Stratigraphy of Lacustrine Sediments Cored in 1996, Bear Lake, Utah and Idaho

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This report has not been reviewed for stratigraphic nomenclature.

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Introduction

The overall goal of our research on Bear Lake is to create records of past climate change for the region, including changes in precipitation (rain and snow) patterns during the last 10,000 years and longer. As part of the project, we are attempting to determine how the size of Bear Lake has varied in the past, to assess the possibility of future flooding and drought. We also seek to understand human influences on sediment deposition, chemistry, and life in the lake.

Evidence of past conditions comes from sediments deposited in the lake, so reconstruction of past conditions requires accurate dating of the sediments. The study includes the upper Bear River watershed as well as Bear Lake itself. The Bear River is the largest river in the Great Basin and the source of the majority of water flowing into the Great Salt Lake. In this region, wet periods may produce flooding along the course of the Bear River and around Great Salt Lake, while dry periods, or droughts, may affect water availability for agricultural, industrial, and residential use.

The Bear Lake basin (fig. 1) is located near the northeastern margin of the Basin and Range province, at its boundary with the Colorado Plateau. The long-term tectonic history of the area is complex, beginning with Laramide foreland thrusting, followed by a reversal of stress with the development of extensional Basin and Range structures. Major studies of the bedrock and surficial geology of the area include Williams and others (1962), Kaliser (1972), and Dixon (1982). The tectonic history of the Bear Lake basin was reviewed by McAlpin (1993; 2003). The area is seismically active as shown by displaced Holocene strata and several historical earthquakes (McCalpin, 2003).

The overall structure of the basin, as reflected by the bathymetry of Bear Lake (Denny and Colman, 2003) and the pattern of deposition of its sediments (described herein), is that of an eastward tilting half-graben, controlled by a master normal fault along the eastern margin of the lake. This fault, the East Bear Lake fault, is steep at the surface and becomes listric at depth. It has experienced 4–6 episodes of faulting in the last 40,000 years, the youngest of which occurred about 2,500 years ago (McCalpin, 2003). The western margin of the graben is largely a hinge or a ramp, but it also is marked by normal faults, the youngest movement on which occurred about 7,000 years ago (McCalpin, 2003).

This report describes the stratigraphy of sediments beneath Bear Lake along a transect of cores obtained in 1996. The stratigraphy is derived mostly from high-resolution acoustic-reflection profiles, supplemented by analytical information from cores that indicate correlations among various horizons. The deep drill hole obtained in 2000 (BL00-1) also is along the same acoustic profile, so the stratigraphy of its upper part also is described in relation to the 1996 cores.

One previous seismic-reflection study has been conducted in Bear Lake (Skeen, 1975). This study used a somewhat lower frequency sound source, which consequently provided data with deeper penetration but lower resolution. The results described here for the upper part of the sedimentary sequence are largely compatible with this earlier study.

Methods

We collected about 202 kilometers (km) of high-resolution seismic-reflection data from Bear Lake in 1997 (fig. 1). The 1997 data were collected using two systems: (1) a side-mounted array of four ORE[1] 3.5 kHz transducers, two sending the signal and two receiving the returns, and (2) a broad-band ("boomer") system, consisting of a Huntec[1] acoustic plate, an ITI[1] 10-element hydrophone streamer, and an ORE[1] 140 receiver/amplifier. In 2002, an additional 75 km of data were collected using a 4-24 kHz Edgetech[1] 424 pulsed frequency ("chirp") system (fig. 1).

The data were located with military-grade GPS (1997) and differential GPS (2002). All data were recorded digitally in SEG-Y format using a Delft Elics[1] recording system.

Results

The acoustic data presented here comprise line 28 (1997) and line 40 (2002), both of which pass through or close to the three 1996 core sites and the BL00-1 drill site (fig. 1). These are east-west lines, approximately parellel to the dip of the lacustrine sedimentary units and perpendicular to the recently active faults. The overall pattern is one of eastward dipping and eastward thickening beds, which pinch out on the western margin of the lake and onlap the uplifted eastern margin (fig. 2). The deepest penetrating data (from the boomer source) are shown on figure 3 for the segment of line 28 passing through the three 1996 core sites and the 2000 drill site core sites. Different types of acoustic data provide different amounts of penetration and resolution. Comparison of the three types of acoustic data for a small segment of the line (fig. 4) shows the differences in penetration and resolution.

