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Stratigraphy of Lake Bonneville deposits along Grouse Creek, northwestern Utah

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ABSTRACT

Stratigraphic studies of Lake Bonneville deposits (the Bonneville Alloformation) exposed along Grouse Creek in northwestern Utah show that the local stratigraphic sequence can be correlated with a generalized stratigraphic model for the Bonneville basin. The correlations are based on lithology and ostracode biostratigraphy. Major features of the Grouse Creek sequence are: 1) deposits representing the Stansbury oscillation, including evidence that suggests multiple fluctuations during Stansbury time; 2) a sand-marl-sand sequence interpreted as representing the open-water phase of Lake Bonneville, and which includes the transgressive, deep-water, and regressive (Provo) phases, and an abrupt contact caused by the Bonneville Flood; and 3) deltaic gravel that represents rapid regression at the end of the lake cycle.

INTRODUCTION

Deposits of Lake Bonneville are well exposed along Grouse Creek in northwestern Utah (Fig. 1). As part of a larger geologic mapping program in the region under the direction of D. M. Miller, these exposures were studied in an attempt to understand the depositional environments and lateral changes in facies over a map distance of 20 km (Plate 1) and altitudinal range of 1340-1460 m (Fig. 2). Stratigraphic sections were measured in the field and correlated by physical (lithologic) mapping, and by ostracode biostratigraphy. Three informal ostracode zones were defined that could be identified consistently from section to section even though the lithofacies changed slightly.

Lake Bonneville was the youngest and deepest of the large Quaternary lakes that formed in the Bonneville basin in response to cyclical climate changes (Gilbert, 1890; Morrison, 1966; Scott and others, 1983; McCoy, 1987; Oviatt and Currey, 1987; Oviatt and others, 1987; Currey, 1990; Oviatt and others, in preparation). The deposits of Lake Bonneville are formally referred to as the Bonneville Alloformation (Currey and others, 1984; McCoy, 1987; Oviatt, 1987). The lake began to rise after about 30 ka, and by about 25 ka had transgressed to altitudes in the lower part of the range in the study area (Fig. 2). Between 22 and 20 ka the lake went through at least one, and possibly several, oscillations on the order of 45 m, and formed the Stansbury shoreline or shoreline complex (Oviatt and others, 1990). Between 20 ka and 18 ka the lake transgressed more rapidly than during any other part of its history. This episode of rapid transgression is documented by numerous radiocarbon ages from shoreline facies (Scott and others, 1983; Oviatt and others, in preparation) and by ostracode and geochemical interpretations of sediment cores from Great Salt Lake (Spencer and others, 1984; Thompson and others, 1990). After 18 ka the transgression rate slowed, but the lake continued to rise until it overflowed into the Snake River drainage basin in southern Idaho about 15 ka. Intermittent overflow probably continued until about 14.5 ka, when the alluvial overflow threshold failed catastrophically and released a flood with discharge as great as 35×10^6 m^3s^{-1} through the Snake River valley in Idaho (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987), an event referred to as the Bonneville Flood. The Flood dropped the lake level approximately 108 m to a stabilized overflow threshold across bedrock, and the Provo shoreline formed during continued overflow between about 14.5 and 14.2 ka (Currey, 1982; Oviatt and others, in preparation). After about 14.2 ka the lake dropped below its overflow threshold and began to contract as a closed-basin lake; by 12 ka it had dropped to very low levels. A modest rise between about 11 and 10 ka formed the Gilbert shoreline.

In the Grouse Creek area, deposits were laid down during the transgressive phase, including part of the Stansbury oscillation, the subsequent deep-water phase, the Provo shoreline phase, and the post-Provo regressive phase (Fig. 2). Distinctive facies were deposited during these time intervals, and the history of the lake can be traced through the sequence of stratigraphic units.

Field studies for this project were completed during a two-week period in August, 1990. Samples were analyzed in the laboratories of the Department of Geology at Kansas State University, and the report was written during the winter and spring of 1990-1991. The work was supported by U.S. Geological Survey Contract 097199-90 to C. G. Oviatt under the direction of D. M. Miller.

STRATIGRAPHY

Introduction

Grouse Creek is an ephemeral stream that drains a large area in northwestern Utah and northeastern Nevada (Fig. 1 and Plate 1). During Lake Bonneville times it probably was a perennial stream with a relatively high discharge rate as indicated by deposits interpreted as fine- and coarse-grained deltaic facies. As Lake Bonneville regressed below the Provo shoreline the base level for Grouse Creek was progressively lowered and the stream entrenched its own deltaic deposits and the deep-water deposits of Lake Bonneville. These units are well exposed along the Grouse Creek valley (Plate 1). Similar deposits are exposed along Thousand Springs Creek, a tributary of Grouse Creek that heads in Nevada, but those deposits were not studied in this project.

