

Balbas et al., 2017, ^{10}Be dating of late Pleistocene megafloods and Cordilleran Ice Sheet retreat in the northwestern United States: Geology, doi:10.1130/G38956.1.

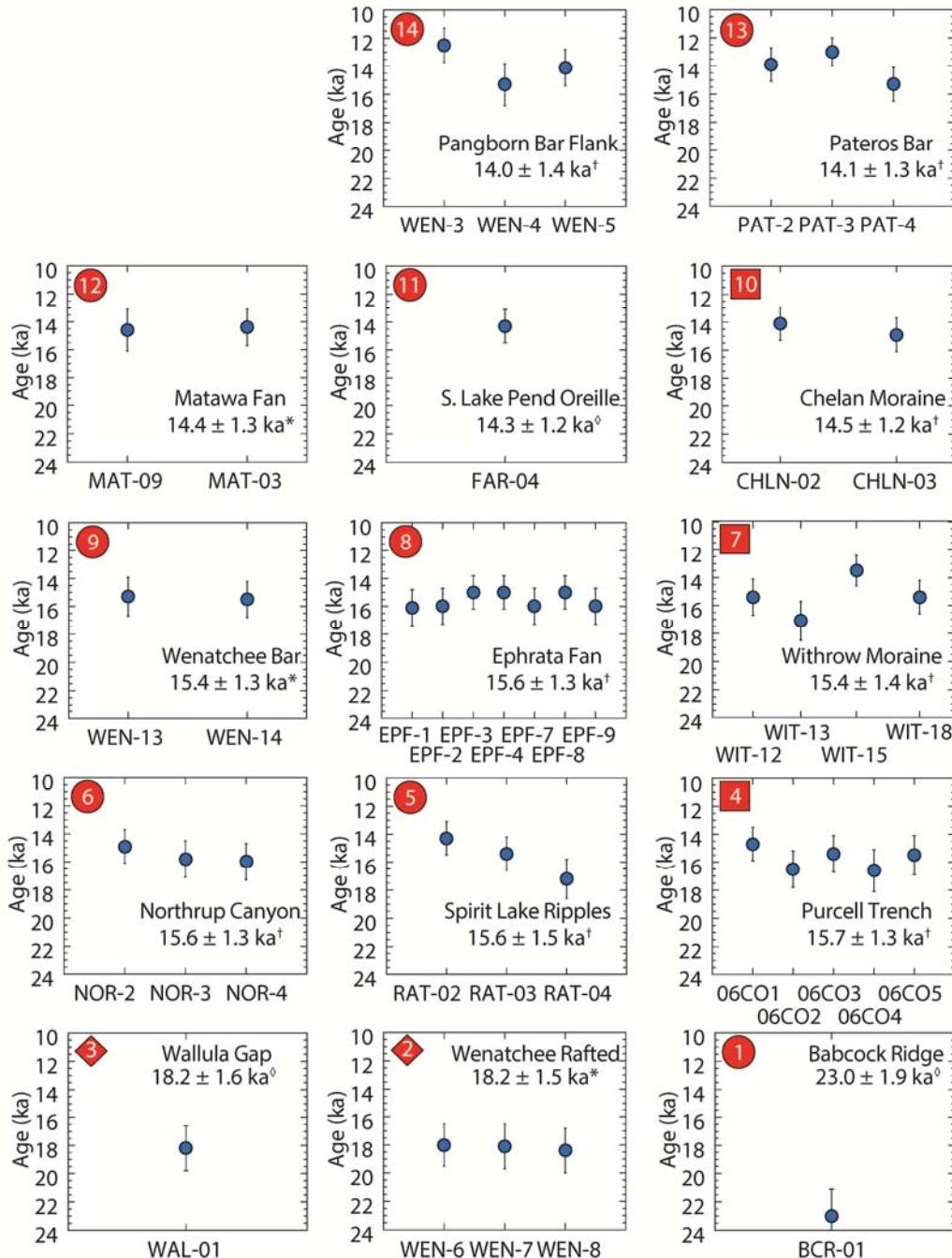


Figure DRI: ^{10}Be surface exposure ages of boulders and bedrock from sites 1-14 (Figure 1, Figures DR2-DR49, Tables DR1, DR2). Individual samples are defined on the x-axis with sample age and 1σ uncertainty on the y-axis. Site numbers appear in the upper left corner of each plot (Figure 1). Circles represent flood deposited boulders except for Northrup Canyon, which is bedrock; squares represent glacier erratics; diamonds represent ice-rafted boulders. Purcell Trench data (site 4) are from ^{18}Be . Individual site ages and uncertainty are shown in the right bottom corners. All errors are reported at 1σ and include the uncertainty in the ^{10}Be production rate used (4.8%). The * represents an error-weighted mean and uncertainty, † indicates a site mean and standard error, and ◊ represents the analytical external error on the single sample.

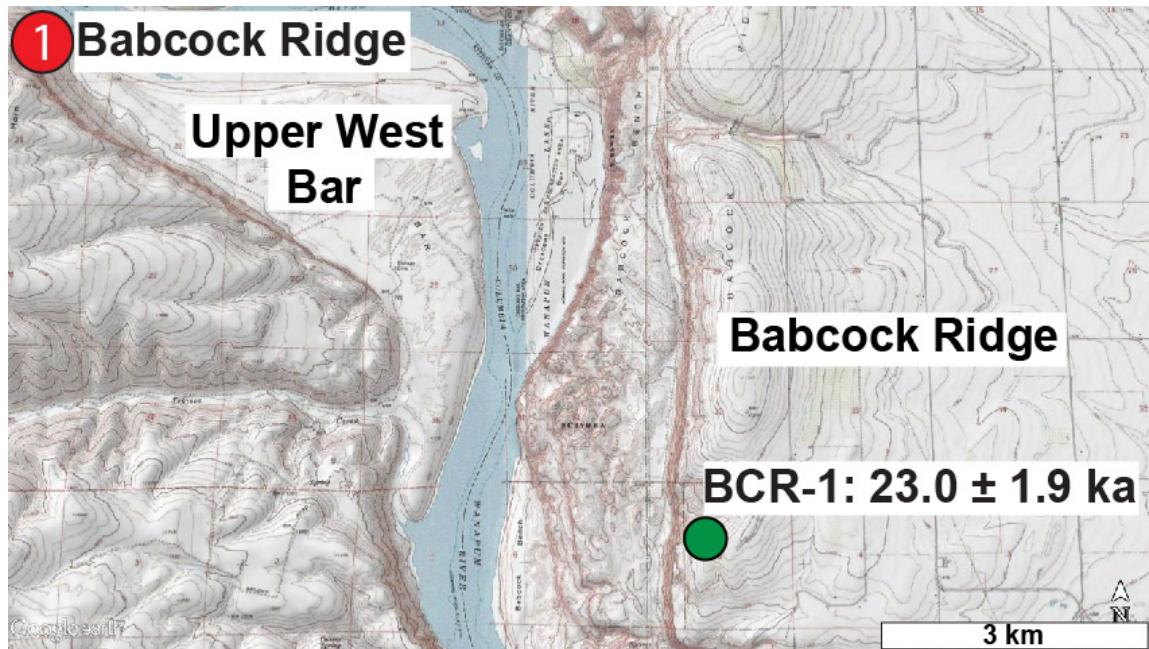


Figure DR2: A topographic map of the Babcock Ridge area. The site number shown in the red circle matches those shown in figures 1 and 2. The green circle represents the location of a sampled boulder. Only samples used in site mean calculations are shown with 1σ external uncertainty (Table DR1). Babcock Ridge is a prominent ridge east of Upper West Bar and southeast of Wenatchee. The ridge formed from continuous erosion by floods moving southward down the Columbia River. The sampled boulder is at ~200 m above the river suggesting deposition by iceberg. We interpret the surface exposure age of this sample to represent the time of deposition by a large magnitude flood.