Several intrabasin faults cross the acoustic profiles. Faults near the steep eastern margin

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[1] Use of trade names is for informational purposes only and does not imply endorsement by the U.S. Geological Survey

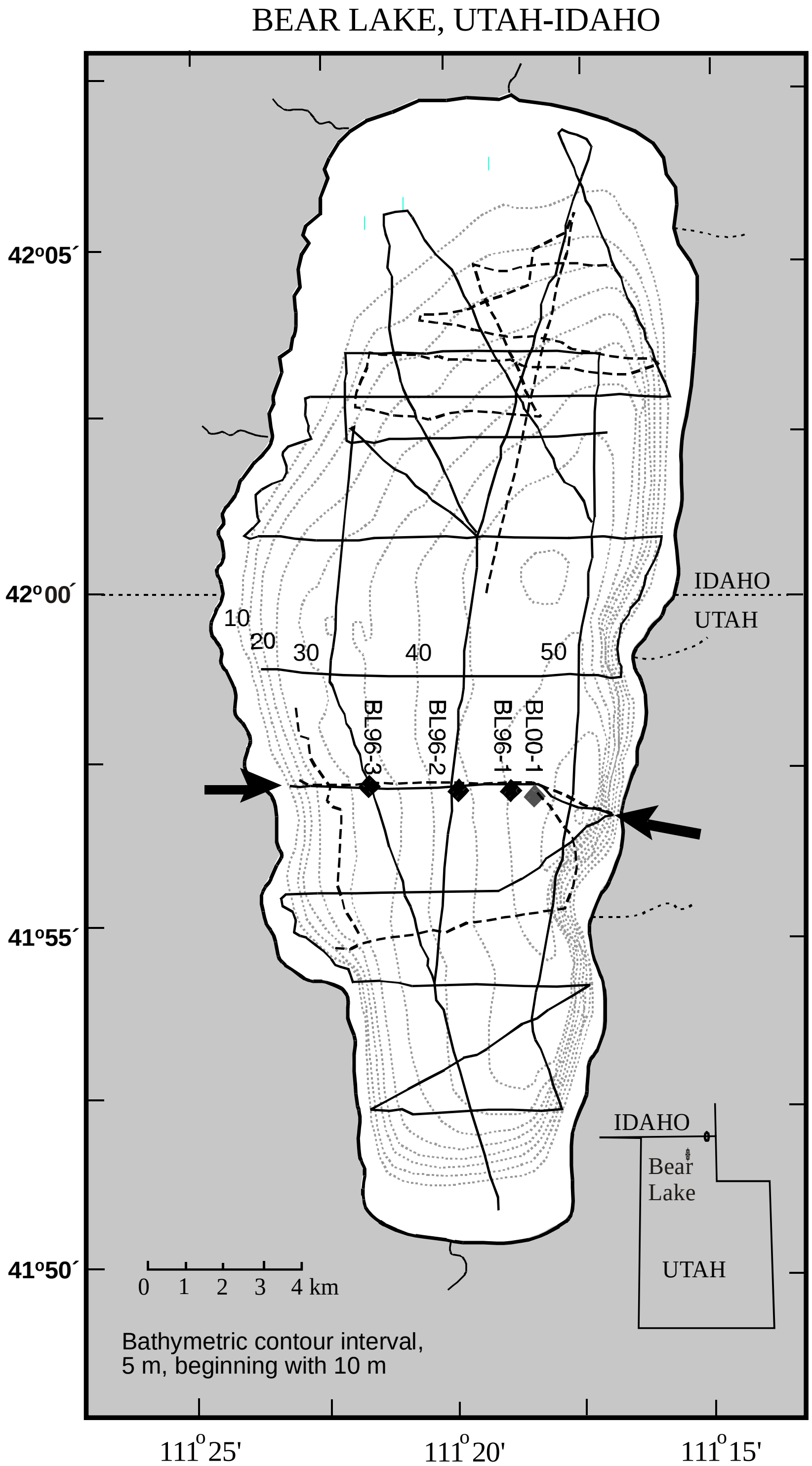

Figure 1. Generalized map of Bear Lake showing tracklines along which acoustic-reflection data were collected. Also shown are four core locations: BL96-1, BL96-2, BL96-3, and BL00-1. Inset shows regional location of Bear Lake (black). Solid lines are tracks of acoustic profiles collected in 1997; dashed lines are those from 2002. Heavy arrows mark the ends of the lines discussed in this report. Bathymetry (dotted lines) from Denny and Colman (2003). Diamonds show the locations of the 1996 piston cores and the 2000 drill hole (BL00-1).