Methods

Surficial deposits were mapped along Grouse Creek in a narrow band several kilometers wide (Plate 1; modified from Miller, 1985; Glick and Miller, 1987; and Miller and Oviatt, in preparation). Field descriptions and measurements of stratigraphic sections were taken at 31 locations in the Grouse Creek area (Plate 1). The descriptions included notes on lithology, grain size, bedding, thickness, color, and fossil content. Three of the 31 sections (17, 26, and 31; Plate 2) were measured at some distance from the Grouse Creek drainage system to serve as controls on the observations of lithologic and biostratigraphic sequences along Grouse Creek. Deposition at these three sections was not influenced by Grouse Creek. Stratigraphic sections were measured using a hand level and rod. Altitudes were determined from topographic maps, and are considered accurate to within one-half the contour interval (10 ft), or $\pm$0.75 m ($\pm$2.5 ft).

Stratigraphic units were traced in the field and plotted on aerial photographs. Correlations between erosional breaks and across valleys were accomplished by assuming continuity of similar stratigraphic sequences and by observations of ostracode faunas (Plate 2; Tables 1 and 2). Ostracodes were plainly visible in most fine-grained calcareous units, and identification to genus level was possible in some cases using 10X and 20X hand lenses in the field. In addition, small sediment samples were taken from critical units for analysis in the evening at the field station (see below), and a number of samples were taken back to Kansas State University for analysis. Ostracode samples consisted of small volumes (about 100 ml) of sediment collected from narrow stratigraphic intervals (<5 cm) from known positions in measured sections (Plate 2).

Laboratory analysis of ostracode samples consisted of the following treatment (after a procedure developed by R. M. Forester, written communication, 1988). A small volume of sediment was placed in a large plastic cup into which approximately 500 ml of boiling water were poured. At least one teaspoon of baking soda ($NaHCO_3$) was then added as a dispersant, the sample was allowed to cool to room temperature, and then at least one teaspoon of calgon (sodium hexametaphosphate plus sodium carbonate) was added and the sample was allowed to sit for approximately 12 hours. The sample was then examined to evaluate how well it had dispersed. If dispersion was incomplete, the sample was frozen solid, and subsequently allowed to thaw and remain at room temperature for approximately 12 hours. After thawing, or if dispersion was complete without freezing, the sample was carefully washed through a 100 mesh (0.149 mm openings) sieve, rinsed with deionized water, and washed onto a stack of paper towels, which were then carefully folded and allowed to dry. Dried samples were sieved by hand through a nested set of 3.5-inch sieves (40, 50, 60, & 80 mesh) and the ostracodes examined or picked and mounted on a micropaleontology slide using a 5/0 red sable brush under low magnification. Ostracodes were identified by C. G. Oviatt in consultation with R. M. Forester, who checked many of the identifications, provided reference slides, and discussed the implications of the faunas. Taxonomic nomenclature used here is that of Forester (Spencer and others, 1984; Forester, 1987; Thompson and others, 1990).

Some samples were treated using a simplified procedure at the field station to facilitate correlations while field work was progressing. Samples were placed in small plastic cups, treated with boiling water and baking soda, allowed to cool to room temperature, then washed through a 60-mesh sieve (0.25 mm openings). The residue was then rinsed onto a paper towel and allowed to dry. The ostracodes in the residue could then be examined under a 60X reflected-light microscope and identified. This procedure, although not as effective as the complete procedure outlined above, did allow the ostracode faunas to be characterized in a general way from each stratigraphic unit, and to be used in conjunction with ongoing field studies.

Informal ostracode zones were established in this study (Table 2) that proved useful in both local and regional correlations (i.e. with the sequence of Thompson and others, 1990).

Stratigraphic Units

A generalized stratigraphic column is presented in Figure 3. It shows the stratigraphic units that were defined in the field, and which were used in descriptions at individual measured sections. Some of these units can be traced throughout the area, whereas others are found only within certain elevation ranges.

Lower transgressive-phase deltaic sand (lower TDS)

The lowest stratigraphic unit (lower TDS; Fig. 3) consists of silt and fine sand exposed at a few localities along lower Grouse Creek east of Lucin (sections 2, 3, 9, 4, 10, & 5; Plate 2). The unit consists of horizontally bedded fine sand, silt, and minor silty clay, all of which are calcareous. A few medium-sand beds 15 to 30 cm thick are composed almost entirely of silicic volcanic ash shards reworked from Miocene deposits, which are widespread in the Grouse Creek drainage basin (D. M. Miller, oral communication, 1990). The unit is thinly to massively bedded, and is pale brown on fresh exposure and light gray on weathered surfaces. Its lower contact is not exposed and the unit is overlain by either transgressive-phase or regressive-phase sandy gravel, depending on the location of the individual section; downstream from section 4 regressive-phase sandy gravel rests on a disconformity at the top of the lower

TDS. The maximum exposed thickness of the lower TDS is about 10 m in sections 3, 4, and 9. Ostracodes are not common in the finer-grained layers, however Limnocythere staplini and fragments of Candona sp., probably C. caudata are present (Table 1). These ostracodes are typical of the L. staplini zone (Table 2), and allow a correlation with unit IIIe of Thompson and others (1990)(Fig. 2).

