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Megafloods and Clovis cache at Wenatchee, Washington

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ABSTRACT

Immense late Wisconsin floods from glacial Lake Missoula drowned the Wenatchee reach of Washington's Columbia valley by different routes. The earliest debacles, nearly 19,000 cal yr BP, raged 335 m deep down the Columbia and built high Pangborn bar at Wenatchee. As advancing ice blocked the northwest of Columbia valley, several giant floods descended Moses Coulee and backflooded up the Columbia past Wenatchee. Ice then blocked Moses Coulee, and Grand Coulee to Quincy basin became the westmost floodway. From Quincy basin many Missoula floods backflowed 50 km upvalley to Wenatchee 18,000 to 15,500 years ago. Receding ice dammed glacial Lake Columbia centuries more—till it burst about 15,000 years ago. After Glacier Peak ashfall about 13,600 years ago, smaller great flood(s) swept down the Columbia from glacial Lake Kootenay in British Columbia. The East Wenatchee cache of huge fluted Clovis points had been laid atop Pangborn bar after the Glacier Peak ashfall, then buried by loess. Clovis people came five and a half millennia after the early gigantic Missoula floods, two and a half millennia after the last small Missoula flood, and two millennia after the glacial Lake Columbia flood. People likely saw outburst flood(s) from glacial Lake Kootenay.

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Missoula floods and the first Americans

Immense ice-age floods shaped eastern Washington. Bretz (1923, 1925, 1928) proposed a colossal 'Spokane' flood had carved the channeled scablands and built scattered huge gravel bars (Fig. 1). After controversy and Pardee (1942) identifying the water source as glacial Lake Missoula, Bretz vindicated his idea (Bretz et al., 1956; Bretz, 1959). Since the 1970s, stratigraphy and ice-water physics show that the floods occurred near the end of the late Wisconsin glaciation, were many and frequent, discharged as colossal jökulhlaups, and at least one monster swept down Columbia valley past Wenatchee (Waitt, 1980, 1982, 1984, 1985; Waitt et al., 2009).

Did humans witness the great floods?—the question is often asked on fieldtrips. Cressman (1960, 1977) argued that a manmade stone knife lay within deposits of Bretz (1925) Spokane flood in upper Columbia gorge—that the first Americans had come earlier. This surmise is sometimes iterated (e.g., Hunn, 1999). Yet some had questioned the 'knife' (C. Melvin Aikens, oral commun., 1997). A claim of pre-Clovis people at Fort Rock Cave, Oregon (Bedwell, 1973; Cressman, 1977) hangs on a dubious stratigraphic relation of artifacts to a 15,800-yr date (Beck et al., 2004; Cannon and Meltzer, 2004). (Except where noted—and there only for historical sense—radiocarbon dates in this report converted to calibrated time by OxCal routine, v. 4.2.3 [Bronk Ramsey, 2009] with IntCal13 curve [Reimer et al., 2013].)

A cache of spectacular fluted Clovis points discovered in 1987 near East Wenatchee lay atop a gravel body that had been identified only a decade or so earlier as a gigantic Missoula floodbar (Waitt, 1977). Here came a new chance to contemplate any affiliation of early humans with the great floods. At the time of excavations in 1988 and 1990, Clovis people were thought to have migrated south through a corridor between receding Laurentide and Cordilleran ice and spread rapidly ~13,400 to 12,900 years ago, peopling the continent and hunting large ice-age mammals into extinction (Haynes, 1964, 1966, 1987; Cressman, 1977; Martin, 1973, 1987). Clovis were thought the first comers, many pre-Clovis claims having been hotly contested or disproved (Dincauze, 1984; Meltzer, 1989).

The many late Wisconsin floods along the Wenatchee reach of Columbia valley is the geologic context for the cache of fabulous Clovis tools.