Figure DR3: Babcock Ridge Sample: BCR-1

^{10}Be age: 23.0 ± 0.7 (ka; 1σ internal uncertainty)

Location: Babcock Ridge

Latitude: 47.169201

Longitude: -119.97806

Elevation: 395 m

Boulder Height: 1.0 m

Lithology: Granite

Shielding: none

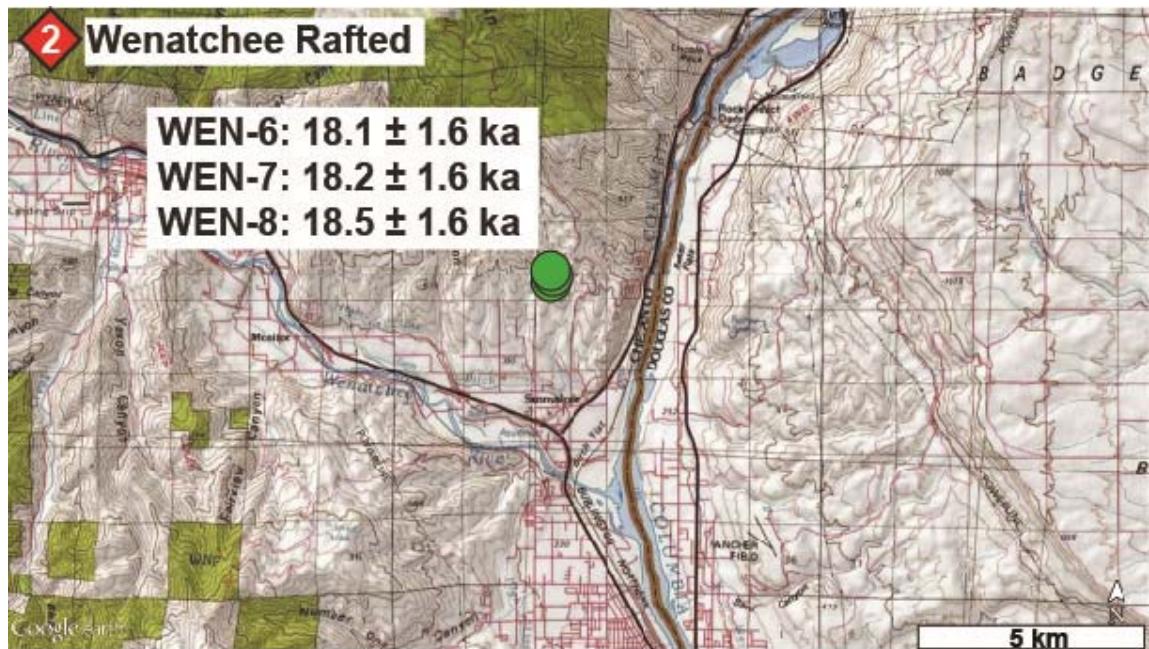


Figure DR4: A topographic map of the Wenatchee area, see figure DR2 for further description. The Wenatchee Ice Rafted is located north of Wenatchee, ~200 m above the current river level at an elevation of 420-440 m. The high elevation of these boulders suggests deposition by icebergs. We interpret the surface exposure ages of these boulders to represent the last the time of a large magnitude flood.



Figure DR5: Wenatchee Rafted Sample: WEN-6

^{10}Be age: 18.1 ± 0.6 (ka; 1σ internal uncertainty)

Location: Northwest Wenatchee

Latitude: 47.49510

Longitude -120.34406

Elevation: 421 m

Boulder Height: 1.2 m

Lithology: Granodiorite

Shielding: none



Figure DR6: Wenatchee Rafted Sample: WEN-7

^{10}Be age: 18.2 ± 0.8 (ka; 1σ internal uncertainty)

Location: Northwest Wenatchee

Latitude: 47.49600

Longitude -120.34360

Elevation: 433 m

Boulder Height: 0.4 m

Lithology: Granodiorite

Shielding: none



Figure DR7: Wenatchee Rafted Sample: WEN-8

10 Be age: 18.5 ± 0.8 (ka; 1σ internal uncertainty)

Location: Northwest Wenatchee

Latitude: 47.49640

Longitude -120.34315

Elevation: 441 m

Boulder Height: 1 m

Lithology: Granodiorite

Shielding: none

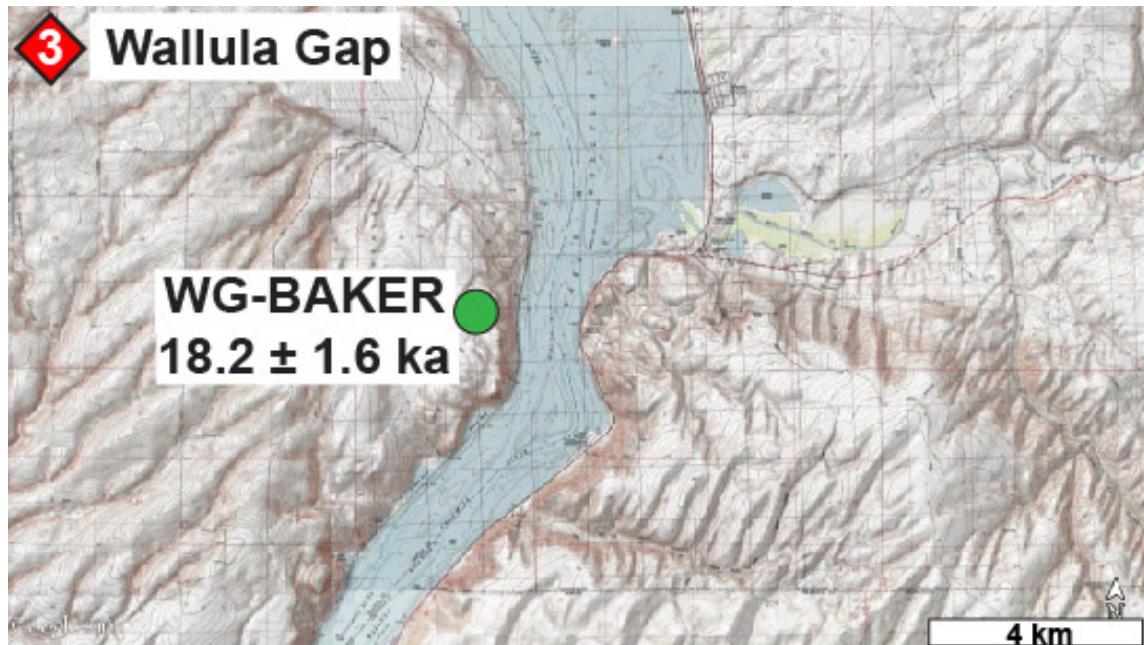


Figure DR8: A topographic map of Wallula Gap, see figure DR2 for further description. The Wallula Gap is located south of Wallula, WA and northeast of the Dalles, OR. This feature is a major constriction point for megafloods traveling down the Columbia River. During megaflooding events, floodwater would be slowed by the gap causing the creation of the ephemeral Lake Louis. We interpret the surface exposure age of this boulder to represent a large magnitude flood.