Based on the above characteristics the lower TDS is interpreted to represent deltaic deposition during the transgressive phase of Lake Bonneville. Similar deposits are present elsewhere in the Bonneville basin where large streams emptied into the rising lake and dropped their fine-grained load offshore. It is likely that the lower TDS is correlative, both temporally and in a facies sense, to the yellow clay of Gilbert (1890), which he interpreted as representing deep-water deposition, but which Oviatt (1987) reinterpreted as a fine-grained deltaic or underflow-fan deposit.

Transgressive-phase deltaic gravel (TDG)

Overlying the lower TDS in sections 5 and 10, and underlying the younger part of the Bonneville sequence in these and other sections upstream, is a sandy gravel unit (TDG; Fig. 3). The gravel consists of slightly rounded clasts of sedimentary (chert, carbonates, sandstone), metamorphic, and volcanic rocks, mostly less than 3 cm in diameter. These pebbles are matrix-supported in sand, which is composed of 10% or more silicic volcanic ash shards reworked from the Miocene deposits in the area. No good exposures of the sandy gravel were found, so information on the bedding is unavailable, but the thickness ranges from about 3 m to over 6 m. The stratigraphic relationships between TDG and the TDS units above and below it are best seen at section 5. No fossils have been found in the TDG sandy gravel.

I interpret the TDG unit to represent deposition in shallow water at the mouth of Grouse Creek where it emptied into Lake Bonneville. Because it is a coarser facies than the lower TDS, it is interpreted as representing a drop in water level, which caused entrenchment upstream from the mouth and reworking of previously deposited debris. Although the progradation of a delta into the lake is an alternative explanation for the coarsening-upward stratigraphic sequence (lower TDS to TDG), by comparison with other well-studied localities in the Bonneville basin (Oviatt and others, 1990), a reasonable inference can be made that the TDG represents the drop in lake level associated with the Stansbury oscillation. Along Grouse Creek, TDG is exposed at altitudes between about 1355 and 1370 m, which is within the expected range of Stansbury deposits for a locality in this position in the basin relative to the isostatic rebound of the basin (Oviatt and others, 1990, Table 2). The treansgressive deltaic gravel along Grouse Creek is analogous to or correlative with a deltaic pebbly sand unit within the yellow clay at the Old River Bed (160 km to the south-southeast), which is interpreted as representing the Stansbury oscillation (Oviatt, 1987). This correlation needs further testing, but is a reasonable working hypothesis until more data become available.

Upper transgressive-phase deltaic sand (upper TDS)

Locally overlying the transgressive-phase deltaic gravel, is another deltaic sand unit (upper TDS; Fig. 3), which is similar to the lower TDS, but is thinner, and contains a much greater percentage of sand. It is best exposed in a gravel pit at section 8 (Plate 1), where it is about 1.5 m thick, but it is not present in all sections in this altitudinal range. Ostracode samples from this unit collected at sections 5 and 8 are dominated by Limnocythere staplini, although other species are present (Table 1). This puts the upper TDS in the L. staplini zone (Table 2), which is correlative with unit IIIe of Thompson and others (1990)(Fig. 2). I interpret the upper TDS as being related to the Stansbury oscillation, which may have involved more than one fluctuation in lake level (Oviatt and others, 1990; Thompson and others, 1990). It may be equivalent to the "upper yellow clay" at the Old River Bed (Oviatt, 1987), but because of the relatively poor exposures at Grouse Creek, this correlation must be considered tentative.

Stansbury gravel (SG)

Well sorted and well rounded gravel (SG; Fig. 3) overlies the upper deltaic sand (TDS) or the transgressive-phase deltaic gravel (TDG) at sections 5, 6, 7, 8, and 13 (Plate 2). Because of its excellent sorting and rounding, and its consistent stratigraphic position, I interpret it as beach gravel marking the final post-Stansbury transgression of the lake. Formation of such a beach gravel would be expected if Grouse Creek had become entrenched in its delta during one or more lake-level fluctuations of the Stansbury oscillation and the transgressing lake reworked sand and gravel on the exposed surface of the delta. The Stansbury gravel is not mapped on Plate 1. The Stansbury gravel discussed here (SG) represents only part of the Stansbury gravel found in piedmont locations away from major streams where the Stansbury shoreline is well preserved (Oviatt and others, 1990). The Stansbury gravel in tufa-cemented shorelines is thicker and probably represents deposition during a large part of the Stansbury oscillation, rather than just the final post-Stansbury transgression.

Transgressive-phase marl and sand (TM)

Stratigraphically above the deltaic facies is a sequence of sand-marl-sand (TM-DWM-PM) that is interpreted as the open-water phase of Lake Bonneville. The lowermost of these units (TM) consists of a fining-upward sequence of calcareous sand, sandy marl, and marl. At sections close to the axis of the Grouse Creek valley, the TM unit is thicker and contains more mud than at more distal sections, probably as a result of the input of mud from Grouse Creek. Ostracodes are common and are representative of the L. staplini zone (Tables 1 and 2). A few gastropods are also present and diatoms are abundant in the upper part of the unit. In some sections the upper part of the unit is laminated, possibly as a result of rapid offshore influx of sediment. Tiny impressions of oppositely branched filamentous plants, possibly of the alga Chara or a related taxon, are common in the laminated mud or marl. The upper contact of TM is abrupt, at least in sections along Grouse Creek. At sections distant from Grouse Creek (17, 26, 31) the upper contact is not as easily defined, but at sections 26 and 31 it is placed at a thin layer of sand and fine gravel in the marl. At section 17, which is the lowest in altitude of all the sections, and which is distant from any stream or other source of coarse sediment, unit TM is laminated throughout and contains abundant diatoms, causing low bulk density.

