Cosmogenic ^{3}He and ^{21}Ne age of the Big Lost River flood, Snake River Plain, Idaho

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ABSTRACT

The Big Lost River flood in southeastern Idaho occurred 20,500 calibrated yr B.P., on the basis of dates derived from cosmogenic ^{3}He and ^{21}Ne measurements of samples from flood-deposited boulders and from scour features. This date corresponds to a date of 16,900 ^{14}C yr B.P. and is close in age to several other cataclysmic flood events in western North America; it may mark evidence for widespread warming at the end of the Pleistocene in western North America. The Big Lost River flood was smaller than some other late Pleistocene floods, such as the Bonneville flood and the Missoula floods; thus, some samples exposed after the flood had significant amounts of cosmogenic ^{3}He and ^{21}Ne that was acquired before the flood occurred.

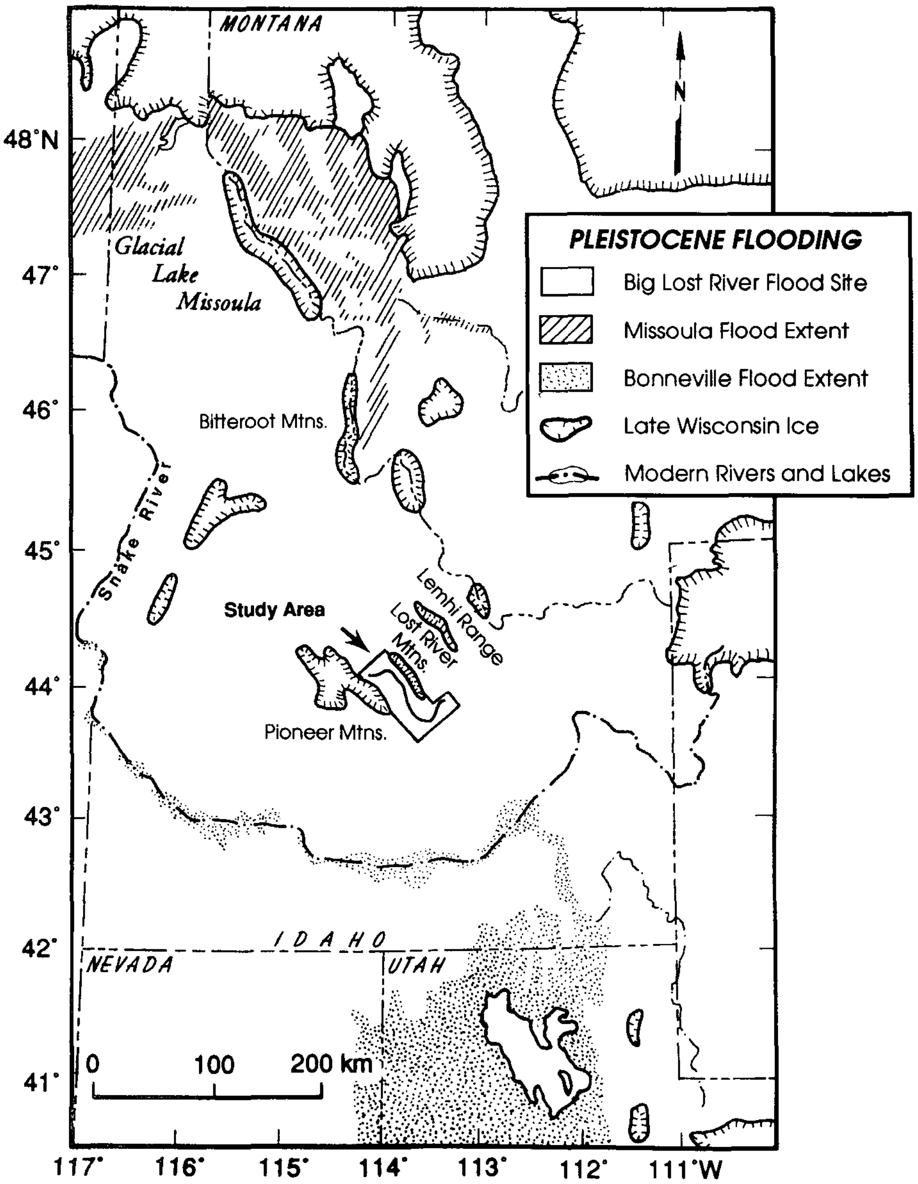

Figure 1. Locality map showing Big Lost River region in relation to Bonneville and Missoula floods in northwestern United States.