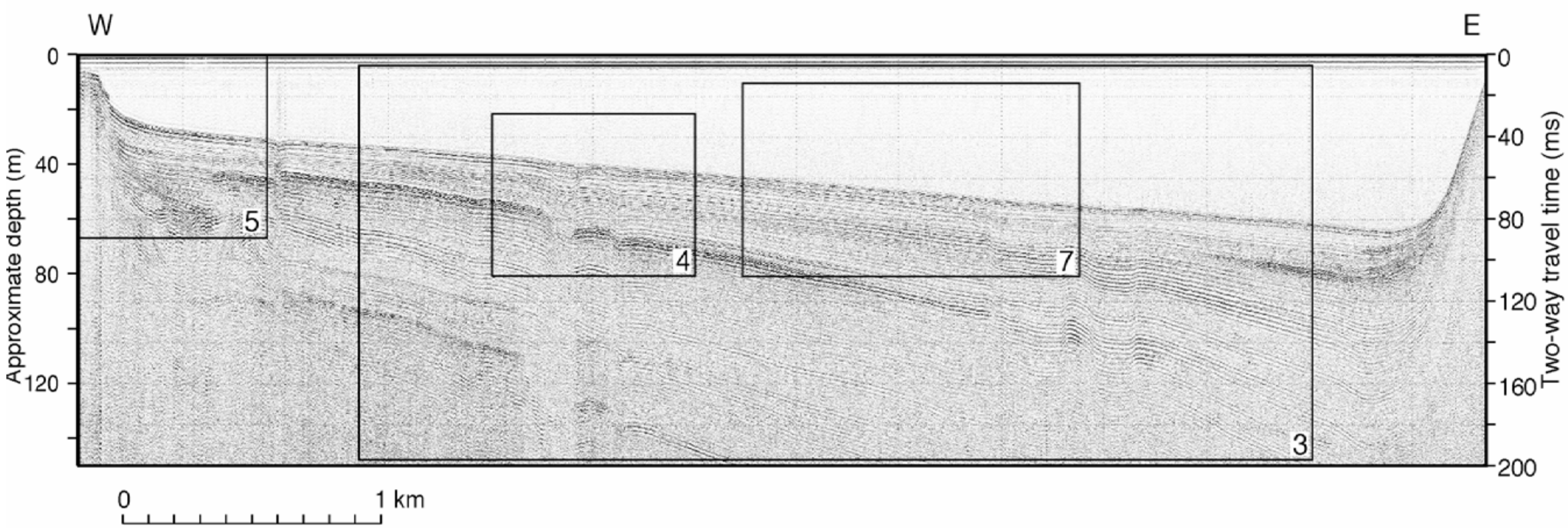

Figure 2. Acoustic profile (boomer system) along the entire length of line 28. Location shown on figure 1. Boxes labeled in their lower right corners indicate the location of data shown in correspondingly numbered figures