Figure DR9: Wallula Gap Ice Rafted Sample: WG-Baker

^{10}Be age: 18.2 ± 0.8 (ka; 1σ internal uncertainty)

Location: Wallula Gap

Latitude: 46.04585

Longitude -118.96192

Elevation: 341 m

Boulder Height: 0.9 m

Lithology: Granite

Shielding: none

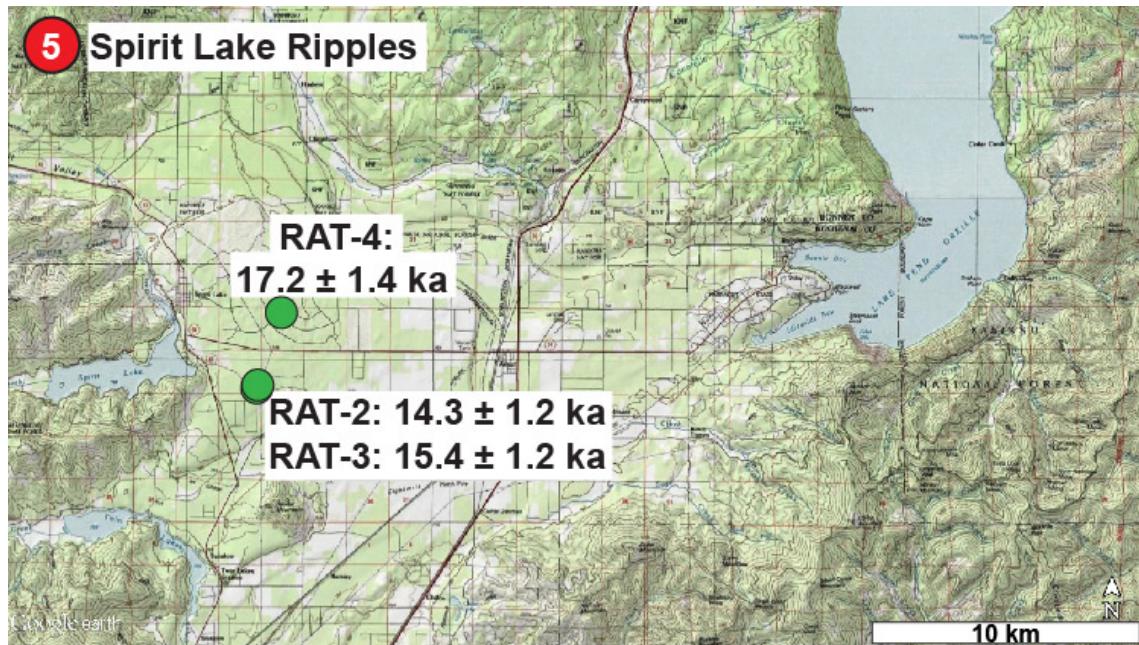


Figure DR10: A topographic map of the Spirit Lake Giant Ripples area, see figure DR2 for further description. The Spirit Lake Giant Ripple mark site is located west of Farrugat Park and east of Spirit Lake. We interpret surface exposure ages of the boulders deposited at this site to represent the last time floods reached large enough magnitudes to crest this feature (~790 m).



Figure DR11: Spirit Lake Ripples Sample: RAT-2

^{10}Be age: 14.3 ± 0.5 (ka; 1σ internal uncertainty)

Location: Spirit Lake Ripples

Latitude: 47.93709

Longitude: -116.83388

Elevation: 796 m

Boulder Height: 1.5 m

Lithology: Granite

Shielding: none



Figure DR12: Spirit Lake Ripples Sample: RAT-3

^{10}Be age: 15.4 ± 0.4 (ka; 1σ internal uncertainty)

Location: Spirit Lake Ripples

Latitude: 47.97075

Longitude: -116.59628

Elevation: 791 m

Boulder Height: 1.3 m

Lithology: Granite

Shielding: none



Figure DR13: Spirit Lake Ripples Sample: RAT-4

^{10}Be age: 17.2 ± 0.5 (ka; 1σ internal uncertainty)

Location: Spirit Lake Ripples

Latitude: 47.95984

Longitude: -116.81949

Elevation: 790 m

Boulder Height: 1.4 m

Lithology: Granite

Shielding: none

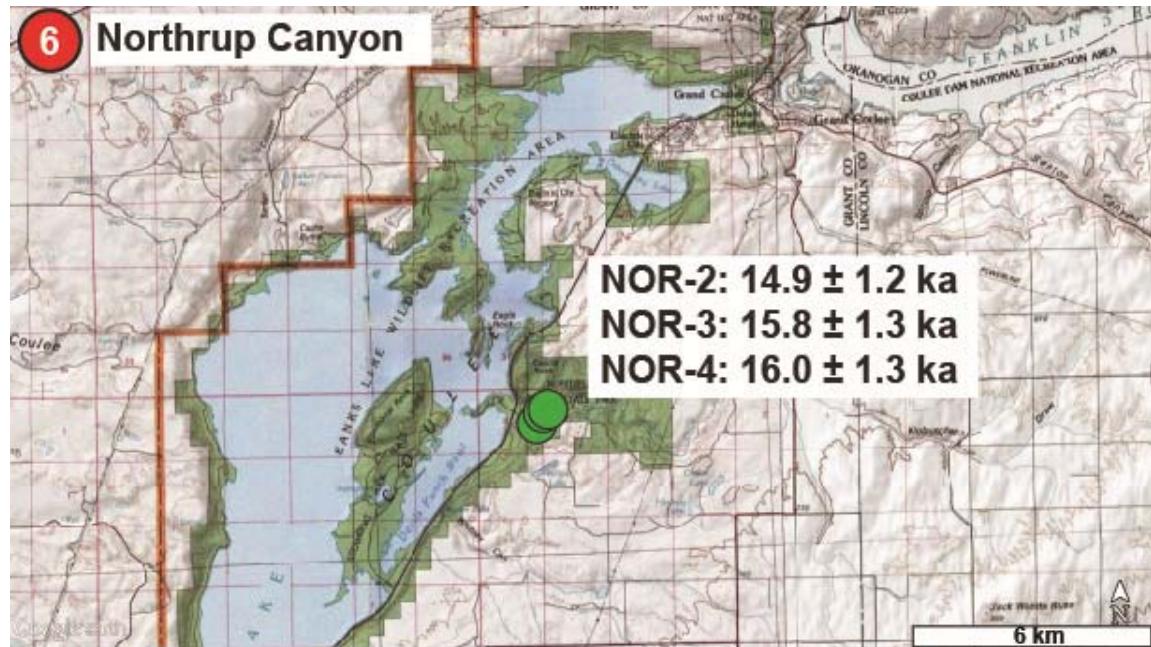


Figure DR14: A topographic map of the Northrup Canyon area, see figure DR2 for further description. Northrup Canyon is found east of Steamboat rock and south of Grand Coulee city. Northrup is a cataract complex that flows into the upper Grand Coulee. We interpret the surface exposure ages of the bedrock to represent the timing at which these inselbergs were unroofed by megaflood erosion.



Figure DR15: Northrup Canyon Sample: NOR-2

^{10}Be age: 14.9 ± 0.4 (ka; 1σ internal uncertainty)

Location: Northrup Canyon

Latitude: 47.86628

Longitude: -119.08377

Elevation: 577 m

Lithology: Granite

Shielding: none



Figure DR16: Northrup Canyon Sample: NOR-3

^{10}Be age: 15.8 ± 0.6 (ka; 1σ internal uncertainty)

Location: Northrup Canyon

Latitude: 47.87080

Longitude: -119.07788

Elevation: 628 m

Lithology: Granite

Shielding: none



Figure DR17: Northrup Canyon Sample: NOR-4

^{10}Be age: 16.0 ± 0.5 (ka; 1σ internal uncertainty)

