CHAPTER 1

INTRODUCTION

Objectives

The material from this dissertation and the concepts discussed therein are regarding the late Pleistocene deposits of Lake Bonneville and specifically a smaller subset of transgressive deposits referred to as the upper Intermediate paleoshorelines. Lake Bonneville is a large, closed pluvial lake that occupied the Bonneville basin of northwestern Utah, southern Idaho, and western Nevada during the termination of the last glacial maximum (Fig. 1). Continual changes in the lake’s water budget and resultant water level have provided a substantial repository of large sedimentological and geomorphic paleoshoreline features within its basin. The constancy of the lake’s water level depended either on threshold controls as the lake flowed out of the basin or by stabilizations of the global/regional climate. During the lake’s history, its water level stabilized to form multiple separate and large repositories or groups of landforms associated with a relative range of water level altitudes. The most prominent of these lake levels include the Stansbury, Bonneville, Provo, and Gilbert levels of Lake Bonneville, respective with time. Studies related to these large lacustrine deposits have provided researchers with a general trend of the basin’s broad climatic history over the last 30,000 years (Fig. 2). However, even though the broad representation of the basin’s lacustrine chronology is well documented, there are many smaller paleoshoreline sets that have not been documented and discussed. It is proposed that these smaller paleoshorelines record small-scale changes in the lake’s water budget during the lake’s transgressive and regressive stages. The evidence of the lake’s temporary levels are closely tied to climatic responses; therefore, resolving its sedimentary
development at a higher resolution has the potential to vastly improve the resolution of regional paleoclimate models and can suggest explain how the Bonneville basin may respond to future small-scale climatic changes.

This dissertation focuses on a subset of these smaller-scale paleoshorelines that Gilbert (1890) referred to as “Intermediate shore-lines” within his paramount monograph regarding Lake Bonneville. Within the dissertation we use the term Intermediate paleoshoreline instead of Gilbert’s usage of the term in order to update the term to modern standards. These Intermediate features are of particular interest because they were deposited during the height of the last glacial maximum and record how Lake Bonneville may have responded to global climatic drivers.

The objectives of this study include the following: 1) Collect a set of stratigraphic, geomorphic, and chronologic data by mapping areas that exhibit excellent examples of the Intermediate paleoshorelines. This first objective was met by mapping the late Pleistocene deposits related to the occupation of Lake Bonneville in the area of the northern Rush Valley near Stockton, UT and the northern Hogup Mountains in UT. 2) Use the data from the extensive mapping project to examine the broad lacustrine and climatic record of the lake and to determine how the Intermediate paleoshorelines relate to the current model of the lake’s history. 3) Determine what sedimentological and environmental factors determine affect how the Intermediate paleoshorelines are formed and preserved in the lacustrine record. 4) Provide a hypothetical model that can be used to attempt to correlate Intermediate paleoshorelines in the mapped areas and in the basin. 5) Provide additional evidence for the hypothesis that Gilbert (1890) suggested regarding the Intermediate paleoshorelines as being evidence for an oscillating lake, and to put this additional evidence will be put in perspective of studies (Oviatt, 1997; Anderson and Link, 1998; Currey and Oviatt, 1985) that have also suggested oscillatory events.
Determine how the current climatic and sedimentological model of Lake Bonneville can be improved by the higher resolution history of the lake basin.

**Terminology**

Table 1 consists of a summary of terms in which the following descriptions are a more detailed explanation of these terms and how they are related to one another.

The term shoreline as described by the U.S. Army Corps of Engineers (2003) is “the line of demarcation between a shore and the water or the intersection of a specified plane of water with the shore or beach.” Past researchers in the Bonneville basin have used this term to indicate the ancient intersection of Lake Bonneville with the land surface. However, this term indicates an active water body and is not a proper term for ancient coastal beaches where the water body is no longer present. Therefore, in this study the term paleoshoreline is used to delineate the physical linear expression of an ancient water body with the land.