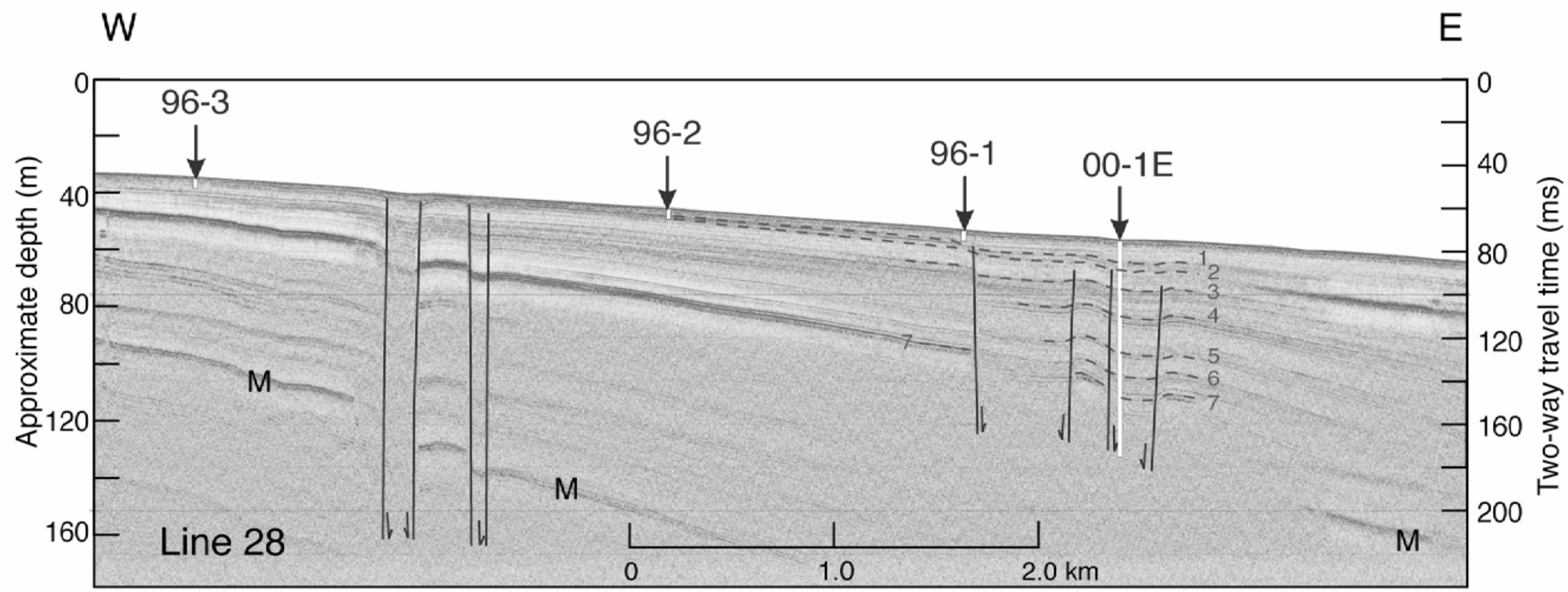

Figure 3. Acoustic profile (boomer system) along the segment of line 28 containing the 1996 core sites and the 2000 drill site. Location shown on figure 2. Horizons labeled 1, 2, … 7 are prominent, arbitrarily selected reflections. M, multiple reflections.

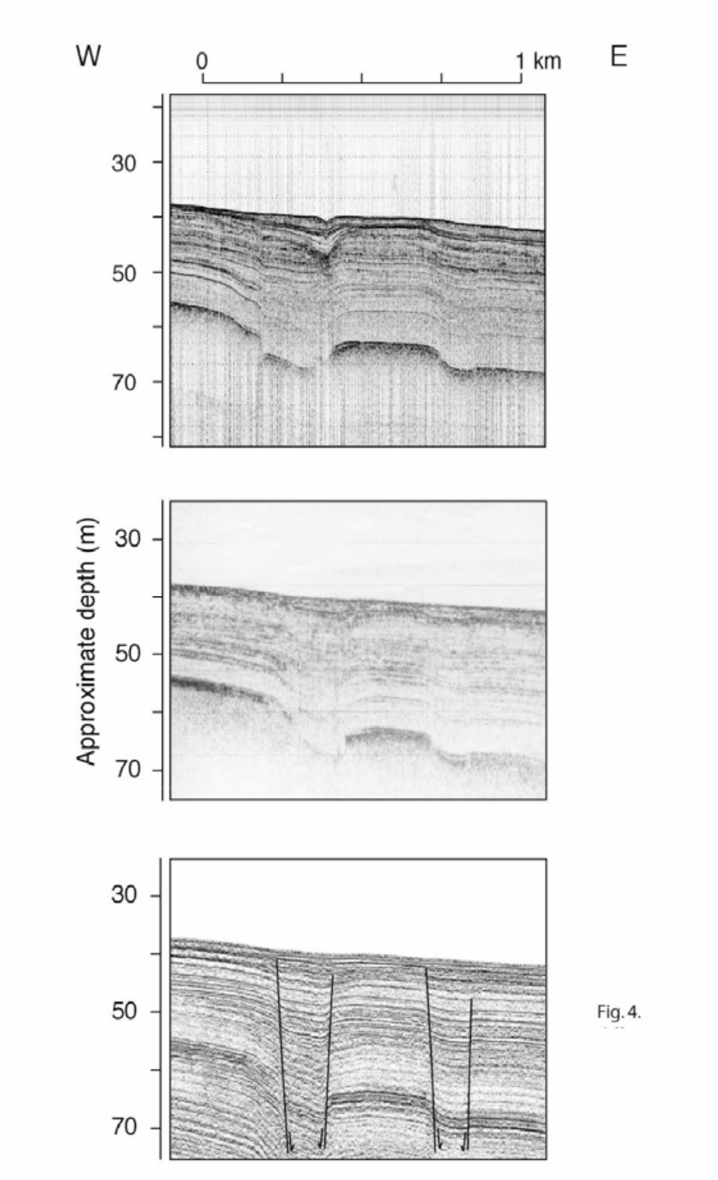

Figure 4. Acoustic profiles from three different systems along a section of the profile line. Location shown on figure 2. Top, chirp; middle, 3.5 kHz; bottom, boomer.

of the lake, seen on other profiles, probably are secondary, antithetic and synthetic, to the masterEast Bear Lake Fault. Others (figs. 3, 4), are small secondary normal faults, facing east or forming small grabens. Some of these secondary faults appear to displace all but the youngest sediments in the lake and to have surface expression on the lake floor. They are, thus, likely to be very young–no more than a few thousand years old.

The chemistry and mineralogy of Bear Lake sediments (Dean and others, 2005) suggest that sublacustrine springs may discharge into the lake through the lake floor. Several possible springs were imaged in the acoustic-reflection data; one example occurs near the western end of line 28 (fig. 5). A small depression occurs on the lake floor, and acoustic noise in the water column suggests flow turbulence. The possible spring lies above a deep normal fault, which displaces sediments in the lower part of the sedimentary section, but does not displace the upper part of the section.