Location: Northrup Canyon

Latitude: 47.87080

Longitude: -119.07823

Elevation: 597 m

Lithology: Granite

Shielding: none

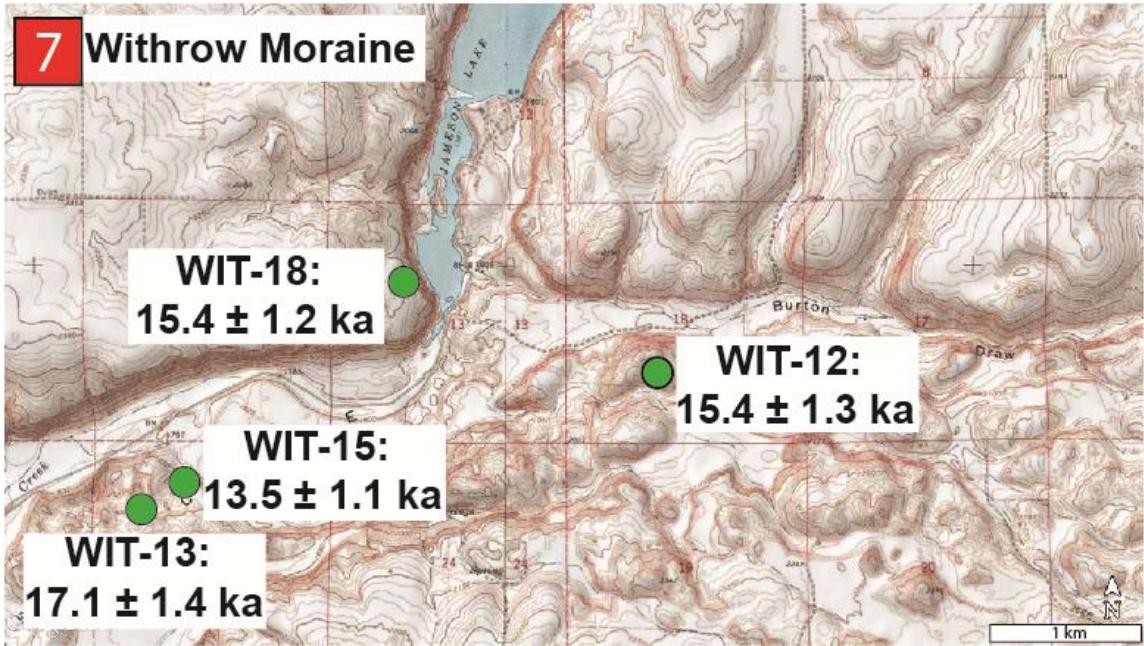


Figure DR18: A topographic map of the Withrow moraine area, see figure DR2 for further description. Withrow moraine is located in Washington on the Waterville Plateau in between Coulee City and the town of Withrow. It marks the southernmost extent of the Okanogan Lobe of the Cordilleran Ice Sheet. Undisturbed felsic boulders associated with this moraine are uncommon in this heavily farmed area. We located several undisturbed boulders within sections of Upper Moses Coulee. Surface exposure ages of boulders on the crest of this moraine are interpreted as representing the onset of retreat.



Figure DR19: Withrow Moraine Sample: WIT-12

^{10}Be age: 15.4 ± 0.5 (ka; 1σ internal uncertainty)

Location: Moses Coulee

Latitude: 47.66025

Longitude: -119.61309

Elevation: 636 m

Boulder Height: 1.4 m

Lithology: Granite

Shielding: none



Figure DR20: Withrow Moraine Sample: WIT-13

^{10}Be age: 17.1 ± 0.5 (ka; 1σ internal uncertainty)

Location: Moses Coulee

Latitude: 47.64924

Longitude: -119.65714

Elevation: 655 m

Boulder Height: 1.05 m

Lithology: Granite

Shielding: none



Figure DR21: Withrow Moraine Sample: WIT-15

^{10}Be age: 13.5 ± 0.4 (ka; 1σ internal uncertainty)

Location: Moses Coulee

Latitude: 47.6499

Longitude: -119.65025

Elevation: 615 m

Boulder Height: 0.6 m

Lithology: Granite

Shielding: none



Figure DR22: Withrow Moraine Sample: WIT-18

^{10}Be age: 15.4 ± 0.5 (ka; 1σ internal uncertainty)

Location: Moses Coulee

Latitude: 47.66525

Longitude: -119.63387

Elevation: 635 m

Boulder Height: 0.6 m

Lithology: Granite

Shielding: none

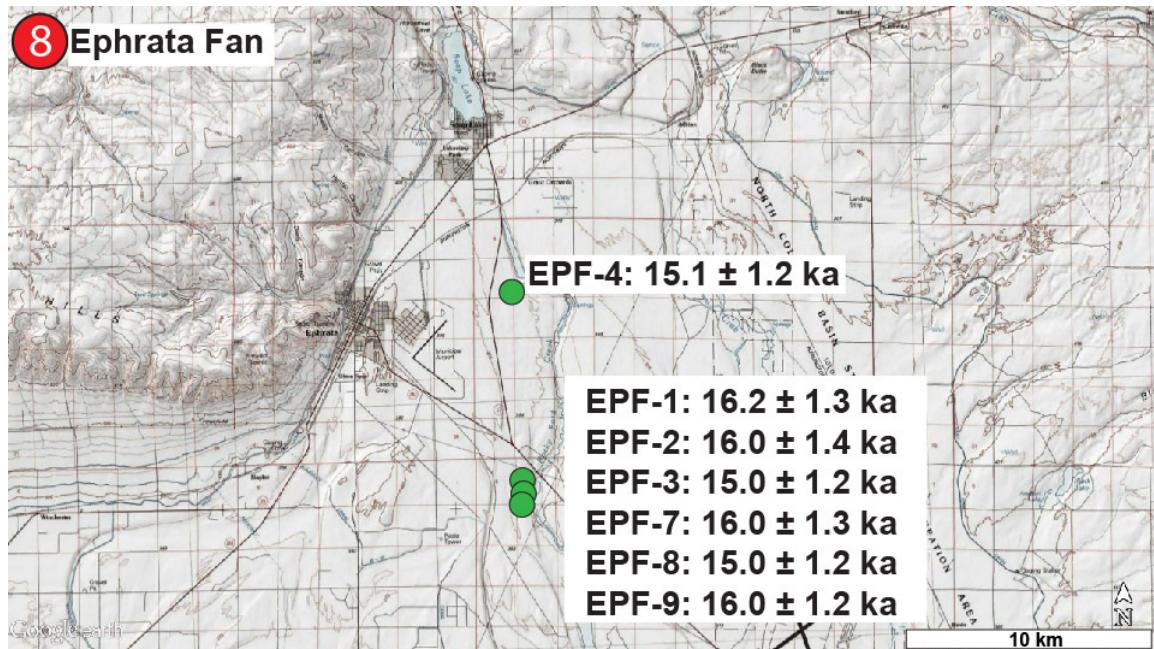


Figure DR23: A topographic map of the Ephrata Fan site, see figure DR2 for further description. Ephrata Fan is located in Washington in between Ephrata and Moses Lake and south of Lower Grand Coulee. Hundreds of large (>1 meter diameter) boulders are deposited on this feature. Surface exposure ages of these boulders are interpreted as representing a debris dam failure that held back Glacial Lake Columbia.



Figure DR24: Ephrata Fan Sample: EPF-1

^{10}Be age: 16.2 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.26265

Longitude: -119.46025

Elevation: 344 m

Boulder Height: 1.6 m

Lithology: Granite

Shielding: none



Figure DR25: Ephrata Fan Sample: EPF-2

^{10}Be age: 16.0 ± 0.6 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.26245

Longitude: -119.46028

Elevation: 341 m

Boulder Height: 1.4 m

Lithology: Granite

Shielding: none



Figure DR26: Ephrata Fan Sample: EPF-3

^{10}Be age: 15.0 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.2618

Longitude: -119.45975

Elevation: 340 m

Boulder Height: 1.2 m

Lithology: Granite

Shielding: none



Figure DR27: Ephrata Fan Sample: EPF-4

^{10}Be age: 15.1 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.32695

Longitude: -119.46948

Elevation: 371 m

Boulder Height: 1.2 m

Lithology: Granite

Shielding: none



Figure DR28: Ephrata Fan Sample: EPF-7

^{10}Be age: 16.0 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.25852

Longitude: -119.46014

Elevation: 344 m

Boulder Height: 1.8 m

Lithology: Granite

Shielding: none



Figure DR29: Ephrata Fan Sample: EPF-8

^{10}Be age: 15.0 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.25588

Longitude: -119.46087

Elevation: 345 m

Boulder Height: 1.6 m

Lithology: Granite

Shielding: none



Figure DR30: Ephrata Fan Sample: EPF-9

^{10}Be age: 16.0 ± 0.5 (ka; 1σ internal uncertainty)

