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Timing of lake-level changes for a deep last-glacial Lake Missoula: optical dating of the Garden Gulch area, Montana, USA

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A B S T R A C T

Glaciolacustrine sediments in the Clark Fork River valley at Garden Gulch, near Drummond, Montana, USA record highstand positions of the ice-dammed glacial Lake Missoula and repeated subaerial exposure. During these highstands the lake was at greater than 65% of its recognized maximum capacity. The initial lake transgression deposited a basal sand unit. Subsequent cycles of lake-level fluctuations are recorded by sequences of laminated and cross laminated silt, sand, and clay deformed by periglacial processes during intervening periods of lower lake levels.

Optically stimulated luminescence (OSL) dating of quartz sand grains, using single-aliquot regenerative-dose procedures, was carried out on 17 samples. Comparison of infrared stimulated luminescence (IRSL) from K-rich feldspar to OSL from quartz for all the samples suggests that they were well bleached prior to deposition and burial. Ages for the basal sand and overlying glaciolacustrine exposure surfaces are indistinguishable within one standard deviation, and give a weighted mean age of 20.9 ± 1.3 ka ($n = 11$). Based on sedimentological and stratigraphic analysis we infer that the initial transgression, and at least six cycles of lake-level fluctuation, occurred over time scales of decades to ~2 ka. Bioturbated sandy slopewash dated at 10.6 ± 0.9 ka and 11.9 ± 1.2 ka unconformably overlies the upper glaciolacustrine deposits. The uppermost sediments, above the glaciolacustrine section, are younger than the Glacier Peak tephra (13.7–13.4 cal ka B.P.), which was deposited across parts of the drained lake basin, but has not been found at Garden Gulch.

Our study indicates that glacial Lake Missoula reached >65 percent of maximum capacity by about 20.9 ± 1.3 ka and either partially or completely drained twelve times from this position. Rapid lowering from the lake's highstand position due to ice-dam failure likely led to scour in the downstream portions of the glacial Lake Missoula basin and megafloods in the Channeled Scabland.

1. Introduction

Glacial Lake Missoula was an ice-dammed lake that inundated about 9500 km^2 of the intermontane valleys of western Montana during the latest Pleistocene glaciation (Breckenridge et al., 1989; Pardee, 1910, 1942). Rapid emptying of glacial Lake Missoula caused giant late Pleistocene floods, or megafloods, that carved the Channeled Scabland of Washington State (Bretz, 1969). The age of glacial Lake Missoula and its lake-level history is primarily inferred from the chronology of downstream flooding in the Channeled Scabland (Atwater, 1984, 1987; Baker and Bunker, 1985; Balbas et al., 2017; Clague et al., 2003; O'Connor and Baker, 1992; Waitt, 1980, 1985; Waitt et al., 2009), the Columbia River Gorge (Benito and O'Connor, 2003), and recorded in offshore deposits in the eastern Pacific Ocean (Gombiner et al., 2016; Zuffa et al., 2000).

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Recognition of multiple floods in the downstream areas led these workers to propose various combinations of one or many more complete or partial drainings during the latest Pleistocene glaciation (~21–14 cal ka B.P.[1]) (Breckenridge and Phillips, 2010; Carrara et al., 1996; Clague et al., 2003; Hanson and Clague, 2016; Smith and Hanson, 2014; Waitt, 1980, 1985). Therefore these multiple filling and draining cycles should have created a complex set of deposits within the basin concurrent with downstream flood deposits. Direct dating of the glacial Lake Missoula deposits in outcrop has been hindered by the absence of fossils, organic carbon, and volcanic tephra.

Dating of the lake deposits provides information complementary to the flood history as inferred from downstream deposits. Although obvious evidence for the lake and for highstand altitudes are wave-cut shorelines (Pardee, 1910), they are discontinuous erosional features and difficult to date. They reach altitudes of 1260–1298 m asl in the Missoula area (Pardee, 1910). Because post-glacial isostatic adjustment has not been estimated from the locally preserved shorelines, a 1280 m altitude maximum highstand is generally accepted (Alho et al., 2010; Pardee, 1910). Lake-bottom sediments are preserved along valley floors in the lake basin from near the former ice dam (at an altitude of 630 m) to ~100 m below the lake highstand of about 1280 m. So far, dating of glacial Lake Missoula has relied on optically stimulated luminescence (OSL or optical dating) analysis of glaciolacustrine deposits (Hanson et al., 2012). Optical dating gives an estimate of the time elapsed since quartz and feldspar grains were last exposed to sunlight, which usually dates deposition and burial; it has proven to be a powerful technique for dating sedimentary deposits (e.g. Roberts and Lian, 2015). Hanson et al. (2012) used optical dating of quartz on glaciolacustrine deposits at the Ninemile and Rail line sections (Fig. 1). Their age for alluvial sand below glaciolacustrine deposits at the Ninemile section was 15.1 ± 0.6 ka and ages for two horizons within glaciolacustrine deposits at the Rail line exposure were 14.8 ± 0.7 and 12.6 ± 0.6 ka (Hanson et al., 2012). A pine needle recovered from near the top of lake deposits, but below the Glacier Peak G tephra, in a core from Flathead Lake, ~100 km north of the Ninemile and Rail line sites (Fig. 1), gave a radiocarbon age of 12,330 ± 50 yr BP (Beta-183416) (M.H. Hofmann pers. comm. 14 February 2017), or 14327 - 13965 cal yr B.P. (at two sigma), which was reported as 14,150 ± 50 cal yr BP by Hofmann and Hendrix (2010). These previous published ages were for sediments deposited below 980 m altitudes, which may represent <20% of the full-pool volume of the lake (Fig. 1). The development of a full history of lake-lowering and lake-filling cycles of sedimentation requires dating deposits at multiple altitudes in the lake basin.