I interpret the TM unit to represent deposition in relatively shallow water immediately after the Stansbury oscillation. The lake at this time would have begun its rapid transgression, but sediment supply was still very high due to the proximity of the shoreline and Grouse Creek. Therefore, accumulation rates were probably high, and the entire thickness of TM (3 to >8 m) could have been deposited in a very short time (hundreds of years?). The top of unit TM approximately coincides with the top of the L. staplini ostracode zone (Table 2), which is regarded as roughly equivalent to unit IIIe in Great Salt Lake core C (Thompson and others, 1990). Deposition of unit IIIe ended at approximately 20 ka (Thompson and others, 1990) (Fig. 2). At section 17, which is about 50 m below the Stansbury shoreline zone, the laminated, low-density marl of unit TM probably represents deposition during most of unit IIIe time, including the time of the Stansbury oscillation.

Deep-water marl (DWM)

Above the abrupt contact at the top of the TM unit is a sequence of laminated marl that grades upward into dense gray marl (DWM; Fig. 3). The laminated marl, which is only found in exposures along Grouse Creek, is conspicuous from a distance because it weathers to form an almost pure white surface in contrast to the grayer marl below and above it. Diatoms are abundant and the ostracodes are transitional between the L. staplini and C. adunca zones (see Tables 1 and 2, and Fig. 3 and Plate 2). Impressions of Chara? are locally abundant in the laminated unit.

The abrupt contact at the top of unit TM is expressed as a thin layer of sand and gravel at sections 26 and 31, which are far from any stream input. Laminations are not present at the base of unit DWM at these two sections or at section 17. The abrupt contact at the base of DWM and the laminations in this unit suggest that it might represent a perturbation in water depth, either a rapid increase or a drop in water level. More work is needed to test these hypotheses.

The laminations in the basal part of DWM grade upward into denser marl that is gray on fresh exposure. Matrix-supported pebbles, which are not uncommon in the marl, are interpreted as dropstones that probably were carried to the depositional site in ice that had picked up pebbles from the shoreline. Bedding is indistinct, and at most consists of diffuse, thin layering. Ostracodes are abundant, and are typical of the C. adunca zone (Tables 1 and 2). The middle of the unit is characterized by an ostracode fauna consisting almost entirely of two species, C. adunca and L. ceriotuberosa. This thin zone, which may be only 20 to 30 cm thick, is distinctive; no other ostracode zone in the sequence resembles it, and because of the large size of C. adunca and the distinctiveness of L. ceriotuberosa, the zone can often be recognized in the field using a hand lens. The dense gray middle to upper part of DWM with its distinctive lithology, ostracode fauna, and widespread distribution, is therefore a useful stratigraphic marker in the field.

Unit DWM is interpreted as being broadly correlative with unit IIId and most of unit IIIc of Great Salt Lake core C (Fig. 2; Thompson and others, 1990). Thompson and others (1990) noted an increase in ostracode abundance and diversity in the upper part of unit IIIc, which suggested to them that the drop in water level caused by the Bonneville Flood brought oxygenated water to the lake bottom without increasing dissolved solids in the water. However, they did not identify a lithologic boundary in the core as representing the Flood. In the Grouse Creek area the upper contact of the DWM unit is abrupt and consists of a sharp change from dense gray marl to finely laminated sandy marl that in some places contains abundant reworked ostracodes (at the base of PM, Fig. 3). This sharp contact, which is typical of many sections throughout the Bonneville basin, is interpreted as representing the Bonneville Flood (after Oviatt, 1987), and is marked on Plate 2 and Figure 3 as BFC. In the upper part of the dense DWM the ostracode diversity typically increases over that in the middle part of unit DWM, where the ostracode fauna may consist of only two or three species (see Table 1, samples 6F, 15C, 16G, 17H, 26E, and 31E, which were collected directly below the BFC). Therefore, at least in some of the Grouse Creek sections, ostracode diversity had begun to increase prior to the Bonneville Flood for some reason, and continued to increase after the Flood (Table 1). Therefore, the Flood probably did cause ostracode diversity to increase as Thompson and others (1990) suggest, but some other event caused increased diversity prior to the Flood in some of the Grouse Creek sections -- possibly oscillations in lake level at or near the Bonneville shoreline (e.g. the hypothesized Keg Mountain oscillation; Currey and others, 1983; Currey and Burr, 1988).

The Bonneville Flood contact (BFC), if correctly identified in measured sections, can be regarded as a time-parallel stratigraphic marker. The Flood occurred about 14.5 ka, and probably lasted less than one year (minimum of 8 weeks; Jarrett and Malde, 1987).

