Quaternary Science Reviews 110 (2015) 166–171

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Chronology of Lake Bonneville, 30,000 to 10,000 yr B.P.

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A R T I C L E I N F O

Article history:
Received 13 August 2014
Received in revised form
29 November 2014
Accepted 18 December 2014
Available online 19 January 2015

Keywords:
Radiocarbon
Lake Bonneville
Geochronology
Isostatic rebound
Great Basin
Paleoclimate

A B S T R A C T

368 radiocarbon ages between 30 and 10 cal ka for samples collected from outcrops and shorelines from the Lake Bonneville basin have been compiled for this paper. Samples include 1. organic materials from sources outside the lake, such as wood, charcoal, plant fragments from emergent aquatics, and dispersed wetland organics, and 2. carbonate materials deposited in the lake, such as mollusk shells, tufa, charophyte debris, ooids, and marl. In general, organic materials provide rather than precise ages for lacustrine events, but their interpretation is less complicated than interpretation of results from carbonate samples. The data set shows evidence of contamination of different carbonate samples with both younger carbon and older carbon. For example, a radiocarbon reservoir at certain places within the lake during the middle transgressive phase accounts for ages of mollusk shells that are older than basal wood ages at similar altitudes. The large number of ages permits an accurate reconstruction of the lake chronology; conflicts between ages can be detected and reliable ages can be meaningfully integrated in interpretations. If fewer ages were available, the chronology might look simpler, but its accuracy would be unknown.

1. Introduction

Lake Bonneville (Fig. 1) was a large late-Pleistocene brackish-to-freshwater lake in the extensional-tectonic basin that has been occupied in Holocene and modern times by Great Salt Lake (GSL) in the eastern Great Basin of western North America. Lake Bonneville was fed by the Bear, Weber, and Provo Rivers in the GSL basin, and the Sevier and Beaver Rivers in the Sevier basin. All these rivers headed in the Wasatch and Uinta mountain ranges, and the lake was not connected hydrographically to the Laurentide or Cordilleran ice sheets. Small mountain glaciers in the headwaters of major rivers contributed sediment to major deltas along the east side of Lake Bonneville; at sites far from clastic sediment sources the primary bottom-mud composition was marl (endogenic carbonate sediment).

Lake Bonneville has been studied from a scientific perspective since the 1800s (Gilbert, 1890), and a tremendous amount has been written about its stratigraphy, landforms, biology, and geochemistry. The earliest workers did not have the tools for accurate numerical age estimates, but since the 1950s radiocarbon dating has been employed in the Bonneville basin and the results used to reconstruct lake history. Hundreds of radiocarbon ages have been obtained from the basin over the last half century, and a number of compilations of the large and accumulating body of information have been published (Eardley et al., 1957; Broecker and Orr, 1958; Broecker and Kaufman, 1965; Morrison and Frye, 1965; Scott et al., 1983; Currey and Oviatt, 1985; Oviatt et al., 1992; Godsey et al., 2005).

The term “Lake Bonneville” is used in this paper to refer to the last major lake cycle in the Bonneville basin, the large fresh-water lake that occupied the basin during late Pleistocene marine Oxygen Isotope Stage (MIS) 2 (Scott et al., 1983), approximately 29–14 cal ka; 25–12 ^{14}C ka B.P. (Lisiecki and Raymo, 2005). Earlier major lake cycles have been given different names and occurred during older oxygen-isotope stages (Oviatt et al., 1999), and they cannot be dated using radiocarbon methods.