Four distinct and large closed-basin (lakes without an external outlet) lakes have been identified in the basin during the Quaternary, in which the Lake Bonneville lake cycle is the most recent of these lakes (Fig. 3). Each of these distinct lakes referred to as a separate lake cycle. Lake cycles are defined as distinct wetter periods in which a lake has occupied the basin, which is then separated by more arid periods in which very small lake systems comparable to today’s hydrologic system exist. Each of these lake cycles have a transgressive (a rising water level) and a regressive (a falling water level) phase of the lake cycle. Lake levels are described as the general altitude of the lake’s water surface during the occupation of the lake. In these transgressive and regressive phases, the
altitude of the lake’s water level may oscillate. During these oscillations, the lake level may rise (transgress) or fall (regress); however, the general trend of the lake’s water surface will either gradually rise (transgressive) or fall (regressive). Within the dissertation, lake level oscillations are referred to as large changes in the altitude of the lake’s water surface (i.e., resultant lake level variations of 10 –45 m) and water budget that correspond to millennial or centennial patterns. Whereas, water level fluctuations are defined as small changes in the altitude of the lake’s water surface (i.e., resultant lake level variations of <10 m) and water budget that are the result of seasonal or decadal patterns. In addition to the transgressive and regressive phases of the Lake Bonneville lake cycle, the basin also exhibited a period in which the lake was an open basin (a lake with an external outlet) that is being referred to as its open-basin phase.

To delineate a chronological history of the Lake Bonneville deposits in the basin, multiple lake levels have been named and correlated (e.g., Stansbury, Bonneville, Provo, or Gilbert levels). As in all lakes, deposits and landforms at a specific altitude do not represent the sedimentological record of a lake with a specific altitude of its water plane. Sediments from a lake with a specific water plane altitude can be deposited at multiple altitudes above or below the mean altitude of the lake’s surface. Therefore, when referring to a certain lake level (e.g., the Bonneville level), the altitude of that level/stage is referring to a mean altitude of the lake’s water plane and the deposits or paleoshorelines related to the specific level exhibited within a relative range of altitudes around the mean. In addition to the four distinct lake levels (Stansbury, Bonneville, Provo, and Gilbert levels) in which the lake resides at or near a specific altitude, the lake has deposits associated with lake levels that developed during periods in which the lake did not reside for long durations. Since there are hundreds of distinct paleoshorelines that can be mapped in the basin, these short-lived paleoshorelines are grouped into sets of paleoshorelines.
that either were either deposited in the relative rise (transgressive phase) or fall (regressive phase) of the lake’s water surface. The isostatically corrected altitudinal and age ranges of the paleoshorelines, associated with the more stable lake levels or associated with the short-lived transgressive or regressive paleoshoreline sets, can be seen in Table 2 or seen schematically in Figure 2.

A notable subset of these paleoshorelines that will be discussed in detail in this dissertation is the set of paleoshorelines referred to as the Intermediate paleoshorelines. Gilbert (1890) originally defined this set of landforms as the “Intermediate shore-lines” since they were landforms that recorded the ancient lake extent that formed during the transgressive rise of the lake during the intermediate altitudinal extent of Provo and Bonneville age landforms. Within the dissertation, we use the term Intermediate paleoshoreline(s) instead of Gilbert’s usage of the term in order to update the term to modern standards.

**General late Pleistocene history of Lake Bonneville**

Closed-basin systems, such as the Bonneville basin of northwestern Utah, have been shown to be very sensitive indicators of regional and global climate changes (Godsey et al., 2005; Kaufman, 2003; Oviatt, 1997; Fritz, 1996; Street-Perrott et al., 1985). The pioneering studies of G. K. Gilbert (1890) initiated research regarding Lake Bonneville, and this closed basin has continually been studied throughout the 20th century to understand a variety of geodynamic, geomorphic, paleontological, sedimentological, and anthropologic processes (e.g., Oviatt and Thompson, 2002). Gilbert (1890) described the geomorphic features of the Bonneville basin and established the relative timing of its various major paleoshorelines; however, the advent of radiometric dating techniques provided researchers with a much more robust
chronologic record of the lake’s major fluctuations of water level and areal extent (e.g., Currey and Oviatt, 1985; Oviatt et al., 1992; Oviatt, 1997; Godsey et al., 2005).