INTRODUCTION

Many cataclysmic floods in the western United States occurred near the end of the last glacial maximum, the best known being the Bonneville flood in the Snake River Plain and the floods from glacial Lake Missoula which formed the Channeled Scabland of central Washington (Fig. 1). The Bonneville flood, because of its association with the history of Lake Bonneville (Malde, 1968; Currey et al., 1984; O'Connor 1993), is well dated at 14,500 ^{14}C yr B.P. (Oviatt et al., 1992). The Channeled Scabland in central Washington was recognized by Bretz (1923) to be a result of cataclysmic flooding; more recent work has shown that multiple floods occurred in the region (Waitt, 1985; Baker and Bunker, 1985; Baker et al., 1991; O'Connor and Baker, 1992). Evidence for a large late Pleistocene flood along the Big Lost River was first recognized in 1982 by J. Tullis and V. R. Baker, who noted the presence of landforms characteristic of other late Pleistocene floods in the western United States (Rathburn, 1993).

In this study, we date the Big Lost River flood using cosmogenic ^{3}He and ^{21}Ne extracted from eroded basalt boulders and scoured bedrock collected in the Box Canyon region of the Big Lost River on the Snake River Plain (Fig. 2). Cosmogenic ^{3}He and ^{21}Ne are useful for dating geomorphic surfaces (Craig and Poreda, 1986; Kurz, 1986; Marti and Craig, 1987; Cerling, 1990), and the production rates for ^{3}He and ^{21}Ne have been established (Cerling and Craig, 1994a, 1994b; Poreda and Cerling 1992).

FIELD RELATIONS AND SAMPLE LOCALITIES

Big Lost River originates in the Pioneer, White Knob, and Lost River Mountains in southeastern Idaho (Fig. 1). It enters the Snake River Plain near Arco, Idaho, and flows into the 11-km-long Box Canyon gorge. Box Canyon is on average 40 m wide and 23 m deep, with vertical walls cut into columnar-jointed, massive, and vesicular basalt (Rathburn, 1993). Quaternary and late Neogene basalts of the Snake River Plain locally are covered with up to several metres of Pleistocene loess. Downstream from Box Canyon, the Big Lost River flows through