Location: Ephrata Fan

Latitude: 47.25848

Longitude: -119.46011

Elevation: 350 m

Boulder Height: 1.6 m

Lithology: Granite

Shielding: none

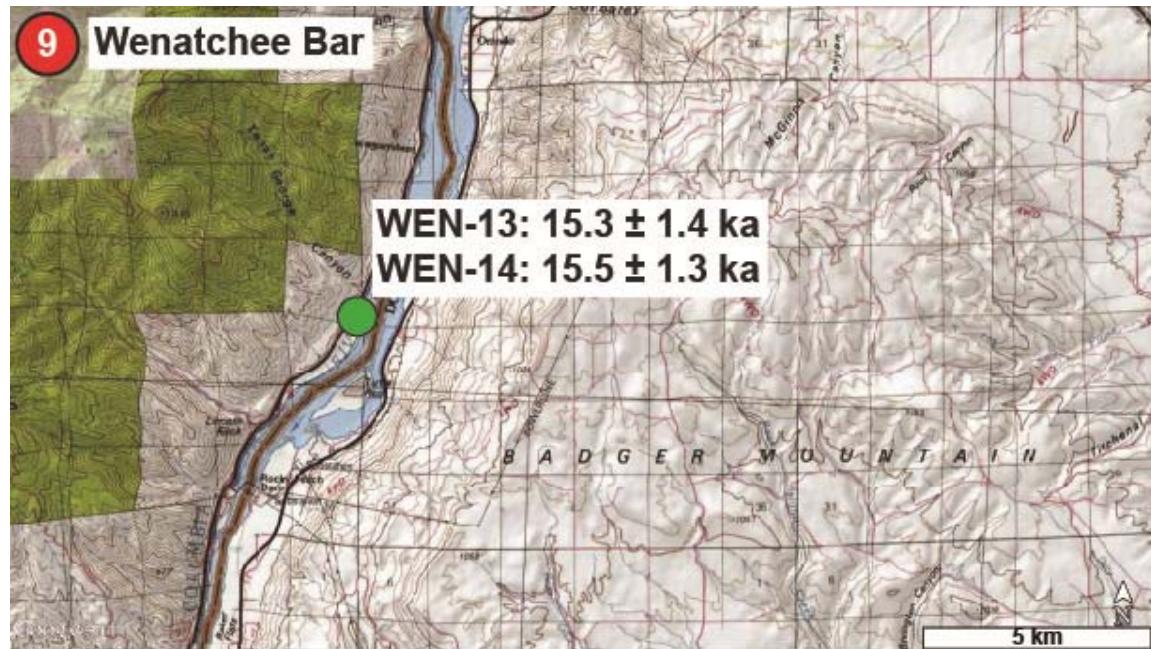


Figure DR31: A topographic map of the Wenatchee Bar site, see figure DR2 for further description. Wenatchee Bar is located north of Wenatchee on the west side of the Columbia River. This feature is armored by dozens of large (>1 meter diameter) boulders. We interpret surface exposure ages of boulders on this feature to represent the most recent megaflooding episode to construct this bar.



Figure DR32: Wenatchee Bar Sample: WEN-13

^{10}Be age: 15.3 ± 0.8 (ka; 1σ internal uncertainty)

Location: Wenatchee Bar

Latitude: 47.56591

Longitude -120.26270

Elevation: 235 m

Boulder Height: 1.5 m

Lithology: Granite

Shielding: none



Figure DR33: Wenatchee Bar Sample: WEN-14

^{10}Be age: 15.5 ± 0.7 (ka; 1σ internal uncertainty)

Location: Wenatchee Bar

Latitude: 47.56591

Longitude -120.26270

Elevation: 235 m

Boulder Height: 2 m

Lithology: Granite

Shielding: none

10 Chelan Moraine

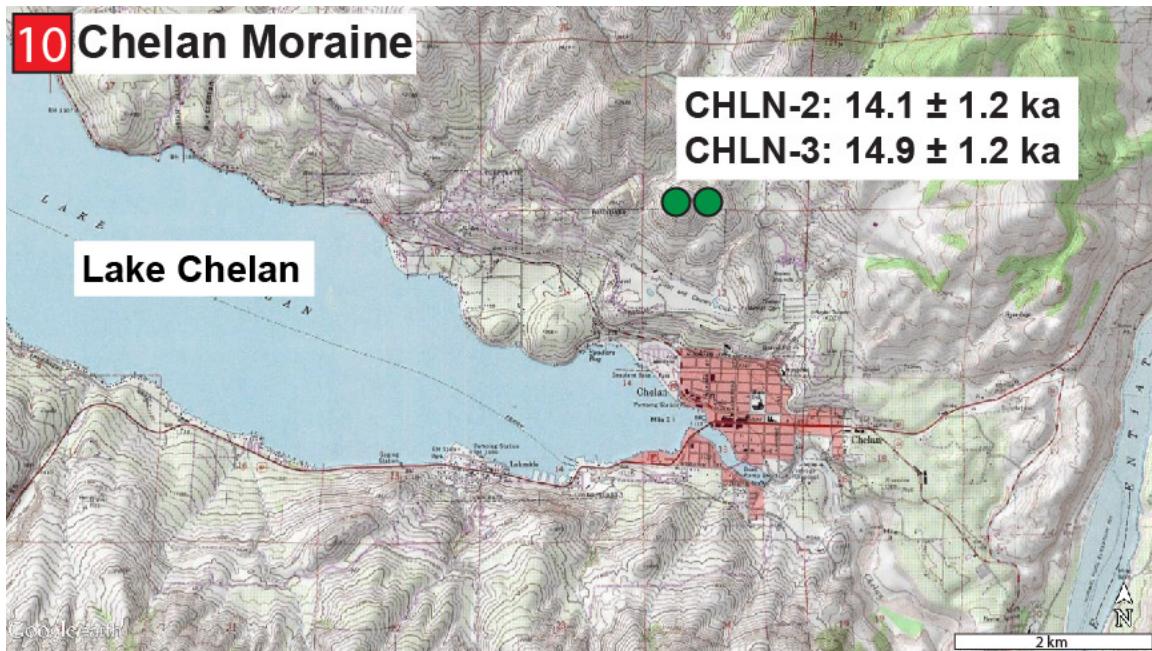


Figure DR34: A topographic map of Chelan Moraine, see figure DR2 for further description. The Chelan Moraine is located north of the town of Chelan. This feature represents a moraine formed when the western side of the Okanogan lobe extended up valley. We interpret the surface exposure ages of boulders at this site to represent the retreat of the lobe in this area.