The Bonneville lake cycle was initiated approximately 27,000 \(^{14}\text{C yr B.P.}\) before present (B.P.) and ended approximately \(10,000 \^{14}\text{C yr B.P.}\) ago at the end of the last glacial maximum (Oviatt, 1997). Continual changes in the lake’s water budget and resultant water level have provided a substantial repository of large sedimentological and geomorphic paleoshoreline features that record the area’s climatic history of the area. The general hydrologic chronology and the broad climatic history inferred by the four major paleoshorelines of the lake cycle (i.e., Stansbury, Bonneville, Provo, and Gilbert lake levels;— Fig 2) have been well-established (Oviatt, 1997; Kaufman, 2003; Balch, 2005; Godsey et al., 2005; Oviatt et al, 2005). Many less prominent paleoshoreline features formed during the transgressive and regressive history of the lake can also be found in the basin; however, these paleoshorelines are not directly associated with the four major paleoshorelines. Even though researchers have briefly discussed these less prominent features (Gilbert, 1890; Scott et al., 1983; Scott, 1988; Burr and Currey, 1988; Oviatt et al., 1994; Sack, 1999) and periodically included them in regional geologic maps (Miller & Oviatt, 1994; Miller & McCarthy, 2002), the literature does not describe their relevance in much depth. G.K. Gilbert in his 1890 Lake Bonneville Monograph, G.K. Gilbert discusses a subset of these less prominent paleoshorelines that he termed the “Intermediate shore-lines.” Gilbert identified these “Intermediate” paleoshorelines as lacustrine landforms that have formed in between the altitudinal limits of the Bonneville and Provo lake levels.

Currey and Oviatt (1985) and Oviatt (1997) have suggested that multiple large-scale oscillations occurred during the transgression of the lake. The Stansbury Oscillation \(\sim 24,000-26,000 \text{}^{14}\text{C yr B.P.}\) is the most prominent and well studied of these oscillations (Oviatt et al.,
transgressive oscillations (termed U1–U3) from 17,000 to 24,000 \(^{14}\text{C yr}\) B.P. The U1–U3 oscillations have been tentatively correlated to global climatic events such as Heinrich events (Oviatt, 1997).

The Lake Bonneville lake rose to its maximum altitudinal limit (~1552 m asl) at ~15,500 \(^{14}\text{C yr}\) B.P. and roughly correlates to the timing of the local glacial maximum of glaciers within the Bonneville Basin (Refsnider et al., 2008). Once the lake level reached the altitude of a topographical threshold near Zenda, Idaho, the lake then overflowed into the Snake River/Columbia River Drainage Basin. When the lake reached this threshold, the water level within the lake stabilized for ~1,000 years to form the paleoshorelines of the Bonneville level. Consistent isostatic adjustment of the region depressed the basin floor during the duration of the lake at the Bonneville level and caused some Bonneville paleoshorelines to have multiple altitudinal expressions (Gilbert, 1890; Burr and Currey, 1988). The surface area and volume of the lake at the Bonneville stage has been calculated at ~51,556 km\(^2\) and ~10,494 km\(^3\), respectively. To aid in the understanding of the relative size and volume of the lake, the ancient lake is compared to the Great Lakes of the northeastern United States (Table 3).

The threshold at Zenda was composed of the weakly consolidated Salt Lake Formation and other unconsolidated alluvial deposits (Janecke and Oaks, 2012). Approximately 14,500 \(^{14}\text{C yr}\) B.P. (O’Conner, 1993) the lake catastrophically breached the threshold, and that breach resulted in a drop in its water level by ~100 m and a loss of ~5,238 km\(^3\) of water. The amount of water lost is in comparison can be compared to slightly more than that the modern Lake Michigan and was approximately half of \(\frac{1}{2}\) of the volume of the lake. The flow of the flood caused massive erosion downstream as the water moved into Marsh Valley, Idaho, the Snake
River, the Columbia River, and then out to the Pacific Ocean. Following the flood, the lake was then constrained by the continued overflow of a new topographical divide south of Red Rock Pass, Idaho (Janecke and Oaks, 2012). Due to the lake overflowing at this new threshold, the water level remained relatively constant, and large paleoshorelines then developed at the lake stage known as the Provo Lake until \( \sim 12,500 \) \(^{14}C\) yr B.P. (Godsey et al., 2011). However, just like the Bonneville level, it has been suggested that the basin isostatically adjusted to the new volume of water at the Provo level, therefore, causing the expressions of the Provo paleoshorelines to also be at a range of altitudinal limits (Burr and Currey, 1988; Godsey et al., 2005).