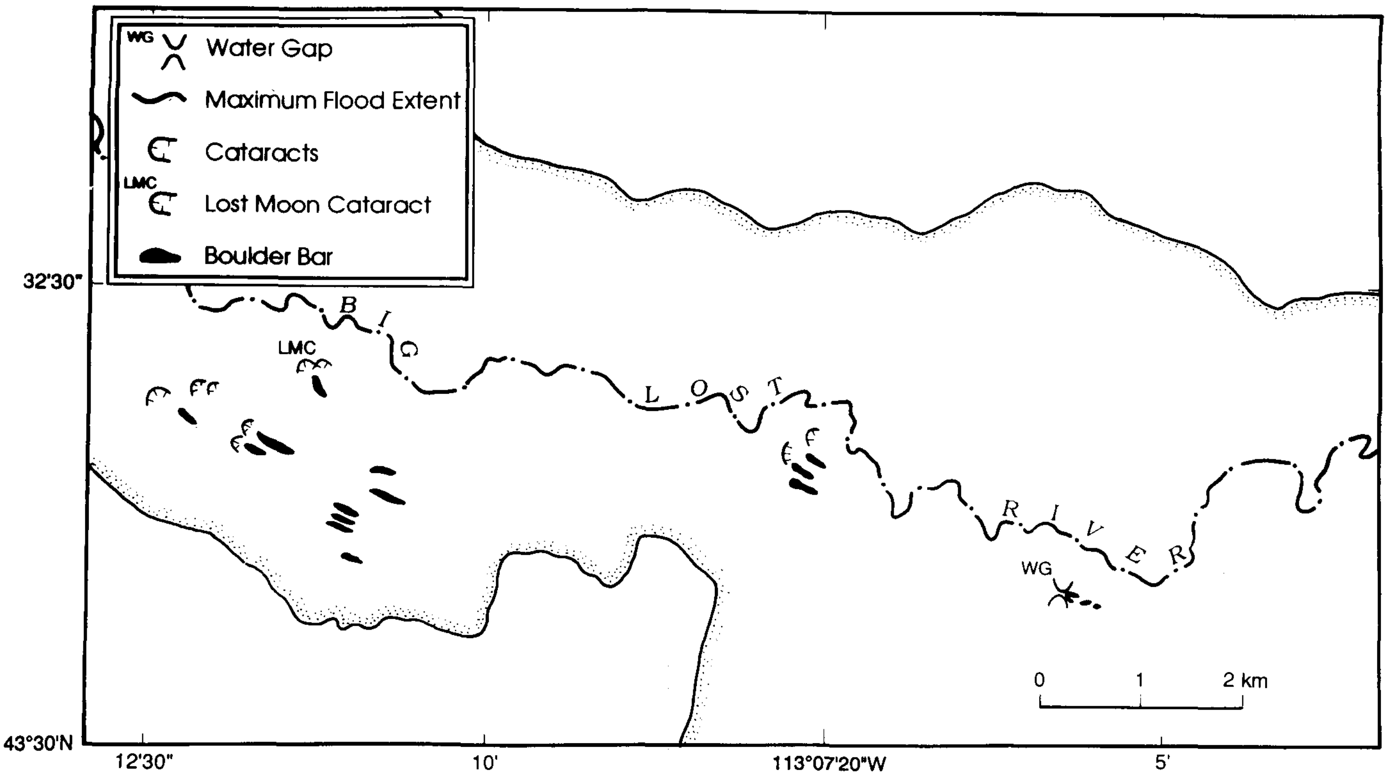

Figure 2. Detailed locality map showing Big Lost River flood extent in Box Canyon region of Big Lost River. Modified from Rathburn (1991, 1993).

the Idaho National Engineering Laboratory (INEL) and ends in the Big Lost River Sinks.

Cataclysmic flooding occurred in the late Pleistocene along the Big Lost River and into the Snake River Plain. Rathburn (1993) recognized scour features, cataracts, boulder bars, and loess hills streamlined by flood waters (Fig. 2). A scabland loess topography with abundant scour features is found inside the valley walls defined by an eroded loess scarp, which is ~5 km wide. Lost Moon Cataract (Fig. 2) has a 9-m-high basalt lip with a 4-m-deep plunge pool. Boulders up to 3 m in diameter were plucked from the basalt lip or transported over its top. In the scour channel below Lost Moon Cataract, boulders decrease in maximum size from ~2 m diameter 50 m downstream to ~1 m diameter 500 m downstream, and show a significant increase in rounding over the same distance (Rathburn, 1993). Numerous boulder bars and boulder trains, up to 300 m long and several tens of metres wide, were deposited parallel to the direction of flood flow. Many of them show imbricate structure. Rathburn (1993) has estimated that the peak discharge of the Big Lost River flood was ~60 000 m^3/s, with a local maximum stream power of 26 000 W/m^2 in the Box Canyon region. By comparison, the late Pleistocene Bonneville flood was estimated to have a peak discharge of 1 000 000 m^3/s with a maximum stream power of 10 000 W/m^2 (O'Connor, 1993); the Missoula flood of the Channeled Scablands was bigger yet, with an estimated discharge and stream power of 17 000 000 m^3/s and 300 000 W/m^2, respectively (O'Connor and Baker, 1992).