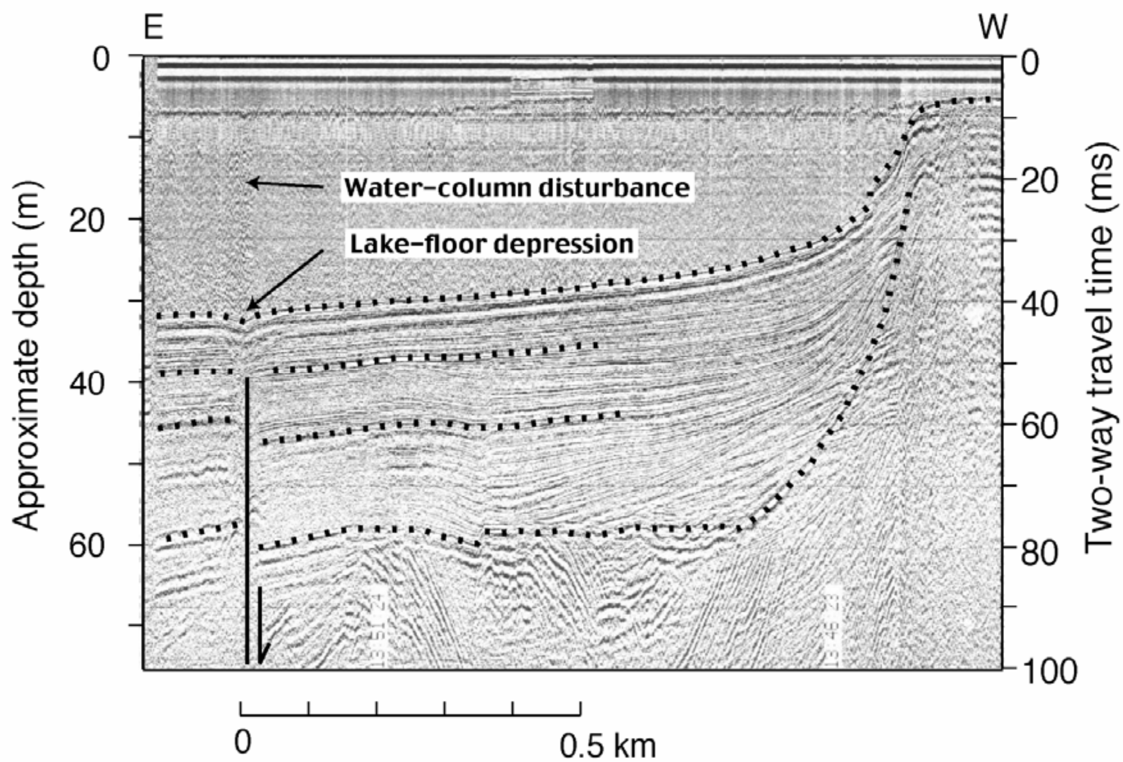

Figure 5. Acoustic profile (boomer system) near the western end of line 28 showing a possible sublacustrine spring above a deep-seated fault. The lake floor, top of bedrock, and two horizons in between are marked by dotted lines. Location shown on figure 2.

Discussion

The 1996 piston cores and the 2000 drill core were obtained in order to reconstruct different aspects of the paleoenvironmental history of the Bear Lake region. Important parts of these reconstructions are the environments of deposition and the stratigraphic framework of the sediments, which can be derived from the acoustic-reflection data. The acoustic stratigraphy also forms a basis for correlating among the cores.

The general lithologic sequence in the cores consists of an upper tan marl of post-glacial age and an underlying red lacustrine mud of late-glacial age. In the 2000 drill core, the red mud is underlain by a variety of lithologies, all of which appear to represent deep lake sediments deposited under a variety of climatic conditions. Major reflections in the acoustic data appear to correlate with major lithologic changes in the drill core (BL00-1; fig. 6). In particular, R2 correlates with the base of the postglacial marl, and R3 correlates with the base of the red late-glacial mud (fig. 6). Reflection R2 also correlates with the base of the postglacial marl in BL96-2 and BL96-3, but BL96-1 did not reach this horizon (fig. 7). None of the 1996 cores reached the base of the red late-glacial mud.

In addition to those derived from acoustic-reflection data, correlations among the cores can be made based on other types of data, including mineralogy, chemistry, diatoms, and magnetic properties of the sediments. Correlations based on these kinds of data, summarized in table 1, are entirely consistent with each other.