Following the occupation of the lake at the Provo level, the water level quickly fell below historic levels for the modern Great Salt Lake (Benson et al., 1992). This dramatic regression has been hypothesized to be related to the Bøelling/Allrød interstadial (Benson et al., 2011; Godsey et al., 2011) and is thought to have occurred in a lasted \( \sim 500–1,000 \) years. The lake then transgressed briefly in the early Holocene to form the Gilbert highstand, and This transgression is thought to be related to the cold period of the Younger Dryas stadial (Oviatt et al., 2005).

**Geologic map of the unconsolidated deposits in the southern portions of the Stockton and South Mountain quadrangles, Tooele County, Utah**

Chapter 2 will discuss the quaternary geology of the area near Stockton, Utah, and specifically the quaternary geology of the southern portions of the South Mountain and the Stockton 7.5’ quadrangles in which Rush Valley resides. Rush Valley is a sub-basin of the main Bonnevile basin. This sub-basin is separated from the main Bonnevile basin by a threshold consisting of a series of large Intermediate and Bonnevile age spits and bars that Gilbert (1890) referred to as the “Stockton Bar.” The altitudinal limit of this threshold into Rush Valley is well
above the Provo level; therefore, it is hypothesized that the paleoshorelines in Rush Valley should be represented by a series of Intermediate and Bonneville age paleoshoreline features. However, Burr and Currey (1988) have also suggested an alternative hypothesis for the paleoshorelines that are within Rush Valley and below the Bonneville level. Burr and Currey (1988) suggest that paleoshorelines below the Bonneville level are not Intermediate in age but remnants of small smaller lakes that were impounded in the sub-basin following the forced regression of the Bonneville flood. Chapter 2 describes the paleoshorelines in the Rush Valley and then discusses the geomorphic and stratigraphic evidence for the chronology of these paleoshorelines. The chapter then discusses the evidence for and against the two competing hypotheses for the Rush Valley paleoshorelines and how these paleoshorelines fit in with the understanding of the main Bonneville basin.

Geologic map of the unconsolidated deposits in the Hogup Bar quadrangle, Box Elder County, Utah

Chapter 3 will discuss the quaternary geology of the Hogup Mountains, specifically the Hogup Bar 7.5’ quadrangle, in northwestern Utah. The Hogup Mountains are a rich archive of multiple coastal landforms that developed during the Lake Bonneville lake cycle and are located in the northwestern portion of the Bonneville basin. The area has unusually well preserved paleoshoreline deposits and erosional features that were formed during the occupation of all four of the lake’s major levels and numerous other temporary lake levels. Specifically, including the area has a well-preserved record of the Intermediate paleoshorelines. The description and map of the area included in this chapter provides a base in which to investigate the preservation, development, and relationship of the major paleoshorelines with the Intermediate
G.K. Gilbert’s Intermediate paleoshorelines of Lake Bonneville

G.K. Gilbert in his 1890 Monograph regarding Lake Bonneville, G.K. Gilbert discusses multiple peculiar paleoshorelines that he termed “Intermediate shore-lines.” Gilbert found it difficult to correlate these features due to the inconsistency of the individual positions (altitude) of the paleoshoreline features and the inconsistency of the appearance of the number of these paleoshorelines at individual localities. Chapter 4 discusses the sedimentological (i.e., original local topography, wave and wind energy, accommodation space, sediment supply, duration of an individual lake level) and geophysical (i.e., isostatic rebound) factors that influence how the Intermediate paleoshoreline formed, why the features are preserved in the geologic record, and why the altitudinal crests of the individual features vary. The Intermediate paleoshorelines in the Hogup Mountain area are used as a test case to display the variation within these paleoshorelines. In addition, a basic model is presented to discuss the potential to correlate individual Intermediate paleoshorelines in the basin.