We collected several samples of basalt boulders and outcrops eroded by the Big Lost River flood. Three of the samples (10913, 10914, and 10915) were collected from two separate boulder bars several kilometres east of Lost Moon Cataract (Fig. 2). Both boulder bars were downstream from a prominent water gap that had a 4-m-deep scour channel. The largest boulder (10915) measured about 2 × 2.5 × 3 m; the others were slightly >1 m in diameter. We collected a large fragment from the exposed top of the boulder to minimize self-shielding of cosmic rays. This is important because the attenuation length (depth where isotope production is 1/*e* of the surface value) for cosmic ray absorption in basalts is ~50 cm (Kurz, 1986; Lal, 1991). Significant erosion, below the level where significant abundance of cosmogenic isotopes formed during previous exposure episodes are to be found (~2 m), exposes fresh surfaces for accumulation of in situ cosmogenic isotopes which allows the age of the erosion event to be determined. All the samples from this locality consist of basalt from the Quaking Aspen flow, which has a late Pleistocene age of <200 ka (Kuntz et al., 1990).

An additional sample was collected in the vicinity of Lost Moon Cataract, which was eroded into the Crater Butte flow (K-Ar date on whole-rock basalt is 519 ±52 ka; Kuntz et al., 1990). Sample 10916 was collected from the lip of the cataract, 3 m below the original flow top.

ANALYTICAL TECHNIQUES

Only the upper 4 cm of the sample was processed. Samples were crushed and sieved to a uniform grain size and separated from rock fragments by hand picking and magnetic separation. Samples were crushed under high vacuum to release mantle helium contained in inclusions. Powders and uncrushed phenocrysts of olivine and plagioclase were melted at 1800 °C in a double-walled modified Turner furnace. Isotopic measurements were made on a VG 5400 mass spectrometer fitted with an electron multiplier and pulse counting electronics. ^{3}He/^{4}He were standardized against the Scripps Institution of Oceanography Yellowstone Park gas at 16.5 R$_A$ (where R$_A$ is the atmospheric ^{3}He/^{4}He ratio); neon was standardized against 76 μcc of air (1.25 ncc of ^{20}Ne). All values in Table 1 were corrected for interference peaks, extraction, and instrumental blanks (Poreda and Cerling, 1992; Poreda and Farley, 1992). Total ^{3}He and ^{4}He are 13 500 ±5000 atoms and 0.1 ±0.03 ncc, respectively, and the ^{20}Ne blank is 30 ±5 pcc with a ^{21}Ne/^{20}Ne air ratio of

TABLE 1. MEASURED ^{4}He AND ^{20}Ne CONCENTRATIONS; ^{3}He/^{4}He, ^{22}Ne/^{20}Ne, AND ^{21}Ne/^{20}Ne RATIOS; AND CALCULATED ^{3}He$_C$ AND ^{21}Ne$_C$ IN SAMPLES FROM THE SNAKE RIVER PLAIN

Sample	Phase	Weight	R/R$_A$		^{4}He	^{3}He$_C$	^{3}He$_C$	^{20}Ne	^{22}Ne/^{20}Ne	^{21}Ne/^{20}Ne	^{21}Ne$_C$	^{21}Ne$_C$
		(g)	crushed	fusion	(ncc/g)	(10^6 atoms/g)	(%)	(pcc/g)	(x 10^4)	(x10^6)	(10^6 atoms/g)	(%)
10913	Olivine	0.514	8.8	47.8 ±1.2	5.2	7.54 ±0.31	81.6	149	1028 ±5	3661±40	2.86 ±0.16	19.3
10914	Olivine	1.021	8.8	78.5 ±2.1	6.5	16.7 ±0.90	88.8	374	1036 ±10	3663±59	7.22 ±0.60	19.3
10914	Olivine	0.574	8.8	204.0 ±4.0	2.0	15.8 ±0.50	95.7	143	1021 ±12	4428±50	6.21 ±0.20	33.2
10915	Olivine	0.500	8.8	319.0 ±6.0	0.6	7.12 ±0.17	97.2	124	1028 ±8	4003±40	3.52 ±0.15	26.2
10915	Olivine	0.501	8.8	424.0 ±8.0	0.6	8.82 ±0.19	97.9	121	1037 ±10	4054±150	3.57 ±0.49	27.1
10916	Olivine	0.411	8.8	1640.0 ±29.	0.6	35.1 ±1.1	99.5	337	1037 ±10	4538±54	14.38 ±0.50	34.9
10916	Plagioclase	0.790						77	1044 ±44	5475±50	5.18 ±0.12	46.0
10916	Plagioclase	0.800						65	1054 ±5	6322±60	5.92 ±0.15	53.2

Note: R is the measured ^{3}He/^{4}He ratio in the sample; R$_A$ is the atmospheric ^{3}He/^{4}He ratio (1.40 x 10^{-6}); ^{3}He$_C$ and ^{21}Ne$_C$ are the cosmogenic components of ^{3}He and ^{21}Ne in the sample.

