have not been found. As more surficial features are dated, shoreline evidence may be discovered.

The proposed drop in lake level between 7690 ± 270 and 2420 ± 135 \(^{14} \text{C} \) yr B. P. coincides with the Hypsithermal interval of warm climate during the middle Holocene epoch (Deevey and Flint, 1957). Warm temperatures, possibly warmer than today (Beget, 1983), may have caused an increase in evaporation and a subsequent drop in lake elevation. The Malad River presumably responded to this decrease in base level by degrading its channel, producing the previously mentioned unconformity at 1289 m.

Numerous pieces of evidence have been documented supporting a rise in the Great Salt Lake approximately 2500 yr B. P. in response to another climatic change (Currey et al., 1988). Geological and biological evidence for a glacial and pluvial maximum at this time has been proposed by Currey and James (1982). Mehringer (1977) suggests that higher lake levels than today's occurred between 3600 and 2800 yr B. P., based on a core from the
bottom of the Great Salt Lake. $^{14}$C dates from the Sevier Desert, Utah, imply that there was a large expanse of wetlands existing in the area at 2000 - 3000 yr B. P. (D. R. Currey, personal communication).

The rise in lake level 2000-3000 yr B. P. corresponds to the most recent period of deposition of the Malad River at 2420 ± 135 $^{14}$C yr B. P. As before, the exact elevation of the lake is uncertain. Based on the presence of the Roshe Springs silt loam, the lowest elevation at which sediment was being deposited in the old Malad River channel was 1288 m. It is suggested that the lake level was just below 1288 m at 2420 ± 135 $^{14}$C yr B. P. Though conclusive shoreline evidence is lacking, possibly due to the nature of the sediment and absence of sufficiently detailed research, a poorly developed shoreline has been discovered at 1286 m (D. R. Currey, personal communication). Such a shoreline supports the proposed lake level and further relates the stratigraphy of the Malad River to the water level of the Great Salt Lake.
CONCLUSIONS

The Malad River exposes fossiliferous Holocene deposits containing a variety of molluscs in Bear River Valley, Utah. Two environments and two periods of time are represented. A predominantly sandy unit was deposited in a low-energy stream environment at about 7690 ± 270 14C yr B. P. One community was present in this environment. Species included Anadonta californiensis, Lithoglyphus hindsii, Physa gyrina, Lymnaea palustris, Helisoma subcrenatum, Gyranulus parvus, Valvata humeralis and Sphaerium striaturn with S. striatinum as the dominant species. Reed plants and blue-green algae were also present. Only slight biostratinomic alteration of the fossil assemblage was found.

A dark-brown silt unit was deposited at 2420 ± 135 14C yr B. P. in a very low energy, river-associated environment, such as an over-bank marsh. Molluscs present included the above species and Lymnaea stagnalis. Three recurring communities were defined. One community, dominated by Sphaerium striatinum, was restricted to substrates with a high sand/silt ratio. This community was present during both periods of deposition. The two remaining communities were dominated by Valvata humeralis and Lymnaea palustris, respectively. Size-frequency distributions of V. humeralis and G. parvus indicate that the fossil assemblage has undergone slight alteration due to biostratinomic processes. The occurrence of only slight biostratinomic alteration is also supported by percentages of right and left pelecypod valves and preservation and orientations of the shells that were present. The biostratinomic effects were limited by the size of the fossils, with only the two minute species of gastropods being affected.

The distribution of molluscan fossils along the Malad River was not totally controlled by sedimentologic parameters. Geomorphic processes limited the regional distribution of the fossiliferous deposits and, thus, fossils are exposed today only where the present Malad River occupies the same channel as it did between 7690 and approximately 2500 years ago.
Two Holocene rises and falls in the elevation of the Great Salt Lake can be inferred from the stratigraphy and geomorphology of the Malad River area. The oldest rise occurred before 7690 ± 270 $^{14}$C yr B. P. in response to a period of worldwide Mesoglaciation (Beget, 1983). The second rise, also due to climatic change, occurred before 2420 ± 135 $^{14}$C yr B. P. at which time the lake reached an elevation of approximately 1286 m (4220').

The level of the Great Salt Lake decreased between 7690 ± 270 and 2420 ± 135 $^{14}$C yr B. P. This period of low water coincided with the Hyspithermal interval of warm climate during the middle Holocene Epoch (Deevey and Flint, 1957). A second drop in lake level occurred after 2420 ± 135 $^{14}$C yr B. P. The lack of younger terraces along the Malad River suggests that the lake dropped to approximately its present level with only minor fluctuations occurring after 2420 ± 135 $^{14}$C yr B. P.

The Malad River overflowed its levees into the head of a sleeper tributary during the last lake rise 2420 ± 135 $^{14}$C yr B. P. Subsequent down-cutting occurred when the base level of the valley dropped, forming a new channel which led to the capture of the Malad River by the Bear River.

The response of the Malad River to major fluctuations in the Great Salt Lake is useful in interpreting regional climatic events. Periods of deposition and erosion are very sensitive to changes in base level, thus making fluvial deposits a reliable indicator of lake level changes. Fluvial deposits are particularly useful when permanent shoreline features do not form due to rapid fluctuation of the lake level and low slope angle.
REFERENCES