The oscillatory record of the transgressive paleoshorelines of Lake Bonneville, U.S.A.

Gilbert’s (1890) hypothesis for the variations that are exhibited for-by the Intermediate paleoshorelines is that these paleoshorelines are a result of an oscillating lake. Chapter 5 describes the stratigraphic evidence for oscillatory events in the Hogup Mountain locality and compares these events to other known events in the basin. The chapter suggests that at least three relatively large oscillations (two in-viethat were previously unknown) can be seen in the Hogup Mountain locality. Combining these oscillatory events with other hypothesized oscillations suggests that there are seven (7) proposed oscillations during the transgressive phase
of the lake. The actual number, amplitude, and timing of these oscillatory events are still relatively uncertain. Therefore, until these factors are better analyzed, it will be difficult to understand how these oscillatory events relate to global and regional climatic patterns.

References


Currey, D.R., and Oviatt, C.G., 1985. Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle,


Refsnider, K.A., Laabs, B.J.C., Plummer, M.A., Mickelson, D.M., Singer, B.S., Caffee, M.W., 2008. Last glacial maximum climate inferences from the cosmogenic dating and glacier modeling of the western Unita ice field, Unita Mountain, Utah. Quaternary Research 69,


### Figures and Tables

Table 1: Common terminology used in the dissertation.

#### Basic terminology related to shorelines and paleoshorelines

<table>
<thead>
<tr>
<th><strong>Paleoshoreline:</strong></th>
<th>physical and geomorphic evidence of the shoreline of relict water bodies (e.g., lakes, oceans). In the context of the dissertation, it is the relict shoreline expressions of Lake Bonneville (Atwood, 2006).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shoreline:</strong></td>
<td>the line of demarcation between a shore and the water or the intersection of a specified plane of water with the shore or beach (U.S.A.C.E., 2003).</td>
</tr>
</tbody>
</table>

#### Basic terminology related to the Lake Bonneville lake cycle

<table>
<thead>
<tr>
<th><strong>Lake cycle:</strong></th>
<th>the complete rise and fall of a lake within a basin. The duration of the lake cycle is demarcated by the period in which the specific lake had lake levels above the modern altitudes of lakes within the basin. The lake cycles occurred during a period of wetter climate, whereas were separated by periods of arid climates.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lake level:</strong></td>
<td>the general (mean) altitude of the lake’s water surface during a defined period of the occupation of the lake in the basin.</td>
</tr>
</tbody>
</table>
Lake level fluctuations: small changes in the lake’s altitude of its water surface (i.e., lake level variations of <10 m) and resultant water budget that correspond to decadal or seasonal patterns.

Lake level oscillations: large changes in the lake’s altitude of its water surface (i.e., lake level variations of 10–45 m) and resultant water budget that correspond to millennial or centennial patterns.

Open basin phase: the period in the lake cycle in which the water surface of the lake was relatively stable due to the lake outflowing into another basin.

Regressive phase: the period in the lake cycle in which the water surface of the closed-basin lake was generally falling.

Transgressive phase: the period in the lake cycle in which the water surface of the closed-basin lake was generally rising.

**Paleoshoreline Sets of the Lake Bonneville lake cycle (in chronologic order)**

Pre-Stansbury paleoshorelines: A series of paleoshorelines that developed during the rise of the lake (transgressive phase) prior to deposition of paleoshorelines related to the Stansbury lake level. The paleoshorelines lie between the altitudinal range of the modern lake level of the Great Salt Lake and the Stansbury...
Lake level.

**Stansbury paleoshorelines:** a series of paleoshorelines (transgressive phase) that developed when the lake level oscillated near the Stansbury lake level.