Excavations at East Wenatchee 1987–1990

In 1987 orchard workers unearthed 5 fluted points, 14 other stone tools, and 4 bone rods at Sumac Orchards along Grant Road in East Wenatchee. Archaeologists Robert Mierendorf and Russell

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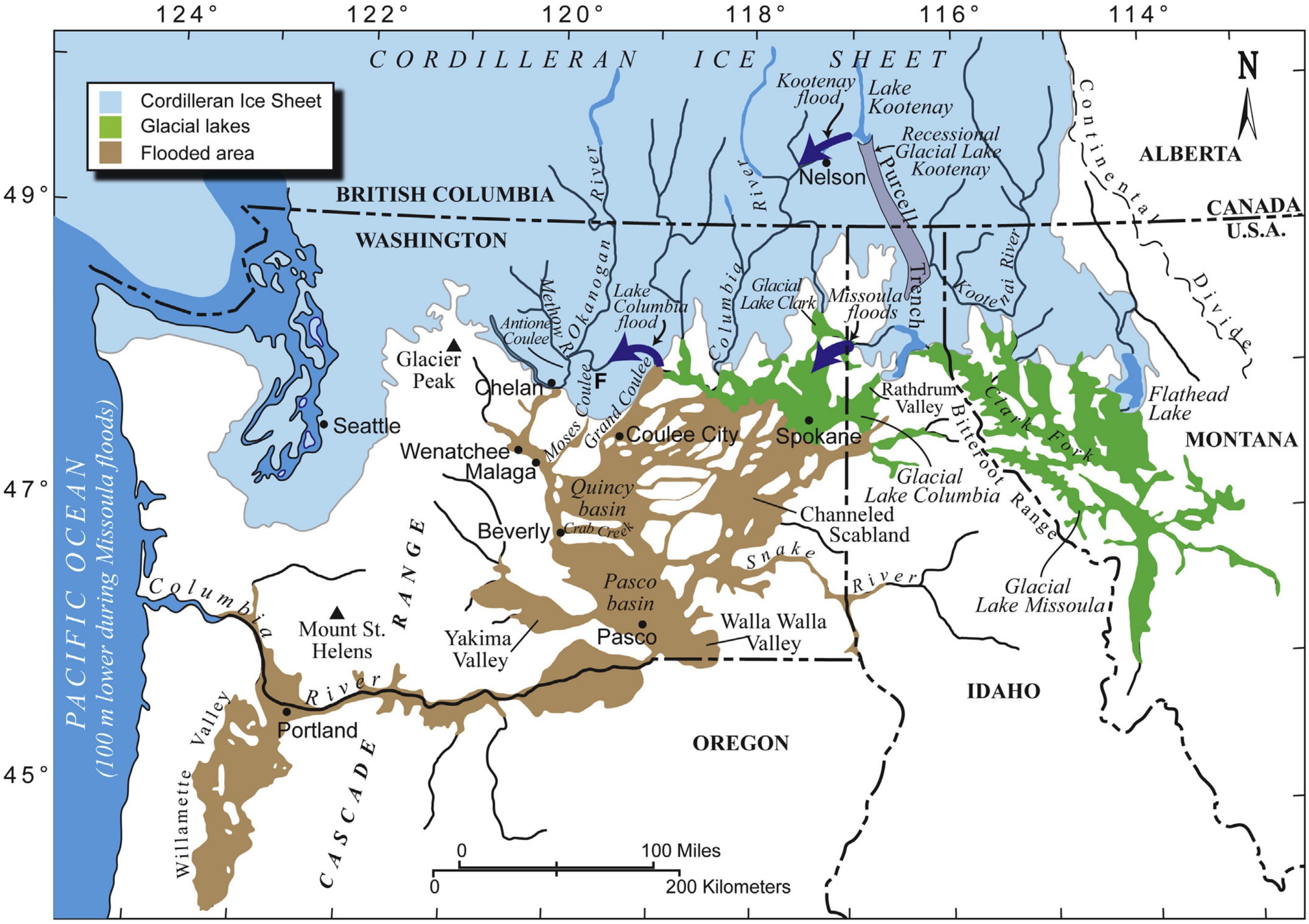


Figure 1. Map showing regional distribution of Cordilleran icesheet at maximum stand, glacial lakes, and Missoula-flood features. F, Foster Creek drainage.