Provo and post-Provo marl and sand (PM)

The sandy marl (PM) directly above the Bonneville Flood contact (BFC) grades upward into marl that is similar to the DWM in many respects, although the Provo marl is generally sandier or may have laminations. The marl itself grades upward into calcareous sand, which in sections near the Provo shoreline (Fig. 3, sections 25, & 27-30), reaches a thickness of over 30 m. In sections 25, 27, 28, 29, and 30 (Plate 2) the Provo sand has a primary dip of as great as 15° down valley, and interfingers with deltaic gravel in the upper part of the sequence. These sections are close to the Provo shoreline and suggest foreset (prograding) deltaic deposition during the prolonged (hundreds of years?) stillstand at the Provo level. A few gastropod shells are present in the sand, and many of the ostracodes appear to be reworked (Table 1). Ostracode diversity increases in unit PM and in general the fauna consists of similar species, but in different proportions than in the older units (see sample 16I, Table 1, for an example of a very diverse fauna in PM). In addition, one common species (L. sappaensis), is not present in the older units. Impressions of Chara? are locally present.

The Provo marl and sand is a coarsening-upward sequence, and is interpreted as having been deposited during the formation of the Provo shoreline, and during the post-Provo regression as the shoreline moved progressively closer and coarse debris became more abundant. Its lower boundary is marked by the Bonneville Flood contact at about 14.5 ka. The age of its upper boundary is time-transgressive, and at any one section is dependent on altitude and the amount of truncation.

Regressive-phase deltaic gravel (RDG)

Overlying the Provo marl and sand is a regressive gravel unit (RDG) that is similar in composition and grain size to the transgressive-phase deltaic gravel (TDG). The contact between the regressive gravel and the underlying Provo sand is probably disconformable in most sections -- it is abrupt and the thickness of the PM is highly variable. Regressive gravel is mapped along the Grouse Creek valley, but thins laterally away from the stream and merges with piedmont lacustrine or alluvial deposits. Because of this distribution and its compositional similarity to the transgressive deltaic gravel (TDG), the regressive gravel is interpreted as deltaic gravel of Grouse Creek that has been reworked by waves at the mouth of the stream. RDG forms arcuate beach ridges on each side of the stream near and below the Provo shoreline and east of Lucin, which give the delta front a cuspate form (Plate 1). The cuspate form and distribution of RDG north of section 9 (Plate 1) suggests that a second distributary, in addition to the main channel south of section 9, was depositing gravel at the lake margin in this area (below about 1365 m). This northern distributary was abandoned after the lake dropped below about 1340 m. Deposition of RDG probably ended by about 12.5 ka (Fig. 2).

Lagoon marl (LM)

Barrier beaches that were formed from regressive deltaic gravel enclose lagoons at several places near the Provo shoreline. Deposits of two of these lagoons were measured in sections 28 and 29 (Plates 1 and 2). The lagoon deposits consist of calcareous sand or sandy marl, and contain reworked ostracodes and a few small gastropods.

CONCLUSIONS

Stratigraphic studies in the Grouse Creek area build on a stratigraphic model that is being developed in other parts of the Bonneville basin (Oviatt, 1987, 1989, 1991; Oviatt and others, 1990). Of importance is the recognition of the following features: 1) deposits representing the Stansbury oscillation, including evidence that suggests multiple fluctuations during Stansbury time (lower TDS, TDG, upper TDS, SG); 2) a sand-marl-sand sequence (TM, DWM, PM) interpreted as the open-water phase of Lake Bonneville, and which includes the transgressive, deep-water, and regressive (Provo) phases, and an abrupt contact representing the Bonneville Flood (BFC); 3) deltaic gravel interpreted as representing rapid regression (RDG); and 4) an ostracode biostratigraphic sequence that can be correlated both locally and with the ostracode zones established in cores taken from the center of the lake basin (Spencer and others, 1984; Forester, 1987; Thompson and others, 1990).

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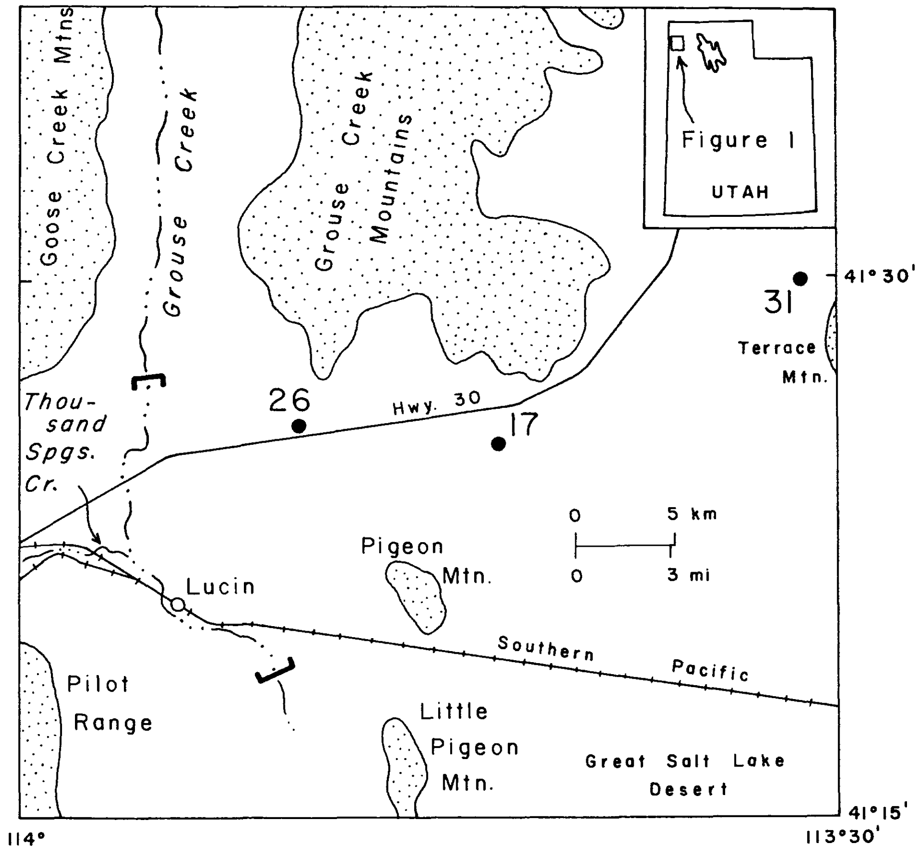