**Post-Stansbury paleoshorelines:** a series of paleoshorelines that developed during the rise of the lake (transgressive phase) following the deposition of paleoshorelines related to the Stansbury lake level. The paleoshorelines lie between the altitudinal range of the Stansbury and Provo lake levels.

**Intermediate paleoshorelines:** a series of paleoshorelines that developed during the rise of the lake (transgressive phase) following the deposition of the Post-Stansbury paleoshorelines. The paleoshorelines lie between the altitudinal range of the Provo and Bonneville lake levels.

**Bonneville paleoshorelines:** a series of paleoshorelines (open-basin phase) that developed during the maximum extent of the Lake Bonneville lake cycle near the Bonneville level. The lake level was relatively stable during the Bonneville level due to the lake over-flowing a natural threshold into the Columbia River Drainage.

**Provo paleoshorelines:** a series of paleoshorelines (open-basin phase) that developed near the Provo level following the forced regression caused by the Bonneville flood. The Provo lake level was relatively stable due to the lake over-flowing a bedrock threshold into
the Columbia River Drainage.

**Regressive paleoshorelines:** a series of paleoshorelines that developed during the fall of the lake (regressive phase) following the deposition of paleoshorelines related to the Provo lake level. The paleoshorelines lie between the altitudinal range of the Provo and Gilbert lake levels.

**Gilbert paleoshorelines:** a series of paleoshorelines (regressive phase) that developed when the lake level oscillated near the Gilbert lake level.
Table 2: Ages and isostatically corrected altitudes of paleoshoreline sets related to the Lake Bonneville lake cycle

<table>
<thead>
<tr>
<th>Lake Phase</th>
<th>Paleoshoreline</th>
<th>Radiocarbon Years B.P.</th>
<th>Calendar Years B.P.⁴</th>
<th>Isostatically Corrected Altitude (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transgressive</strong></td>
<td>Pre-Stansbury</td>
<td>25,000–22,000³</td>
<td>--------</td>
<td>~1320–1336</td>
</tr>
<tr>
<td></td>
<td>Stansbury</td>
<td>22,000–20,000³</td>
<td>24,400–23,200</td>
<td>1339–1378</td>
</tr>
<tr>
<td></td>
<td>Post-Stansbury⁴</td>
<td>20,000–18,000</td>
<td>23,200–20,500</td>
<td>~1378–1443</td>
</tr>
<tr>
<td></td>
<td>Intermediate⁵</td>
<td>~18,000–15,500</td>
<td>21,200–16,800</td>
<td>~1449–1545</td>
</tr>
<tr>
<td><strong>Open Basin</strong></td>
<td>Bonneville</td>
<td>15,500–14,500⁶</td>
<td>18,000–16,800</td>
<td>1545–1552</td>
</tr>
<tr>
<td></td>
<td>Provo</td>
<td>14,500–12,000⁷</td>
<td>16,800–13,500⁸</td>
<td>1424–1445</td>
</tr>
<tr>
<td><strong>Regressive</strong></td>
<td>Regressive⁹</td>
<td>~12,000–11,000</td>
<td>~13,500–12800</td>
<td>~1295–1424</td>
</tr>
<tr>
<td></td>
<td>Gilbert</td>
<td>11,000–10,000⁹</td>
<td>12,800–11,600</td>
<td>1291–1296</td>
</tr>
</tbody>
</table>