TABLE 2. CONCENTRATIONS OF COSMOGENIC ^{3}He AND ^{21}Ne IN SAMPLES FROM THE BIG LOST RIVER FLOOD CORRECTED TO THE SURFACE OF THE SAMPLE, LOCAL PRODUCTION RATES (J*) OF COSMOGENIC ^{3}He AND ^{21}Ne USED IN THE CALCULATIONS, AND THE ^{3}He$_C$ AND ^{21}Ne$_C$ AGES OF THE SAMPLES

Sample	Phase	^{3}He$_C$(0)	^{21}Ne$_C$(0)	J*^{3}He$_C$	J*^{21}Ne$_C$	Cosmogenic age		
		(10^6 atoms/g)		(atoms • g^{-1} • yr^{-1})		^{3}He$_C$	^{21}Ne$_C$ cal yr B.P.	average
10913	Olivine	7.69±0.32	2.92±0.16	387	159	19,900	18,400	19,100±1100
10914	Olivine	17.03±0.92	7.36±0.61	387	159	44,000	46,400	43,000±2800
10914	Olivine	16.12±0.51	6.33±0.20	387	159	41,700	39,900	
10915	Olivine	7.26±0.17	3.59±0.15	387	159	18,800	22,600	21,900±2100
10915	Olivine	9.00±0.19	3.64±0.50	387	159	23,300	23,000	
10916	Olivine	35.80±1.12	14.67±0.51	396	162	90,400	90,300	92,800±5900
10916	Plagioclase		5.28±0.12		59		89,000	
10916	Plagioclase		6.04±0.15		59		101,600	

Note: Local production rates are calculated using the ^{3}He$_C$ and ^{21}Ne$_C$ production rates of Cerling and Craig (1994b) and Poreda and Cerling (1992), respectively, scaled for latitude and altitude (Lal, 1991)

0.002956. The equations for the calculation of ^{3}He$_C$ and ^{21}Ne$_C$ are

$$^3\mathrm{He_C} = (^4\mathrm{He_{meas}}) \times [(^3\mathrm{He}/^4\mathrm{He})_\mathrm{meas} - (^3\mathrm{He}/^4\mathrm{He})_\mathrm{crush}],$$

$$^{21}\mathrm{Ne_C} = (^{21}\mathrm{Ne_{meas}}) \times [(^{21}\mathrm{Ne}/^{20}\mathrm{Ne})_\mathrm{meas} - (^{21}\mathrm{Ne}/^{20}\mathrm{Ne})_\mathrm{air}],$$

where ^{3}He$_C$ and ^{21}Ne$_C$ are the amounts of cosmogenic ^{3}He and ^{21}Ne, respectively; ^{4}He$_{meas}$ and ^{21}Ne$_{meas}$ are the measured amounts of ^{4}He and ^{21}Ne in the sample released by heating to 1800 °C; $(^3\mathrm{He}/^4\mathrm{He})_\mathrm{meas}$ and $(^{21}\mathrm{Ne}/^{20}\mathrm{Ne})_\mathrm{meas}$ are the measured ^{3}He/^{4}He and ^{21}Ne/^{20}Ne ratios in the sample released by heating to 1800 °C, respectively; and $(^3\mathrm{He}/^4\mathrm{He})_\mathrm{crush}$ and $(^{21}\mathrm{Ne}/^{20}\mathrm{Ne})_\mathrm{air}$ are the ^{3}He/^{4}He and ^{21}Ne/^{20}Ne ratios in the crushed sample or air, respectively. R/R$_A$ is the measured ^{3}He/^{4}He ratio divided by the atmospheric ^{3}He/^{4}He ratio.