Figure 1. Map showing the location of the study area along Grouse Creek. The area in which surficial deposits are mapped in Plate 1 is between the brackets. The locations of measured sections 17, 26, and 31 are shown as dots.

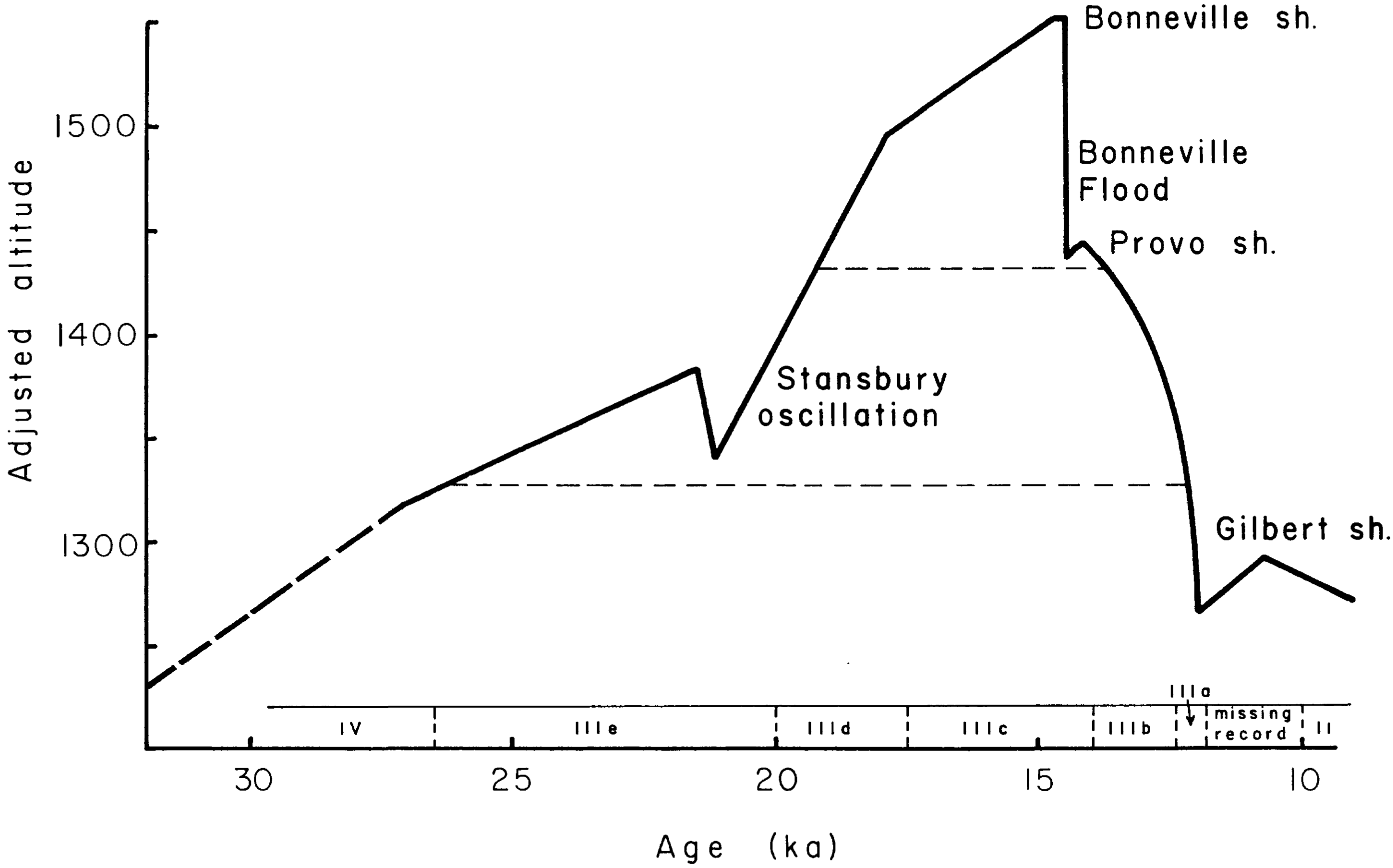

Figure 2. Time-altitude diagram for Lake Bonneville (after Oviatt and others, in preparation). The altitude of the water surface is plotted against time (in ka). Altitudes have been adjusted to account for the effects of differential isostatic rebound in the basin (Oviatt and others, in preparation). The exposures along Grouse Creek are found within the altitudinal interval shown by the shaded pattern. Units of Great Salt Lake core C (Thompson and others, 1990) are shown along the base of the diagram.