Figure DR35: Chelan Moraine Sample: CHLN-2

^{10}Be age: 14.1 ± 0.6 (ka; 1σ internal uncertainty)

Location: Chelan Moraine

Latitude: 47.85951

Longitude: -120.02119

Elevation: 629 m

Boulder Height: 0.6 m

Lithology: Pegmatitic Granite

Shielding: none



Figure DR36: Chelan Moraine Sample: CHLN-3

^{10}Be age: 14.9 ± 0.5 (ka; 1σ internal uncertainty)

Location: Chelan Moraine

Latitude: 47.85949

Longitude: -120.0213

Elevation: 633 m

Boulder Height: 1.0 m

Lithology: Granodiorite

Shielding: none

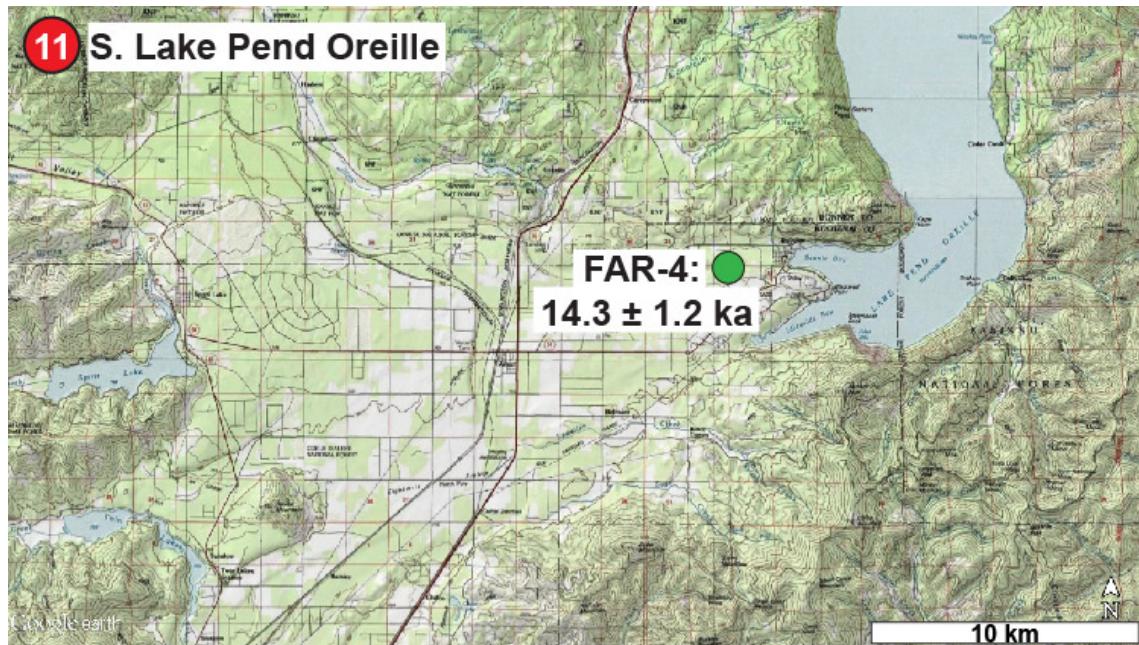


Figure DR37: A topographic map of the South Lake Pend Oreille area (Farragut Park), see figure DR2 for further description. The South Lake Pend Oreille site in Idaho is located northwest of Farragut Park. We interpret surface exposure ages of the boulder at this site to represent the last time floods from Glacial Lake Missoula passed through the Lake Pend Oreille basin and the Purcell Trench.



Figure DR38: Sample south of Lake Pend Oreille: FAR-4

^{10}Be age: 14.3 ± 0.5 (ka; 1σ internal uncertainty)

Location: S. Lake Pend Oreille

Latitude: 47.97075

Longitude: -116.59628

Elevation: 734 m

Boulder Height: 0.9 m

Lithology: Granite

Shielding: none

12

Mattawa Fan

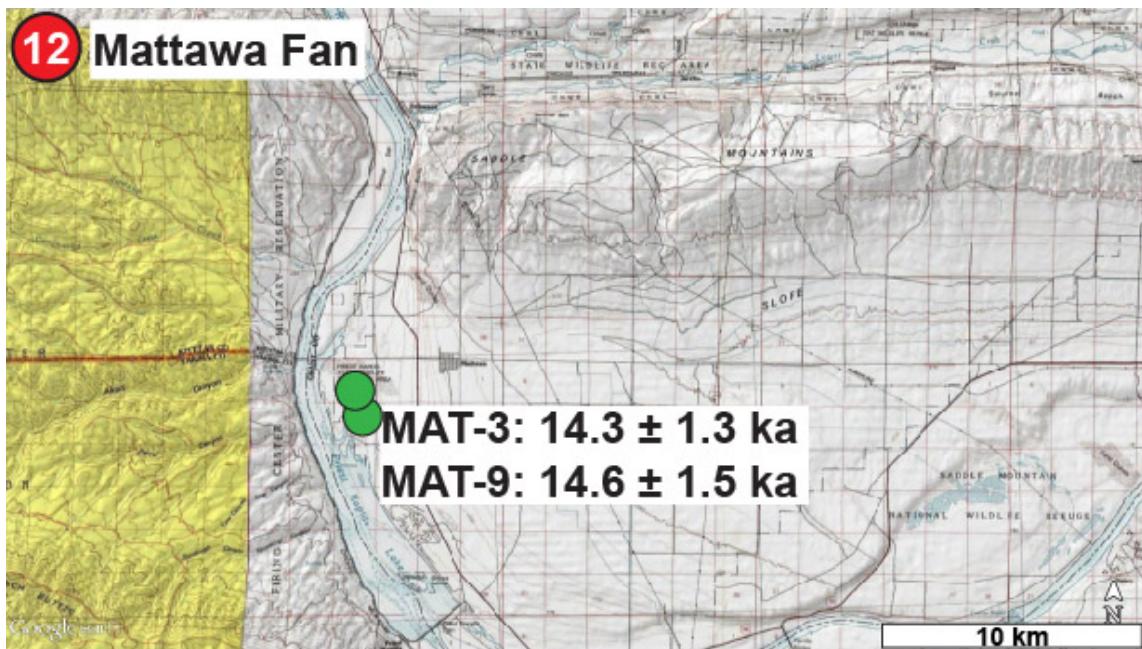


Figure DR39: A topographic map of the Mattawa Fan area, see figure DR2 for further description. Mattawa Fan is located south of Sentinel Gap where the Columbia River cuts through the Saddle Mountains in Washington. Hundreds of large boulders (>1 meter diameter) are deposited on this feature on the eastern side of the Columbia River. Surface exposure ages of boulders deposited on this feature are interpreted as representing the last large flood that traveled through the Sentinel Gap.



Figure DR40: Mattawa Fan Sample: MAT-3

^{10}Be age: 14.3 ± 0.7 (ka; 1σ internal uncertainty)

Location: Mattawa Fan

Latitude: 46.7145

Longitude -119.94356

Elevation: 155 m

Boulder Height: 1.1 m

Lithology: Gneiss

Shielding: none



Figure DR41: Mattawa Fan Sample: MAT-9

^{10}Be age: 14.6 ± 1.0 (ka; 1σ internal uncertainty)