Lake Bonneville history can be subdivided into three major periods (modified from Fig. 11 of Currey, 1990), the transgressive phase, the overflowing phase, and the regressive phase (Fig. 2). During the transgressive phase the lake occupied a hydrographically closed basin, where all water that entered the system, from direct precipitation, river runoff, and groundwater, exited by evaporation. This made the lake sensitive to changes in climate, and it experienced a series of oscillations and fluctuations in response to changes in its water budget (Gilbert, 1890; Currey, 1990; Oviatt, 1997). The overflowing phase began when the lake

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http://dx.doi.org/10.1016/j.quascirev.2014.12.016
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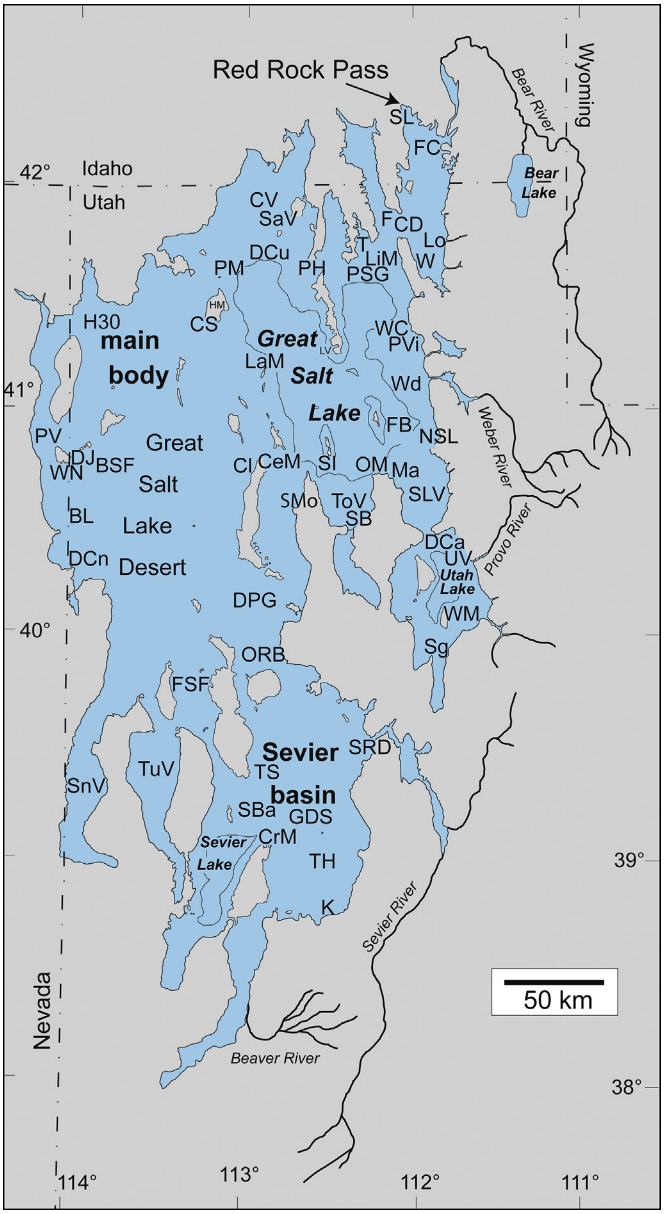

Fig. 1. Map of Lake Bonneville at its highest altitude, showing the outline of the Bonneville shoreline (after Currey, 1982). Approximate locations of radiocarbon sample sites, as listed in Table 1, are shown with letters – refer to Table S2 for an explanation of the symbols.

catastrophically washed out the natural dam at the lowest point on its basin rim, alluvial-fan gravel and underlying unconsolidated Neogene sediment, in the vicinity of Red Rock Pass, ID (Gilbert, 1890). The Bonneville flood resulted from this catastrophic collapse of the alluvial-fan dam and caused the lake to drop over 100 m to where it flowed out of the basin as a river for about three thousand years across a broad and gradually rising threshold on landslide deposits (Miller et al., 2013). The Provo shoreline developed in the basin during this time of overflow. The regressive phase marks the return to closed-basin hydrology, and the lake dropped rapidly, but not catastrophically, to levels comparable to those of modern GSL. After Lake Bonneville dropped below the topographic threshold between the Sevier and GSL basins, it spit into two lakes, an overflowing lake in the Sevier basin (Lake Gunnison) and a rapidly regressing lake in the GSL basin (Fig. 2).