The purpose of the present work is to propose a glacial Lake Missoula history from the Garden Gulch area along the Clark Fork River, Montana. These outcrops are topographically higher than those previously dated and therefore may record water-level fluctuations of deeper lake stands. We present optical ages on alluvium and periglacially modified surfaces of subaerial exposures in three glaciolacustrine sections.

2. Stratigraphic and geomorphic setting

Glaciolacustrine silt and clay of the former lake bottom locally blanket the Clark Fork River and Flathead River valleys (Figs. 1 and 2). Glaciolacustrine sediments near Garden Gulch along the Clark Fork River, about 10 km northwest of Drummond, Montana, are among the highest elevation deposits recognized in the lake basin (Berg, 2005, 2006, Lonn et al., 2007, 2010). The site is 75 km upstream of the Missoula and Ninemile valleys and 350 km upstream of the Purcell Trench ice dam, at altitudes of 1173–1186 m. The deposits were excavated to depths of >13 m across a meander loop of the Clark Fork River (Figs. 1 and 2). This excavation occurred during straightening of the railbed between 1883 and 1915 (Campbell et al., 1915). The deposits were apparently not eroded due to protection by a bedrock outcrop along the upstream (eastern) margin. The sediments record lake levels above elevations of ~1200 m and water volumes of ≥65 percent of the maximum recognized size of glacial Lake Missoula (Fig. 1). The location, sedimentology, and periglacial features of two of the three measured sections (Fig. 3, sections I and II) at the site were described previously (Smith, 2017; Smith and Hanson, 2014).

Stratigraphic sections were measured along the top of the talus using standard field techniques (Figs. 3 and 4). Section II is a composite of eight sections correlated by distinctive beds (Smith, 2017). The other sections were measured in continuous excavations. Loose, dried sediment was removed to depths of 0.2–1 m in 1–4 m-wide vertical swaths along the outcrop and then the exposed section faces were scraped with sharpened tools. The exposed deposits in the Garden Gulch area include, from the bottom to top, (1) a fining-upward sequence of paleo-Clark Fork River alluvium over bedrock; (2) transgressive basal sand; (3) rhythmically bedded glaciolacustrine deposits, and (4) capping slopewash with pedogenic alteration (Fig. 3). These units are described in detail in the following.

2.1. Paleo-Clark Fork alluvium

The lower portion of two outcrops at sections I and II (Fig. 3) are cobble and boulder-sized gravel with a coarse-grained sand matrix with west-directed (downstream) paleocurrent indicators. These deposits are interpreted as alluvium deposited by the Clark Fork River prior to inundation by glacial Lake Missoula (Smith, 2017). The gravel is overlain by locally derived colluvium and alluvium at section I, which is cross cut by medium-grained fluvial sand that overlies gravel at section II.

2.2. Deposits of the glacial Lake Missoula transgression (basal sand)

Sand with minor gravel was deposited across an inclined surface near section I and over paleo-Clark Fork River alluvium at section II. The unit ranges in thickness from about 5 to 100 cm. It contains moderately sorted cross-stratified sand and poorly sorted sandy angular and subangular gravel of locally derived Jurassic and Cretaceous sedimentary rocks (Fig. 2). At the top of the sandy gravel, rhythmically laminated beds of coarse and medium-grained silt are interbedded with gravelly sand, and intraclasts of laminated glaciolacustrine sediment; these fragments indicate that dried or frozen lake-bottom sediments were incorporated into the basal sand (Fig. 4B and C). Interlayering of this unit with overlying glaciolacustrine sediment indicates deposition during a transition from fluvial to glaciolacustrine sedimentation as glacial Lake Missoula transgressed eastward to this location (Smith, 2017). At section III the transgressive deposits consist of 3–5 cm of silty sand with minor gravel deposited over fractured bedrock (Fig. 3).

2.3. Periglacially modified glaciolacustrine deposits and silty gravel

Most of the exposure shown in Fig. 4 is made up of cycles of rhythmically bedded glaciolacustrine silt and clay with intervening beds of silty gravel. Each of the 12 sequences shown in Fig. 3,

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[1] All radiocarbon ages are reported as cal. ka B.P. or cal. yr B.P., depending on how they were originally published, and were calibrated with OxCal 4.2 using the IntCal13 calibration curve (Reimer et al., 2013). Optical ages are reported in ka with standard error.