Location: Mattawa Fan

Latitude: 46.71987

Longitude -119.94468

Elevation: 162 m

Boulder Height: 0.8 m

Lithology: Granite

Shielding: none

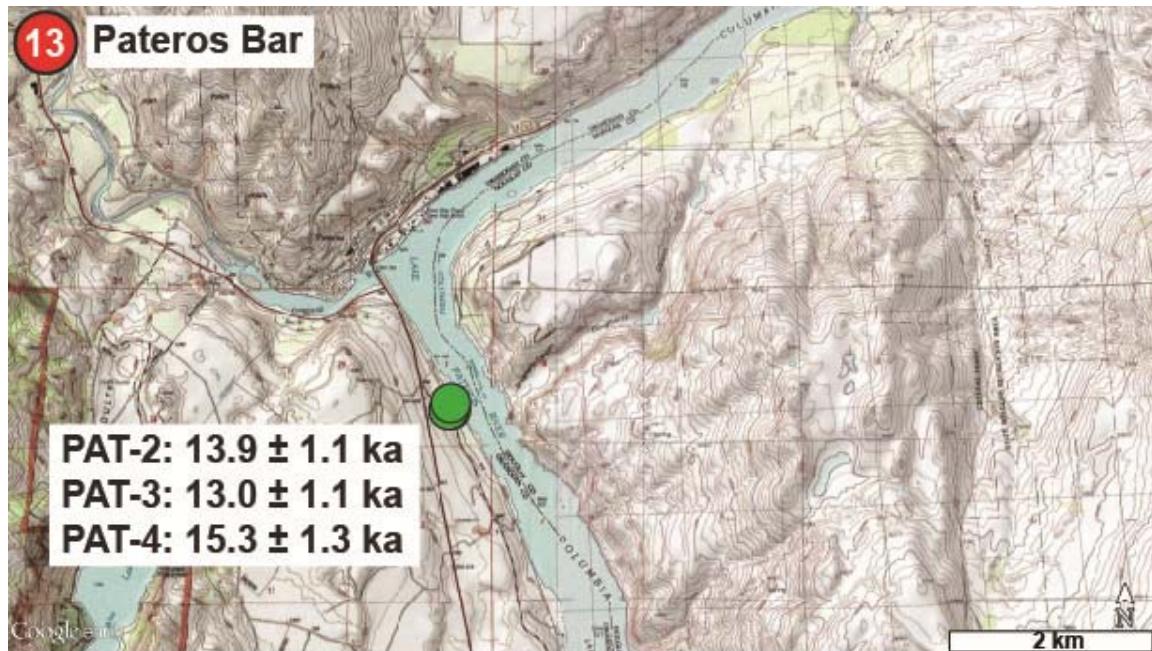


Figure DR42: A topographic map of the Pateros Bar area, see figure DR2 for further description. Pateros bar is an armored bar found along the Columbia River north of Chelan. The boulders on the bar were deposited when the Northern Columbia opened after the retreat of the Okanogan Lobe. We interpret the surface exposure ages of boulders at this site to represent the time in which the Northern Columbia opened to floodwaters.



Figure DR43: Pateros Bar Sample: PAT-2

^{10}Be age: 13.9 ± 0.5 (ka; 1σ internal uncertainty)

Location: Pateros Bar

Latitude: 48.03601

Longitude -119.89242

Elevation: 256 m

Boulder Height: 1.7 m

Lithology: Granite

Shielding: none



Figure DR44: Pateros Bar Sample: PAT-3

^{10}Be age: 13.0 ± 0.4 (ka; 1σ internal uncertainty)

Location: Pateros Bar

Latitude: 48.03601

Longitude -119.89254

Elevation: 262 m

Boulder Height: 1.5 m

Lithology: Granite

Shielding: none



Figure DR45: Pateros Bar Sample: PAT-4

^{10}Be age: 15.3 ± 0.5 (ka; 1σ internal uncertainty)

Location: Pateros Bar

Latitude: 48.03591

Longitude -119.89272

Elevation: 262 m

Boulder Height: 1 m

Lithology: Granite

Shielding: none

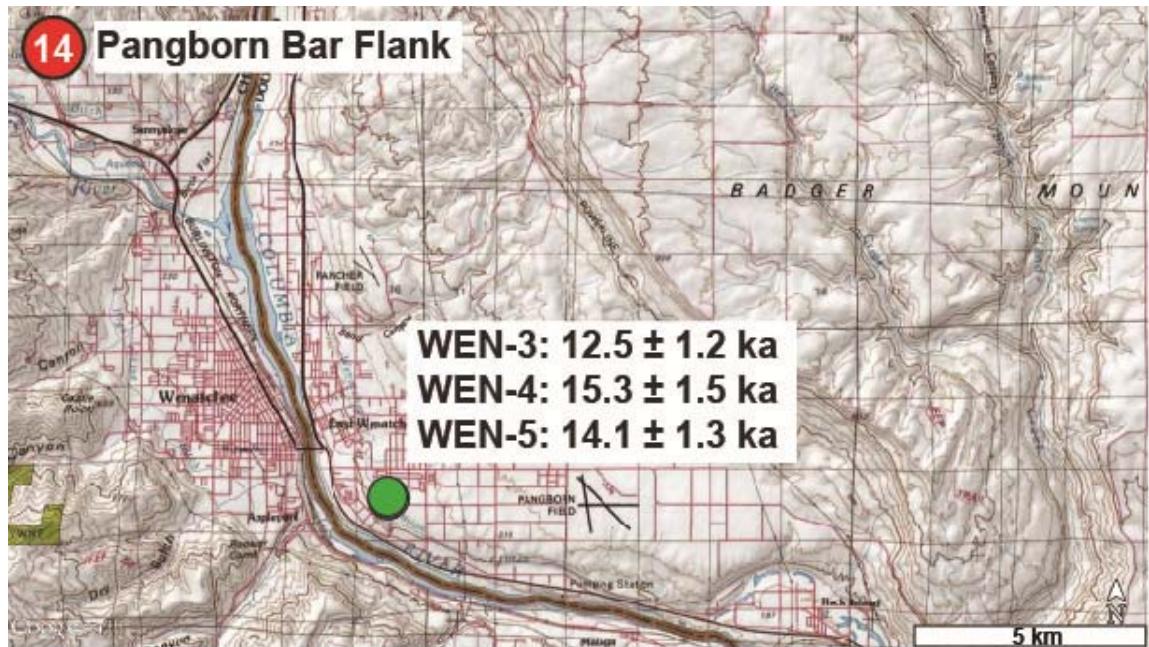


Figure DR46: A topographic map of the Pangborn Bar Flank area, see figure DR2 for further description. Pangborn Bar Flank is the low-lying area of Pangborn Bar, which is located in East Wenatchee, Washington. This site is associated with erosion of Pangborn Bar by younger floods. We interpret surface exposure ages of boulders of this feature as representing the youngest floods to shape this feature.



Figure DR47: Pangborn Bar Flank Sample: WEN-3

^{10}Be age: 12.5 ± 0.7 (ka; 1σ internal uncertainty)

Location: East Wenatchee

Latitude: 47.39828

Longitude -120.2715

Elevation: 274 m

Boulder Height: 0.7 m

Lithology: Granite

Shielding: none

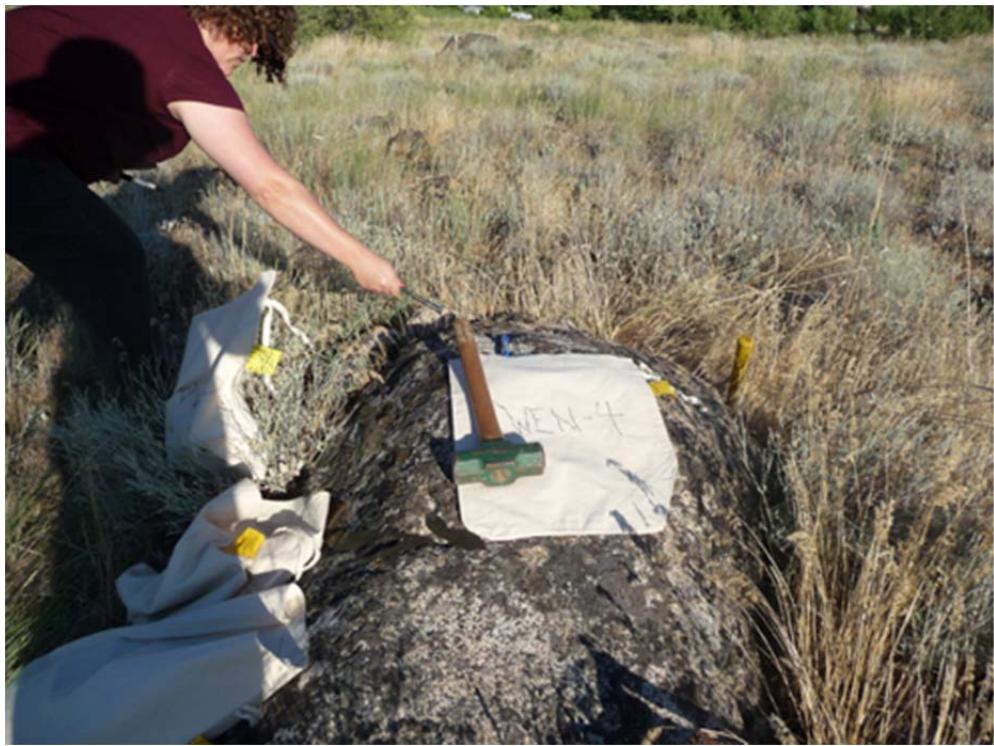


Figure DR48: Pangborn Bar Flank Sample: WEN-4

^{10}Be age: 15.3 ± 1.0 (ka; 1σ internal uncertainty)