Congdon identified them as Clovis type and determined others lay *in situ*.

Headed by Dr. Peter J. Mehringer, Jr. of Washington State University, an exploratory excavation in spring 1988 brought veteran archaeologists George Frison, C. Vance Haynes, Richard Daugherty, Melvin Aikens, Dennis Stanford, Matthew Root, and others. Mehringer's team retrieved five finely fashioned stone artifacts including two 23.5 cm long, the largest fluted Clovis bifaces then known. To augment a monotonous stratigraphy at the excavation, Mehringer and Haynes opened backhoe trenches 40–625 m north-northeast of the Clovis site (Fig. 2A).

The site's stratigraphy and description of 1988 excavations lie in an unpublished (seemingly unreviewed) report (Mehringer, 1989b), a topical piece on Glacier Peak ash (Mehringer and Foit, 1990), and popular summaries (Mehringer, 1988, 1989a; Kirk and Daugherty, 2007). The stratigraphy was obscure in the briefly exposed archaeological pits only two-thirds meter deep. Glacier Peak ash is too thin to see in the field as far south as Wenatchee—except in ideal undisturbed low-energy deposits.

The deeper 1988 backhoe trenches north of the Clovis site did reveal ash layers of Glacier Peak and Mazama eruptions, deposits Mehringer extrapolated south toward the archaeological site. Then by microscopic study, Mehringer noted grains of Glacier Peak ash within deeper sediment samples of the site, and noted silica crusts and ash grains cemented to the undersides of some of the stone points. Glacier Peak ash, then thought about 13,050 cal yr BP (Mehringer et al., 1984; Foit et al., 1993), is now revised to about 13,600 yr (Kuehn et al., 2009). From the backhoe trenches two close dates from below Mazama ash average 9800 yr (Mehringer, 1989b). The Clovis toolkit seemed to have been set in patchy Glacier Peak ash soon after the ashfall (Mehringer, 1989b; Mehringer and Foit, 1990). The tools lay on a surface slightly more compact than silty fine sand above—Mehringer's "contact A."

A larger excavation (Fig. 2B) in fall 1990 directed by Dr. R. Michael Gramly of the Buffalo (N.Y.) Museum of Science included archaeologists, a flint knapper (D.C. Waldorf), an artist (Valerie Waldorf), and volunteer excavators. This team recovered about 30 bone and stone tools including a new largest fluted Clovis point 24.5 cm long (Fig. 3). They opened geological trenches just north and east of the site, and meters away dug pits as deep as 2.5 m (Fig. 2B). My geological investigation came when these excavations were deepest.

Gramly documents the 1990 excavations and inventories artifacts (Waldorf, 1992; Gramly, 1993a, 1993b, 1996) and infers blood residues from bison, bovine, deer, and rabbit on three stone tools (Gramly, 1991). Flint knapper Waldorf (1991) infers three separate artisans made the biface points, one of them a left-handed master craftsman. Later studies conclude the 14 bi-beveled bone rods, some of them decorated, functioned as hafting wedges for the large stone points (Lyman et al., 1998) or were transportable segments of a ceremonial shaft (Meatte, 2013). Washington State Historical Society (2007) images the artifacts. Some archaeological and inventory data lie in an unpublished report, a slide set, an artwork poster (Waldorf, 1992)—these and source materials archived at the Center for the Study of the First Americans, Texas A&M University.