The acoustic data show stratigraphic units that are remarkably uniform and continuous. All units thicken to the east and thin or pinch out to the west. Almost no onlap, off-lap, or down-lap relations are apparent in the data. With one exception, no erosional or depositional structures indicative of lake level significantly lower than present were observed. The single exception is a prominent step and bench, the top of which is about 8 meters (m) below present lake level (fig. 5, west side). This structure has a morphology suggestive of a wave-cut notch and may indicate lake level about 22 m below present, which is the inflection point in the concave-up profile at the base of the bench. No other wave-cut structures and no nearshore depositional features were observed in the acoustic data.

Little modern deposition occurs in water depth less than about 30 m. The postglacial marl thins to a few tens of centimeters (cm) at this depth (that is, at core site BL96-3) and is not resolvable in the acoustic data landward of that point. Theoretically, comparisons of the depth at which different units pinch out might indicate differences in lake level at the time of deposition, but in practice, the pinch outs are so gradual that their positions are difficult to define accurately.

Many aspects of the Bear Lake basin and its fill that were described by Skeen (1975) are compatible with the results described here, although the more recent data suggest differences in detail. The half-graben structure of the basin, the eastward dipping and thickening sedimentary sequence, the pinch-outs of units on the western side of the basin, and the existence of shallow bedrock on the west side of the basin (fig. 5) are well established. One possible erosion surface within the sedimentary sequence (Skeen, 1975) is deeper than the penetration of our acoustic systems; within our data, all major deep-water units appear to be conformable.

Based on his acoustic data and an assumed sound velocity of 2.4 km/s, Skeen (1975) estimated the thickness of the sediments in the basin to be 387 m. In addition, he used sedimentation rates of 5–12 cm/10^2 yr, in part derived from Yellowstone Lake, to estimate an age of 325,000–775,000 years for the base of the sedimentary sequence. A sound velocity of 2.4 km/s for unconsolidated sediments is much higher than normally assumed; 1.6 km/s is more likely. This lower velocity would result in a thickness of the sedimentary fill of 258 m, although it is not certain that the base of the sedimentary sequence was reached. Sedimentation rates for

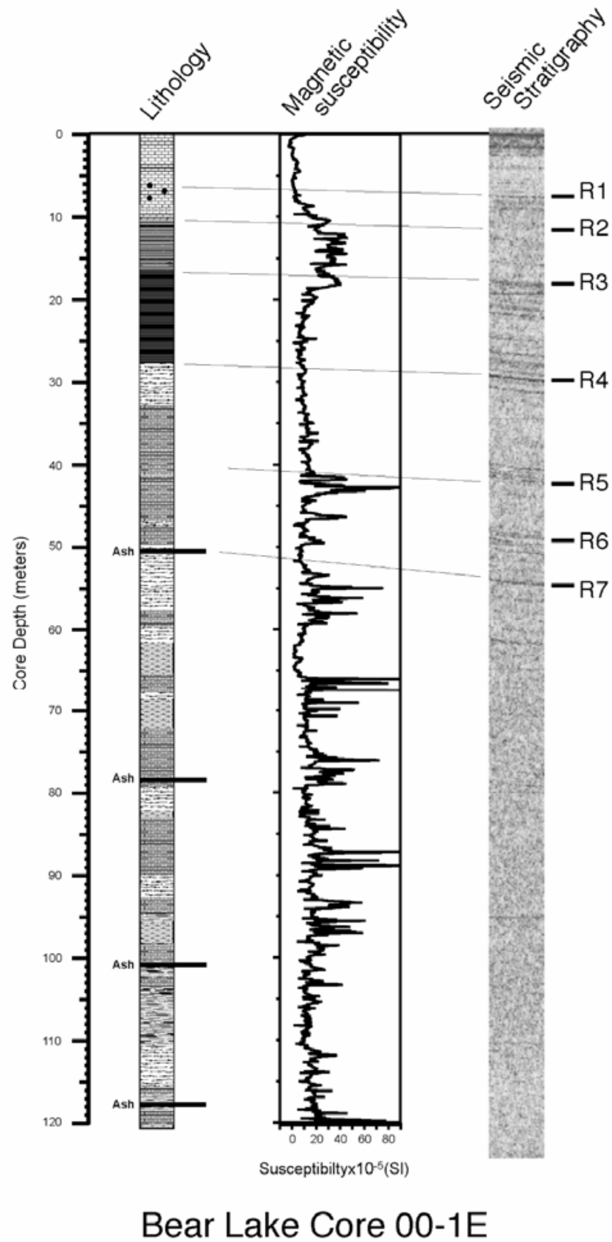

Figure 6. Correlation among the lithology of BL00-1E, magnetic susceptibility (C. Heil, written commun., 2001), and the acoustic-reflection data (boomer system) at the site.