Interlaboratory calibration of the University of Rochester laboratory with the Isotope Laboratory at Scripps Institution of Oceanography on identical sample splits (reported in Cerling, 1990; Poreda and Cerling, 1992; and Cerling and Craig, 1994b) shows that ^{3}He$_C$ and ^{21}Ne$_C$ differences greater than 5% are above the analytical uncertainty.

RESULTS

Table 1 reports the measured concentrations of ^{3}He$_C$ and ^{21}Ne$_C$ in olivine, and ^{21}Ne$_C$ in plagioclase from samples associated with the Big Lost River flood. Low levels of ^{4}He were released during crushing. Crushing of sample 10914 released 2.2 ncc/g of ^{4}He with a ratio of 8.8 R/R$_A$. This represents an upper limit to the inherited value because we found that up to 1% of the cosmogenic ^{3}He was released during vigorous crushing, resulting in high ^{3}He/^{4}He ratios at very low ^{4}He concentrations. We were unable to satisfactorily measure the crush value for the Crater Butte flow because of low ^{4}He concentrations, and we therefore use the 8.8 value obtained for the Quaking Aspen flow in our calculations. The ^{3}He$_C$ and ^{21}Ne$_C$ concentrations are corrected to the surface of the rock assuming a basalt density of 2.8 and an attenuation of 150 g/cm^2 (Lal, 1991), and they are reported as ^{3}He$_C$(0) and ^{21}Ne$_C$(0) in Table 2. Table 2 gives the local production rates for ^{3}He$_C$ (J*^{3}He$_C$) and for ^{21}NeC (J*^{21}Ne$_C$) for the local latitude and altitude which have been corrected (using Lal, 1991) from the production rates of ^{3}He and ^{21}Ne determined by measuring samples of known age (Cerling and Craig, 1994b; Poreda and Cerling, 1992). The best determined production rate for cosmogenic ^{3}He and ^{21}Ne is that of the Tabernacle Hill flow in Utah, which is 109 atoms$\cdot$g$^{-1}\cdot$yr^{-1} and 45 atoms$\cdot$g$^{-1}\cdot$yr^{-1}, respectively in olivine (Fo$_{80}$), and 17 atoms$\cdot$g$^{-1}\cdot$yr^{-1} for plagioclase (Ab$_{30}$ to Ab$_{40}$) for the calibration in the Rochester laboratory (Poreda and Cerling, 1992). These are calibrated production rates and have been corrected for the difference in the calibrated time scale and the ^{14}C time scale (see Cerling and Craig, 1994b) and are given for high latitude and sea level (Lal, 1991; Cerling and Craig, 1994a). Calibrated ages are labeled "cal yr B.P." and ^{14}C ages are labeled "^{14}C yr B.P."

DISCUSSION

Two samples have cosmogenic exposure ages between 19,000 and 22,000 cal yr B.P., and two others give much older ages (Table 2). Coexisting olivine and plagioclase give similar ages. The discrepancy in ages for all of the samples is probably because some of them had a preflood exposure age. Because the attenuation depth [the production rate varies with depth as $J^*(z) = J^*(z = 0)xe^{-z/z^*}$, where z* is the attenuation depth] of cosmic rays by basalt is ~50 cm, >2 m of erosion is needed to get below the depth where the cosmogenic production is only 1% of the surface value. We suspect that the two samples (10914 and 10916) with older ages had significant ^{3}He$_C$ and ^{21}Ne$_C$ concentrations prior to the time of the Big Lost River flood. Sample 10914 was a basalt in the same boulder bar as 10915, which gave a significantly younger age. Sample 10916 was a scoured basalt from the nickpoint of Lost Moon Cataract which was eroded headward several metres, possibly several tens of metres, during the Big Lost River flood. The present nickpoint is about 3 metres below the original flow top of the Crater Butte flow. The channeling of flow through Lost Moon Cataract probably resulted from a preflood topography that may have been eroded to a level below the original flow top, perhaps even by previous floods of similar origin. It is possible that the age for this sample, 92,800 cal yr B.P., may be associated with an earlier flood event. This age will be modified when the production rate for cosmogenic isotopes is calibrated beyond 20,000 years (Cerling and Craig, 1994a, 1994b).