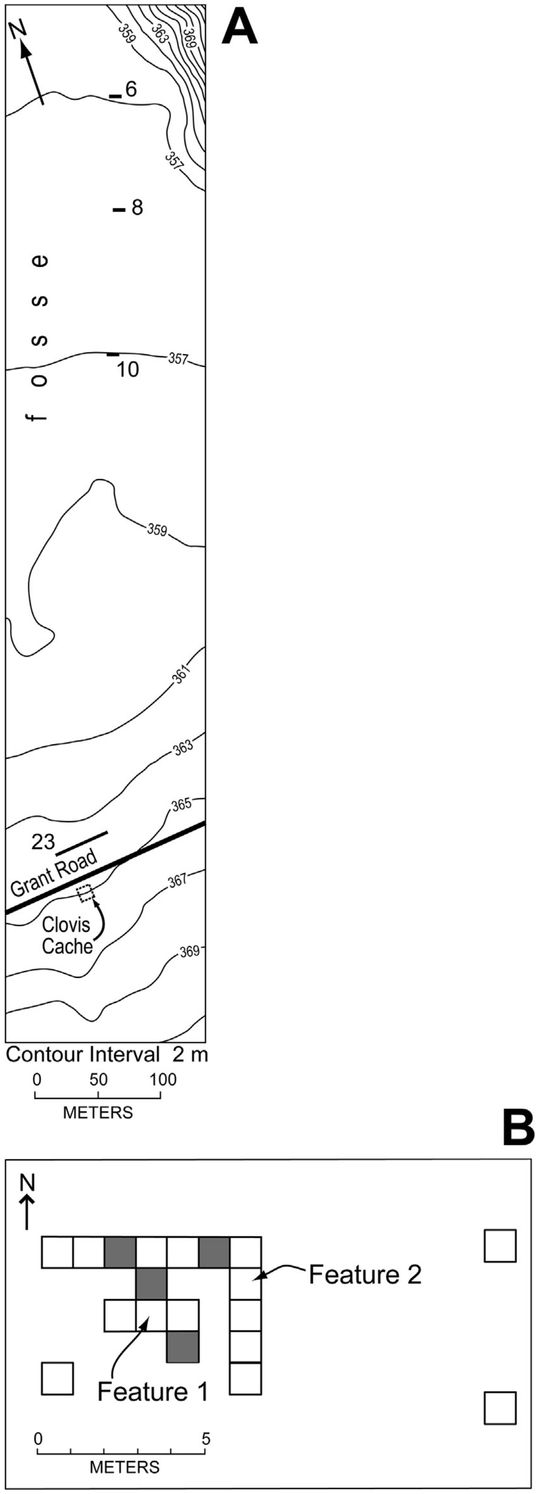


Figure 2. Map of East Wenatchee Clovis excavations in 1988 and 1990. A, position of backhoe trenches (numbered) in fosse north of cache site; adapted from Mehringer (1989b, Fig. 13). B, archeologic site; gray squares excavated in 1988, white ones in 1990; adapted from Gramly (1996, Fig. 1) and showing positions of Gramly's "features."

Meatte (2012) interprets the East Wenatchee and three other caches in Idaho, Wyoming, and Colorado to have been stashed by the Clovis for future use.

The current paper is the only published geologic report of the 1990 Clovis excavation—provisional reports of 1990 and 1997 having gone unpublished.

Figure 3. Photograph of two large points in place at East Wenatchee Clovis cache, November 1990. Copper blanks show size and position of five other large Clovis points that had been excavated and collected in 1988. Photograph courtesy of R.M. Gramly.

Surficial geology of Wenatchee reach

From British Columbia and northern Idaho downstream to Wenatchee, Columbia valley and its north tributaries cross diverse crystalline and metasedimentary rocks (Douglas, 1970; Tabor et al., 1982, 1987; Stoffel et al., 1991; Lewis et al., 2006). Through Wenatchee the river crosses weak Cenozoic sandstone and at Rock Island enters Columbia River Basalt. Basalt underlies most of Missoula-floodswept eastern and central Washington. But glacial drift of the Purcell Trench lobe in north Idaho abounds in stones from older nonbasalt rock belts.