¹Calendar-calibrated ages of most paleoshorelines have not been published. Calendar-calibrated ages shown here, except for the age of the end of the Provo paleoshoreline, are from D.R. Currey, University of Utah (written communication to Utah Geological Survey).
²Estimated based on elevation in comparison to the lake’s hydrograph published by Oviatt (1997). –No calibration curve exists past 25,000 calendar years B.P.
³Oviatt et al. (1990). Currey (written communication to the Utah Geological Survey, 1996) assumed a maximum age for the Stansbury paleoshoreline of 21,000 ¹⁴C yr B.P., which is used in the conversion to calendar years.
⁴Post-Stansbury paleoshorelines are transgressive shorelines positioned in between the Provo and Stansbury levels of the lake system. The shorelines do not specify a particular altitude such as Sack’s (1999) description, but includes all paleoshorelines within the altitude range. However, the extent of the age of the paleoshorelines is based on the extent of radiocarbon dates summarized in Sack (1999) and Oviatt (1990).
⁵Intermediate paleoshorelines are transgressive shorelines positioned in between the Provo and Bonneville levels of the lake system. The age of these paleoshorelines are estimated based on the dates obtained in this publication and based on the elevation in comparison to the lake’s hydrograph published by Oviatt (1997) and based on dates obtained in this publication.
⁶Oviatt et al. (1992), Oviatt (1997).
⁷Oviatt et al. (1990), Oviatt (1997).
⁸Godsey and others (2005) revised the timing of the occupation of the Provo paleoshoreline and subsequent regression; Oviatt and others (1992) and Oviatt (1997) proposed a range from 14,500 to 14,000 ¹⁴C yr B.P. Oviatt and Thompson (2002) summarized many recent changes in the interpretation of the Lake Bonneville radiocarbon chronology.
⁹Calendar-calibrated age of the end of the Provo paleoshoreline estimated by interpolation from data in Godsey and others (2005), table 1: Stuiver and Reimer (1993) — calibration.
⁰Regressive paleoshorelines positioned in between the Gilbert and Provo levels of the lake system. The estimated age and altitude range of these paleoshorelines are based on the constraints of the Provo regression and the Gilbert level.
<table>
<thead>
<tr>
<th></th>
<th>Surface Area (km²)</th>
<th>Volume (km³)</th>
<th>Elevation (m asl)</th>
<th>Max Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Superior</td>
<td>82,000</td>
<td>12,000</td>
<td>180</td>
<td>407</td>
</tr>
<tr>
<td>Lake Huron</td>
<td>60,000</td>
<td>3,500</td>
<td>176</td>
<td>228</td>
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<tr>
<td>Lake Michigan</td>
<td>58,000</td>
<td>4,900</td>
<td>176</td>
<td>282</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>25,700</td>
<td>480</td>
<td>174</td>
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<tr>
<td>Lake Ontario</td>
<td>19,000</td>
<td>1,640</td>
<td>75</td>
<td>245</td>
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<table>
<thead>
<tr>
<th></th>
<th>Lake Bonneville</th>
<th>Lake Provo</th>
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<tbody>
<tr>
<td>Lake Bonneville</td>
<td>51,556</td>
<td>10,494</td>
<td>1,552</td>
<td>352</td>
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<tr>
<td>Lake Provo</td>
<td>38,369</td>
<td>5,256</td>
<td>1,444</td>
<td>244</td>
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<table>
<thead>
<tr>
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<th>Difference following the Bonneville Flood</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Difference</td>
<td>13,187</td>
<td>5,238</td>
<td>108</td>
<td>108</td>
</tr>
</tbody>
</table>

Table 3: Isostatically corrected Lake Bonneville volumes, area, and depth in comparison with the modern Great Lakes of the northeastern United States. Data for the Great Lakes was acquired from EPA Atlas (2012).
Figure 1: A. Regional map of the extent of Lake Bonneville at its maximum in relation to the maximum of other pluvial lakes in the Great Basin; B. The maximum extent of the modern Great Salt Lake and the maximum extent of each of the major lake levels of the Lake Bonneville lake cycle.
Figure 2: Lake Bonneville hydrograph modified from Oviatt (1997) and Godsey et al. (2011). Altitudes are adjusted for effects of differential isostatic rebound in the basin (Oviatt, 1992). Amplitude limits of lake-stage fluctuations associated with the U1, U2, and U3 oscillations are approximate and are shown here schematically. The temporal range of the transgressive, regressive, and open phases of the lake cycle are shown horizontally whereas the altitudinal range of each of the paleoshoreline sets are shown vertically within either the transgressive or the regressive phases of the lake cycle.
Figure 3: A schematic hydrograph of lake cycles in the Bonneville basin in the last 700,000 years (modified from McCoy, 1987). Abbreviations are as follows: B (Bonneville), CD (Cutler Dam), LV (Little Valley), PP (Pokes Point), and LC (Lava Creek) lake cycles.