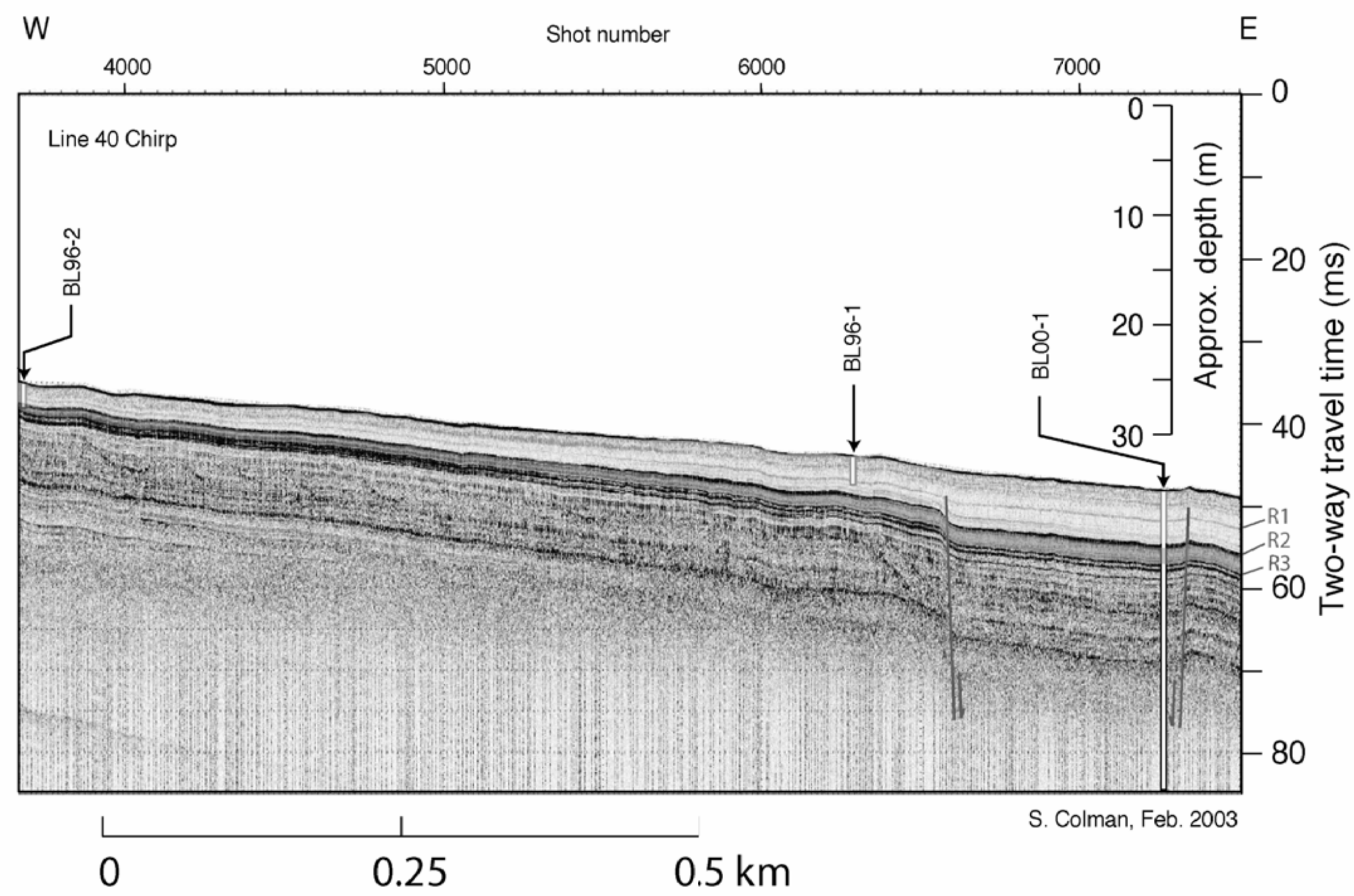

Figure 7. Acoustic profile (chirp system) along the segment of line 40 containing the core sites BL98-1, BL96-2, and BL00-1E. Yellow, post-glacial marl; red, late-glacial red lacustrine mud. Location shown on figure 2.

Table 1. List of correlative horizons in the Bear Lake 1996 piston cores and the 2000 drill core.

Shading indicates acoustic-reflection horizons. References in brackets are written communications.