Reported surficial geology of the salient East Wenatchee site is sparse. Bretz thought Columbia valley from Wenatchee to Moses Coulee unswept by great flood and interpreted large boulders and four wavy coarse-gravel bodies below Wenatchee as moraines from a Pleistocene glacier down Columbia valley or Wenatchee valley (Bretz, 1930, p. 287–390, 395 and Fig. 1). Waters (1933) and Flint (1937) then showed that Pleistocene ice in Columbia valley terminated near Chelan Falls 30 km above Wenatchee, and Page (1939) showed Wenatchee valley glaciers ended 20 km above the Columbia. Yet the Wenatchee area was still thought covered by some sort of glacial drift (e.g., Hunnting et al., 1961).

Deposits of landslides, glacial drift, catastrophic floods, and other processes have since been mapped in some detail through the Chelan-Vantage reach of the Columbia (Waitt, 1977, 1982, 1987) and summarized in regional reports and fieldguides (Waitt, 1984, 1985, 1994; Waitt et al., 2009) as well as in several abstracts and now-obscure fieldguides of the 1970s and 1980s. This report outlines late Wisconsin geology of the Wenatchee reach and places the Clovis cache in the sequence of megafloods that swept Columbia valley.

Large landslides

From basalt cliffs rimming both valley sides, occasional huge landslides swept into the valley below Wenatchee and dammed Columbia River. The dammed lake(s) left laminated silt–clay beds at high as 140 m above river level (Waitt, 1982, 1985; Gresens, 1983). Such big slides predate the last-glacial Missoula floods, their extensive coarse debris underlying flood deposits.

Ice margin and dammed lakes

From British Columbia the Cordilleran ice-sheet limit descends through the high Cascade Range and down the Okanogan, Methow, and Chelan troughs to its digitate terminus in lower Chelan and Columbia valleys. End moraines and a head of outwash at Chelan Falls define the maximum late Wisconsin stand of the Okanogan lobe in Columbia valley (Flint, 1937; Waitt, 1987; Waitt et al., 2009). The outer moraine ascends east to Waterville plateau and arcs east to upper Grand Coulee (Fig. 1).

The Okanogan lobe at its maximum blocked the ‘great bend’ of Columbia valley and diverted the river down Grand Coulee, across Quincy basin, and down lower Crab Creek to reenter its natural valley at Beverly. This lobe ponded glacial Lake Columbia to volumes 30–60 km^3, its level held stable by a rock spillway at 473 m at Coulee City in Grand Coulee. Farther east the Purcell Trench lobe dammed Columbia River's Clark Fork to form glacial Lake Missoula of peak volume 2200–2500 km^3. The lake's only outlet was through the ice. This hydraulically unstable dam repeatedly released immense jökulhlaups (Waitt, 1985)—Earth's largest known freshwater discharges (Booth et al., 2004). Changing configurations of the Purcell Trench and Okanogan ice lobes caused the great floods at different times to drown the Wenatchee reach to different depths by different routes.

Surficial deposits along Columbia River (Fig. 4) include outwash from the late Wisconsin ice margin at Chelan Falls but largely are gravel and sand deposited by colossal Missoula floods and later megafloods.

Sequence and routings of cataclysmic floods past Wenatchee

Early down-Columbia flood(s)

Pangborn airfield in East Wenatchee crowns a giant gravel body 15 km long and 3.5 wide, as high above the river as 210 m (Figs. 5A and 6). From about 60 m above the river upstream, it rises downvalley to 201 m above the river. Mapping in the 1970s discovered it to be a gigantic flood bar (Waitt, 1977, 1982). Porter (1969) had correctly inferred a large flood bar on the river's west bank in north Wenatchee. Conspicuous transverse giant current dunes atop Pangborn bar (Fig. 6) are diversified by hundreds of smaller linguloid dunes that are hard to recognize except by vertical aerial airphotos. To call the Pangborn surface a river “terrace” (Mehringer, 1989; Kilby and Huckell, 2014) is to misrepresent it.