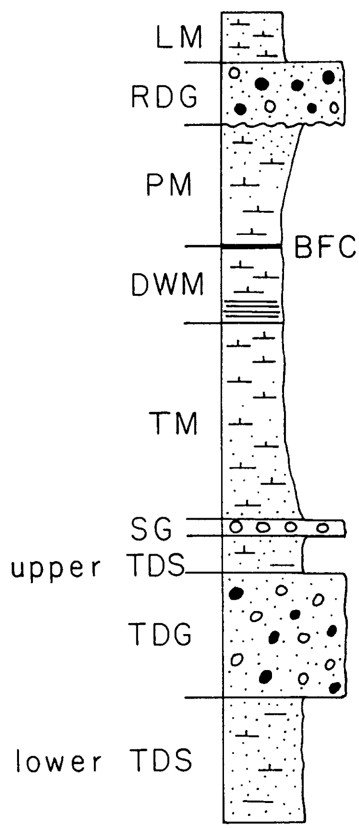

Figure 3. Generalized stratigraphic sequence in Lake Bonneville deposits along Grouse Creek. See text for explanation of the stratigraphic sequence and Plate 2 for explanation of lithologic symbols. Not drawn to scale; see Plate 2 for ranges in thickness of the individual stratigraphic units. LM = lagoon marl; RDG = regressive deltaic gravel; PM = Provo marl and sand; DWM = deep-water marl; TM = trangressive marl and sand; SG = Stansbury gravel; upper TDS = upper transgressive sand; TDG = transgressive deltaic gravel; lower TDS = lower transgressive sand; BFC = Bonneville Flood contact.

TABLE 1. Ostracodes[1] from stratigraphic sections in the Grouse Creek area

measured section	strat. unit[2]	sample letter	taxa[3]
3	TDS (lower)	A	*L. staplini C. sp.
5	TDS (upper)	A	*L. staplini L. ceriotuberosa Candona sp.
5	TM	B	*C. caudata *L. ceriotuberosa *L. staplini
5	DWM	C	*C. decora *C. adunca *C. caudata *L. ceriotuberosa L. staplini C. eriensis
5	PM	D	*L. ceriotuberosa *Cytherissa lacustris *C. adunca *C. decora *C. caudata C. patzcuaro or rawsoni L. staplini C. eriensis
5	PM	E	*L. ceriotuberosa C. adunca C. patzcuaro or rawsoni C. decora L. staplini
6	TM	A	*L. ceriotuberosa *C. caudata C. patzcuaro or rawsoni L. staplini
6	TM	B	*Candona sp. juv. *C. caudata *L. staplini C. adunca L. ceriotuberosa C. decora Cytheromorpha fuscata?

TABLE 1 (continued)

6	DWM	C	*C. caudata *C. decora L. ceriotuberosa L. staplini C. adunca
6	DWM	D	*C. adunca *L. ceriotuberosa C. caudata C. eriensis
6	DWM	F	*L. ceriotuberosa Cytherissa lacustris Candona sp. fragments
6	PM	G	*Cytherissa lacustris *L. ceriotuberosa C. caudata reworked C. adunca reworked C. decora C. eriensis reworked
6	PM	E	*Cytheromorpha fuscata ? L. ceriotuberosa C. caudata C. eriensis Cytherissa lacustris L. staplini
7	TM	A	*L. ceriotuberosa *Candona sp. fragments (prob. C. caudata) L. staplini C. decora
7	DWM	B	*C. caudata *L. ceriotuberosa L. staplini C. decora
8	TDS (upper)	A	*L. ceriotuberosa *C. patzcuaro or rawsoni L. staplini Cytheromorpha fuscata ?
15	TM	E	*C. patzcuaro or rawsoni *C. caudata *Cytheromorpha fuscata ? *C. adunca L. ceriotuberosa L. staplini

TABLE 1 (continued)

15	TM	A	*C. caudata (or like C. caudata) *L. staplini
15	DWM	B	*C. decora *L. staplini L. ceriotuberosa
15	DWM	C	*C. eriensis *C. caudata *L. ceriotuberosa *Cytherissa lacustris C. adunca
15	PM	D	*C. eriensis *L. ceriotuberosa *C. patzcuaro or rawsoni *Cytherissa lacustris C. caudata L. staplini C. adunca almost all valves are opaque-white indicating reworking
16	TM	L	*L. staplini L. ceriotuberosa C. patzcuaro or rawsoni Candona sp.
16	TM	A	*L. staplini *Candona sp. juv. (prob. caudata) C. caudata C. adunca C. decora Cytheromorpha fuscata ?
16	TM	B	*Candona sp. fragments (prob. caudata)
16	TM	C	*Candona sp. fragments (prob. caudata)
16	DWM	D	*Candona sp. fragments (prob. caudata) *L. staplini C. decora L. ceriotuberosa
16	DWM	E	*C. adunca *L. ceriotuberosa
16	DWM	F	*L. ceriotuberosa *C. adunca *C. eriensis