Horizon	Depth (m) in BL96-3	Depth (m) in BL96-2	Depth (m) in BL96-1	Depth (m) in BL00-1E	Data type	Source	Comment
AA1		0.10	0.55		AA-14C	Kaufman (2005)	Amino acid-^{14}C match
D1		0.25	0.97		Diatoms	Moser and Kimbal, (2005)	*N. oblongata* spike
D2		0.63	1.67		Diatoms	Moser and Kimbal, (2005)	Top, zone 3b
AA2		1.40	4.50		AA-14C	Kaufman (2005)	Amino acid-^{14}C match
D3		1.50	4.27		Diatoms	Moser and Kimbal, (2005)	Bottom, diatom zone 3b
IS1		1.70	4.95		Isotopes	Dean and others (2005)	Increase in ^{18}O to 5.7, increase in 13C to 2.2
IS2		1.70	4.95		Isotopes	Dean and others (2005)	Increase in ^{18}O to 5.7, increase in 13C to 2.2
Min1	0.15	1.75			Mineralogy	Dean and others (2005)	Calcite decrease, aragonite increase
R1	0.50	1.90	5.80	7.3	Seismic	This paper	Base of upper marl
IS3	0.10	2.20			Isotopes	Dean and others (2005)	^{18}O peak
Mag1	0.11	2.35			Magnetics	Rosenbaum (2005)	
Min3	0.27	2.37			Mineralogy	Dean and others (2005)	Sharp increase in aragonite
MS1		2.25		8.7	MS	[Rosenbaum, 2003]	
R2	< 0.5	3.10	9.40	10.4	Seismic	This paper	Top of red unit
Min2	0.40	3.10			Mineralogy	Dean and others (2005)	Begin calcite increase, decline in quartz
Mag2	0.40	3.10			Magnetics	[Rosenbaum, 2003]	
MS2		3.10		10.4	Magnetics	[Rosenbaum, 2003]	Top of red unit
Mag3	0.65	3.60			Magnetics	[Rosenbaum, 2003]	
MS3	1.05	3.60		11.5	Magnetics	[Rosenbaum, 2003]	
MS4	1.40			12.1	Magnetics	[Rosenbaum, 2003]	

the 1996 piston cores (Colman and others, 2005) and unpublished estimates for the 2000 drill core suggest a long-term sedimentation rate of about 0.5 m/10^3 yr, yielding an age of about 410,000 years for the base(?) of the 258 m of sedimentary fill.

A basin-wide analysis of the new acoustic data in Bear Lake is in progress. This analysis will allow a more complete reconstruction of patterns of deposition in the lake, as well as delineation of faulting and structure in the sedimentary sequence.

Acknowledgements

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References Cited

Colman, S.M., Kaufman, D.S., Rosenbaum, J.G., and McGeehin, J.P., 2005, Radiocarbon dating of cores collected from Bear Lake, Utah and Idaho: U.S. Geological Survey Open-File Report 05–xxx.

Dean, W.E., Forester, R.M., Colman, S.M., Liu, A., Skipp, G., Simmons, K.R., Swarzinski, P., Anderson, R., and Thornburg, D., 2005, Modern and glacial-Holocene carbonate sedimentation in Bear Lake, Utah and Idaho, U.S. Geological Survey Open-File Report 05–1124.

Denny, J.F., and Colman, S.M., 2003, Geophysical surveys of Bear Lake, Utah-Idaho, September, 2002, U.S. Geological Survey Open-File Report 03–150.

Dixon, J.S., 1982, Regional structural synthesis, Wyoming salient of the western Overthrust Belt: American Association of Petroleum Geologists, Bulletin, v. 66, p. 1560–1581.

Kaliser, B.N., 1972, Environmental geology of the Bear Lake area, Utah and Idaho, Utah Geological and Mineral Survey, Bulletin 28, 56 p.

Kaufman, D.S., 2005, Amino acid racemization in ostracodes in cores BL96-1 and BL96-2 from Bear Lake, Utah and Idaho: U.S. Geological Survey Open-File Report 05–1129.

McCalpin, J.P., 1993, Neotectonics of the northeastern Basin and Range margin, western USA: Zeitschrift fur Geomorphologie, v. 94, p. 137–157.

McCalpin, J.P., 2003, Neotectonics of Bear Lake Valley, Utah and Idaho: A preliminary assessment: Salt Lake City, Utah, Utah Geological Survey, Miscellaneous Publication 03–4, 43 p.

Moser, K.A., and Kimball, J.P., 2005, Diatom analysis of Bear Lake Cores 96-1, 96-2 and 98-10, U.S. Geological Survey Open-File Report 05–xxx.

Rosenbaum, J.G., 2005, Magnetic properties of cores BL96-1, -2, and -3 from Bear Lake, Utah and Idaho: U.S. Geological Survey Open-File Report 05–1203.

Skeen, R.C., 1975, A reflection seismic study of the subsurface structure and sediments of Bear Lake, Utah-Idaho: Salt Lake City, Utah, unpublished Senior Thesis, University of Utah, 24 p.

Williams, J.S., Willard, A.D., and Parker, V., 1962, Recent geological history of Bear Lake Valley, Utah and Idaho: American Journal of Science, v. 260, p. 24–36.