Holding diverse crystalline stones from upvalley and exposing tall downvalley-dipping foreset beds, Pangborn bar accumulated during one or more immense floods down Columbia valley (Fig. 4, bars ‘e’). The upper limit of megaflood at Wenatchee is marked by angular granitic cobbles and boulders scattered on basalt-landslide slopes ½ to 4 km northeast of the Clovis site and in lower Wenatchee valley. The erratics are angular despite coming more than 400 km from north Idaho. They could only have come in icebergs. This upper limit of flood at Wenatchee lies about altitude 500 m—325 m above Columbia River that has since cut down little if at all (Fig. 7A, B) (Waitt, 1982). The giant current

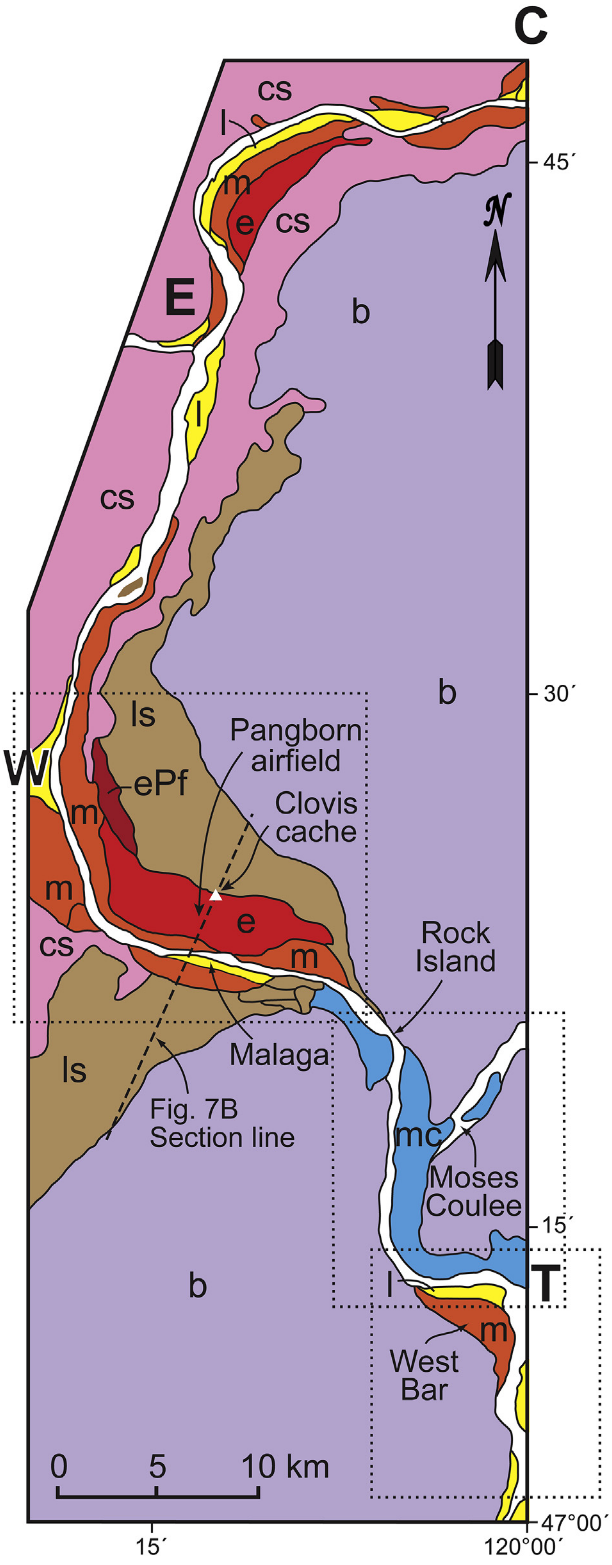
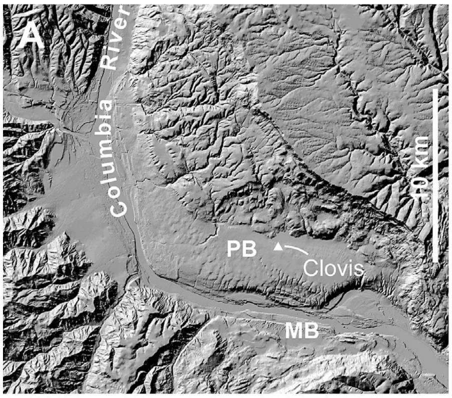
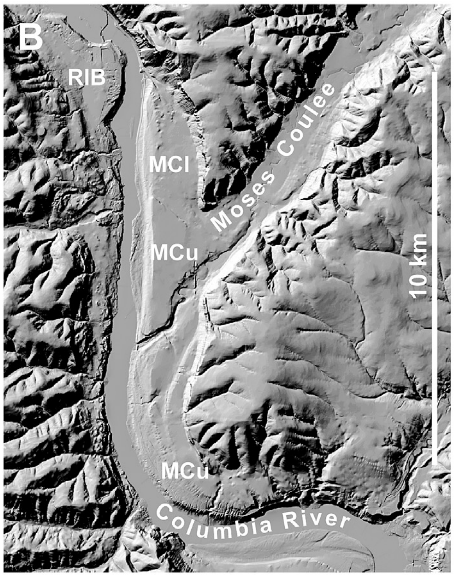