Two samples give similar ages for the Big Lost River flood of ~20,500 cal yr B.P. Sample 10913 gives an average cosmogenic age of 19,100 ±1100 cal yr B.P., and sample 10915 gives an age of 21,900 ±2100 cal yr B.P. Together, these samples suggest a maximum age of ~20,500 ±1970 cal yr B.P. for the Big Lost River flood. Using the correction for absolute years compared to the ^{14}C scale (Bard et al., 1990), 20,500 cal yr B.P. corresponds to a ^{14}C age of 16,900 ^{14}C yr B.P.

The Bonneville flood was a one-time event, unlike the Big Lost River and Missoula floods, which resulted from glacial dam collapses. The Bonneville flood has been accurately dated at 14,500 ^{14}C yr B.P. (Oviatt et al., 1992), which corresponds to 17,600 cal yr B.P. A boulder deposited near Pocatello, Idaho, by the Bonneville flood contains 6.1×10^6 atoms/g $^3\mathrm{He_C}$ (Cerling and Craig, 1994b), a value smaller than that of the Big Lost River flood when corrected for latitude (42.86°) and elevation (1380 m). These data give an age of 17,400 ±400 cal yr B.P. for the Bonneville flood using the local $^3\mathrm{He_C}$ production rate at the Bonneville flood locality (356 atoms$\cdot$g$^{-1}\cdot$yr^{-1}; Cerling and Craig, 1994b) although this age is not completely independent of the $^3\mathrm{He_C}$ production rate determination (see Cerling and Craig, 1994b). The age of the Bonneville flood as determined using cosmogenic isotopes is younger than the Big Lost River flood.

Cerling (1990) reported that olivine from basalts eroded by the Owens River flood (California) contained $4.57 \times 10^6 \pm 0.18 \times 10^6$ atoms/gram cosmogenic ^{3}He. Using the revised production rate of Cerling and Craig (1994b) scaled to the Owens River locality ($J^{*3}\mathrm{He_C}$ = 223 atoms$\cdot$g$^{-1}\cdot$yr^{-1} for 35.98° latitude and 994 m elevation), the Owens River flood is calculated to have occurred 20,500 ±800 cal yr B.P., essentially the same time as the Big Lost River flood.

The Channeled Scabland in central and western Washington results from multiple floods of Lake Missoula in northern Idaho and western Montana, although details of the history are still controversial (Waitt, 1985; Baker and Bunker, 1985; Baker et al., 1991). Tephra correlation of ash buried in slackwater deposits indicate that flooding began ~16,000 ^{14}C yr B.P. (20,000 cal yr B.P.).

CONCLUSIONS

The Big Lost River flood through Box Canyon in south-central Idaho has been dated with $^3\mathrm{He_C}$ and $^{21}\mathrm{Ne_C}$ at 20,500 ±1900 cal yr B.P., about the same time as the Owens River flood in California, which was dated by $^3\mathrm{He_C}$ at 20,500 ±800 cal yr B.P. These ages are about the same as the beginning of the Missoula floods which, on the bases of tephrochronology and ^{14}C dating, started at about 20,000 cal yr B.P. The near-coincidental ages of three cataclysmic flood events in the western United States may mark the beginning of glacial melting at ~20,500 cal yr B.P. The 20,500 cal yr B.P. age of the Big Lost River flood predates the Bonneville flood, which occurred ~17,600 cal yr B.P.

APPENDIX 1. SAMPLE AND LOCALITY INFORMATION

Samples 10913, 10914, and 10915 were from boulder bars below a water gap, and sample 10916 was from a bedrock sample on the lip of Lost Moon Cataract. Latitudes, longitudes, and elevations are 43°31′51″N and 113°05′37″W at 1548 m for sample 10913; 43°31′47″N and 113°05′29″W at 1548 m for samples 10914 and 10915; and 43°32′02″N and 113°11′20″W at 1579 m for 10916. Samples 10913, 10914, and 10915 were from the olivine phyric Quaking Aspen basalt flow, and sample 10916 was from the olivine phyric Crater Butte basalt flow.

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