TABLE 1 (continued)

16	DWM	G	*L. ceriotuberosa *C. eriensis *Cytherissa lacustris *C. caudata C. adunca
16	PM	H	*L. ceriotuberosa *C. caudata *C. eriensis C. patzcuaro or rawsoni Cytherissa lacustris C. adunca
16	PM	I	*C. patzcuaro or rawsoni *C. caudata (some reworked) *C. eriensis *L. ceriotuberosa *L. friabilis ? *Ilyocypris gibba Physocypria globula C. distincta L. staplini
16	PM	J	Candona sp. fragments L. ceriotuberosa juv.
16	PM	K	Candona sp. fragments and juv. L. ceriotuberosa C. patzcuaro or rawsoni Cytheromorpha fuscata ? Cytherissa lacustris C. adunca most ostracodes in this sample appear reworked
17	TM	A	*L. staplini
17	TM	B	*L. staplini *C. caudata
17	TM	C	*L. staplini *C. caudata
17	DWM	D	*L. ceriotuberosa *C. caudata L. staplini
17	DWM	E	*L. ceriotuberosa Candona sp. fragments C. adunca L. staplini

TABLE 1 (continued)

17	DWM	F	*C. adunca *L. ceriotuberosa C. caudata
17	DWM	G	*C. adunca *L. ceriotuberosa C. caudata
17	DWM	H	*C. adunca *L. ceriotuberosa C. caudata L. staplini
17	PM	I	*C. eriensis *C. adunca *L. ceriotuberosa C. caudata L. sappaensis L. staplini
17	PM	K	*Candona sp. fragments and juv. C. caudata C. eriensis L. sappaensis L. staplini L. ceriotuberosa C. adunca juv. many or most of the ostracodes in this sample may be reworked
26	DWM	A	*C. caudata *C. sp. similar to C. caudata C. decora L. ceriotuberosa C. adunca L. staplini
26	DWM	B	*L. ceriotuberosa C. adunca C. decora C. caudata
26	DWM	C	*L. ceriotuberosa Candona sp. fragments C. caudata C. patzcuaro or rawsoni
26	DWM	D	*L. ceriotuberosa C. adunca C. caudata

TABLE 1 (continued)

26	DWM	E	*L. ceriotuberosa *C. adunca *C. caudata C. eriensis L. sappaensis L. staplini
26	PM	F	C. adunca L. ceriotuberosa L. sappaensis L. staplini C. eriensis
31	TM	A	*Candona sp. similar to C. caudata *C. caudata *L. staplini C. adunca C. decora L. ceriotuberosa
31	DWM	B	*L. ceriotuberosa *C. caudata C. adunca C. decora L. staplini
31	DWM	C	*C. adunca *L. ceriotuberosa
31	DWM	D	*C. adunca *C. caudata *L. ceriotuberosa C. eriensis L. staplini L. sappaensis
31	DWM	E	*C. eriensis *L. ceriotuberosa *C. caudata Cytherissa lacustris C. adunca
31	PM	F	*C. caudata *C. eriensis *C. adunca *L. ceriotuberosa *Cytherissa lacustris L. staplini L. sappaensis

TABLE 1 (continued)

31	PM	G	*C. eriensis *C. patzcuaro or rawsoni *L. sappaensis Candona sp. similar to C. caudata L. ceriotuberosa L. staplini

[1]Ostracodes identified by C. G. Oviatt in consultation with R. M. Forester, U.S. Geological Survey, Denver, Colorado.

[2]see Fig. 5 and Plate 2

[3]Ostracode species are listed in order of relative numbers of adult valves in each sample, species marked by an asterisk (*) are dominant in the sample.

[4]In this table C. refers to Candona; L. refers to Limnocythere; C. caudata represents C. sp. aff. caudata; C. eriensis represents C. cf. eriensis (after Thompson and others, 1990)

TABLE 2. Informal ostracode zones recognized in this study

Zone	Stratigraphic units	Characteristic taxa[1]	Additional taxa commonly present
L. sappaensis	PM	L. sappaensis C. eriensis	C. caudata C. adunca L. ceriotuberosa Cytherissa lacustris C. patzcuaro or rawsoni (some of these may be reworked from older units)
C. adunca	DWM	C. adunca L. ceriotuberosa	C. caudata C. eriensis C. decora Cytherissa lacustris L. staplini
L. staplini	TM, TDS	L. staplini C. caudata	L. ceriotuberosa C. patzcuaro or rawsoni C. decora Cytheromorpha fuscata ?

[1]In this table C. refers to Candona; L. refers to Limnocythere; C. caudata represents C. sp. aff. caudata; C. eriensis represents C. cf. eriensis (after Thompson and others, 1990)