Location: East Wenatchee

Latitude: 47.39861

Longitude -120.2717

Elevation: 274 m

Boulder Height: 0.4 m

Lithology: Granite

Shielding: none



Figure DR49: Pangborn Bar Flank Sample: WEN-5

^{10}Be age: 14.1 ± 0.7 (ka; 1σ internal uncertainty)

Location: East Wenatchee

Latitude: 47.3982

Longitude -120.2718

Elevation: 274 m

Boulder Height: 0.3 m

Lithology: Granite

Shielding: none

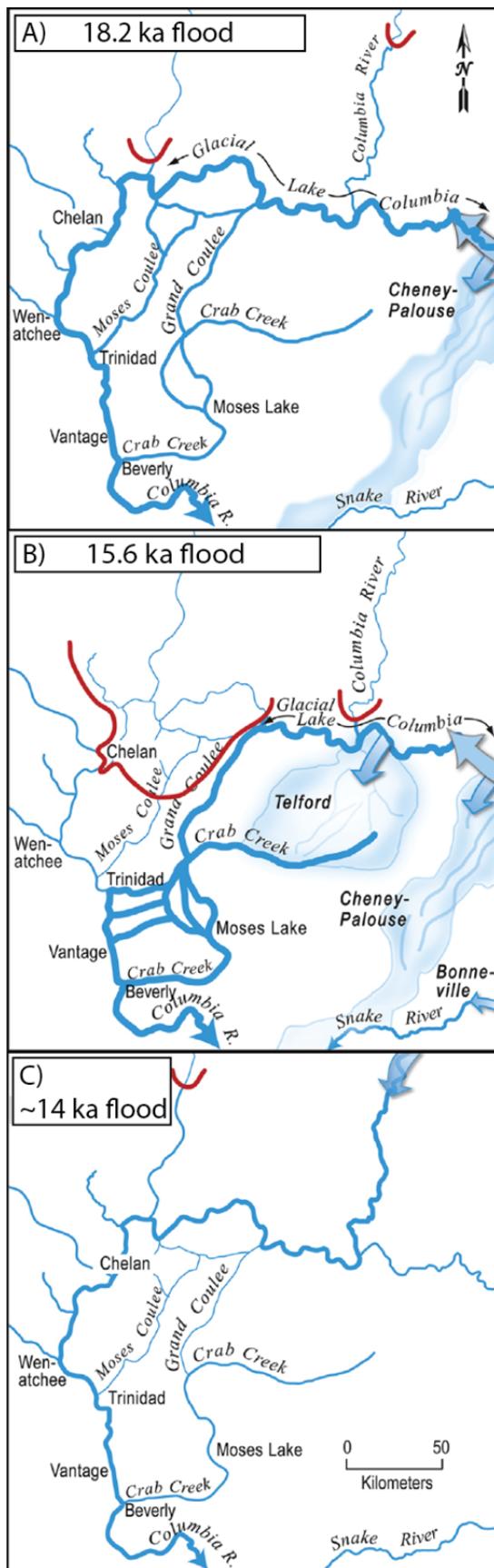


Figure DR50: The routing of floods through time adapted from figure 10 of Waitt (2016) with ages from this study. Arrows and bold blue lines represent flood routing directions. Red lines represent the extents of glacial lobes. (A) The routing of the 18.2 ± 1.5 ka flood. (B) The 15.6 ± 1.3 ka flood. (C) The late 14.0 ± 1.4 ka and 14.4 ± 1.3 ka floods.

Table DR1: Be Blank Analyses

Blank No.	⁹ Be Carrier Added* g	¹⁰ Be/ ⁹ Be	¹⁰ Be/ ⁹ Be 1σ	¹⁰ Be atoms	¹⁰ Be 1σ (atoms)	AMS Std^
1	0.253	3.57E-15	7.31E-16	6.46E+04	1.32E+04	07KNSTD
2	0.255	4.57E-15	8.81E-16	8.31E+04	1.60E+04	07KNSTD
3	0.862	7.93E-16	3.24E-16	1.63E+04	6.67E+03	07KNSTD
4	0.875	7.59E-16	2.59E-16	1.59E+04	5.42E+03	07KNSTD
5	0.875	7.72E-16	2.57E-16	1.62E+04	5.39E+03	07KNSTD
6	0.878	7.44E-16	3.96E-16	1.56E+04	8.32E+03	07KNSTD
7	0.875	3.98E-16	4.59E-16	8.34E+03	9.60E+03	07KNSTD
8	0.881	8.04E-16	3.04E-16	1.69E+04	6.41E+03	07KNSTD
9	0.871	1.26E-15	4.46E-16	2.63E+04	9.29E+03	07KNSTD

*Carrier ⁹Be concentration is 358 ppm.

[^]AMS standard which ratios and concentrations are measured. ¹⁰Be/⁹Be ratio is 2.85×10^{-12}
(Nishiizumi et al., 2007, Nuclear Instruments and Methods in Physics Research B, v. 258, p. 403–4)

Table DR3: Scaling Framework Comparison

Feature	SA Age (ka)	SF Age (ka)	ST Age (ka)	LM Age (ka)	LI Age (ka)	DU Age (ka)	DE Age (ka)
Pangorn Bar Flank	14.0±1.4	13.6±1.3	13.3±1.3	13.4±1.3	15.2±1.4	15.5±1.5	15.3±1.5
Pateros Bar	14.1±1.3	13.7±1.3	13.4±1.2	13.3±1.3	15.2±1.4	15.6±1.4	15.4±1.4
Mattawa Fan	14.4±1.3	14.0±1.3	13.9±1.2	13.8±1.2	15.5±1.4	15.9±1.4	15.7±1.4
S. Lake Pend Oreille	14.3±1.2	14.0±1.2	14.3±1.2	13.9±1.2	15.5±1.3	16.0±1.4	15.8±1.4
Chelan Moraine	14.5±1.2	14.2±1.2	14.5±1.2	14.0±1.2	15.7±1.3	16.2±1.4	16.0±1.3
Wenatchee Bar	15.4±1.3	14.9±1.3	14.7±1.3	14.8±1.3	16.6±1.4	17.1±1.5	16.9±1.5
Ephrata Fan	15.6±1.3	15.2±1.2	15.2±1.2	14.9±1.2	16.8±1.3	17.3±1.4	17.1±1.4
Withrow Moraine	15.4±1.4	15.0±1.4	14.8±1.4	14.8±1.4	16.7±1.5	17.1±1.6	16.9±1.6
Northrup Canyon	15.6±1.3	15.2±1.2	14.9±1.2	15.0±1.2	16.8±1.4	17.3±1.4	17.1±1.4
Spirit Lake Ripples	15.6±1.5	15.3±1.5	15.1±1.5	15.2±1.5	16.9±1.6	17.5±1.7	17.3±1.7
Purcell Trench Moraine	15.7±1.3	15.5±1.3	15.5±1.3	15.6±1.3	17.0±1.4	17.7±1.4	17.5±1.4
Wallula Gap	18.2±1.6	17.7±1.7	17.3±1.6	17.3±1.6	19.5±1.8	20.0±1.8	19.8±1.8
Wenatchee Rafted	18.2±1.5	17.8±1.5	17.5±1.4	17.5±1.4	19.6±1.6	20.2±1.7	20.1±1.7
Babcock Ridge	23.0±1.9	22.0±1.9	22.3±1.9	22.2±1.9	24.8±2.1	25.6±2.2	25.4±2.2

SA = Lifton et al. (2014); SF = Lifton et al. (2014); ST = Lal (1991) and Stone (2000); LM = Balco et al. (2008); LI = Lifton et al. (2005, 2008); DU = Dunai (2001); DE = Desilets et al., (2006)