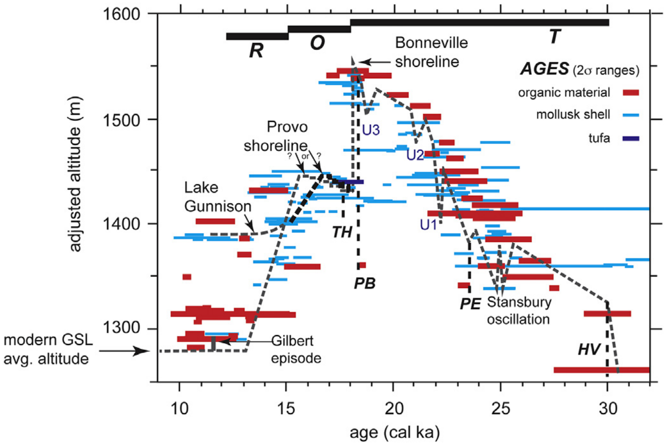

Fig. 2. Plot of calibrated radiocarbon ages using altitudes adjusted for isostatic rebound (except for collection altitudes below 1300 m – see text). Two-sigma calibrated age ranges are shown as horizontal bars. Some ages listed in Table 1 are not shown in this plot – this includes most tufa ages (except for those at the Tabernacle Hill site [Table 1]), and ages for other carbonate materials (ooids, marl, soil carbonate, ostracodes). The transgressive phase (***T***), overflowing, Provo-shoreline phase (***O***), and regressive phase (***R***) are marked with the bold black lines at the top of the figure. Basaltic ashes (Oviatt and Nash, 1989; Miller et al., 2008; Oviatt and Nash, 2014): ***HV*** = Hansel Valley; ***PE*** = Pony Express; ***PB*** = Pahvant Butte; ***TH*** = Tabernacle Hill. U1, U2, U3 = unnamed transgressive-phase oscillations (Oviatt, 1997). Overflow began in the Sevier basin when the regressing lake reached an altitude of about 1400 m. The Old River Bed threshold (ORBT in Fig. 1), which was composed of unconsolidated lacustrine mud, was gradually eroded down to about 1390 m where Lake Gunnison stabilized and continued to overflow to the Great Salt Lake basin (Madsen et al., in press). The gray short-dashed line represents approximate lake-level change, but it does not show the many fluctuations that must have occurred during the transgressive and regressive phases when the lake occupied a hydrographically closed basin. Two different possible chronologies for the Provo shoreline are shown (Godsey et al., 2011; Miller et al., 2013).

2. Methods

2.1. Radiocarbon ages

Radiocarbon ages have been compiled for this paper from published and a few unpublished sources (to be as complete as possible). Considering the large number of available ages it is possible some have been overlooked for this compilation, but if any additional ages exist, especially if they are for carbonate materials, they probably would have little affect on the overall interpretation of the lake chronology (Fig. 2). Because hundreds of radiocarbon ages are available, and they cannot all be correct, it is necessary to adopt a method to evaluate them in terms of their viability or usefulness for reconstructing lake history, although this discussion does not cast doubt on the analytical procedures used by the radiocarbon laboratories themselves.

One approach to the evaluation of ages is to use stratigraphic principles. An age is not considered in the reconstruction of lake history in this paper if it is too old for its setting (for example, ages Beta-27560 and Beta-27463 [Table S1] are "infinite" ages for mollusk shells collected from deposits of the Bonneville lake cycle), or if a sample has no stratigraphic or geomorphic context (for example, an isolated sample of tufa cemented to a bedrock exposure where no sedimentary deposits are present). Another approach to evaluate radiocarbon ages is to compare ages of different materials. For example, an age for wood, charcoal, or fragments of emergent aquatic plants (plants that are rooted in water but that take their CO_2 from the atmosphere) from a basal stratigraphic position indicates that the enclosing sediment has to be the same age as, or younger than, the sample age. Ages of carbonate materials (e.g., shell, tufa, marl) that are older than wood or