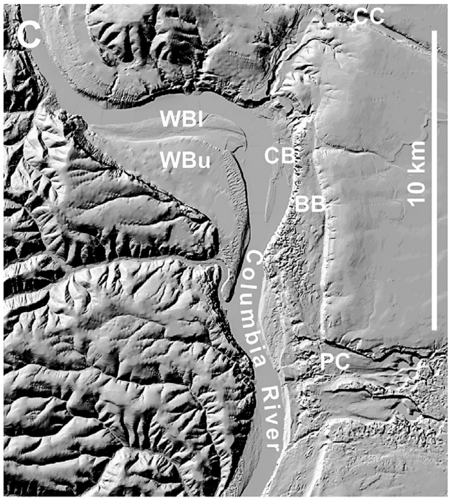
Figure 4. Summary geologic map of Chelan–Trinidad reach of Columbia River valley, Washington, redrawn from Waitt et al. (2009), simplified from Waitt (1982, 1987). Rock and sediment bodies: Mesozoic crystalline and Tertiary sedimentary rock (cs) overlain by Columbia River basalt (b), which has shed large landlsides (ls) toward the Columbia. Early Pleistocene megaflood gravel (ePf). Last-glacial Missoula-flood deposits include early megaflood(s) down the valley (e) and from Moses Coulee (mc). Late megaflood deposits from glacial Lake Columbia (m) and the upper Columbia (l). C, Chelan; E, Entiat; W, Wenatchee; T, Trinidad. Clovis cache is near the airfield atop Pangborn bar. Dotted boxes, DEM images of Figure 5.



Wenatchee and Pangborn Bar



Mouth of Moses Coulee and bars



West Bar, Babcock Bench, Potholes cataract

Figure 5. Digital-elevation models (DEMs) at 10-m resolution of three reaches of Columbia valley (boxes on Fig. 4): **A**, Wenatchee area: PB, Pangborn bar; MB, Malaga bar. **B**, Mouth of Moses Coulee: RIB, Rock Island bar; MCu, Moses Coulee upper bar; MCl, Moses Coulee loweer bar. **C**, West bar and Trinidad area: WBu, West bar upper bar; WBl, West bar lower bar, CB Crescent bar; BB, Babcock Bench high scabland; CC, Crater cateract; PC, Potholes cataract. DEMs derived from The National Map (http://nationalmap.gov).

dunes atop Pangborn bar lie more than 100 m below peak floodwater.

Such high evidence of flood traces up the Columbia to beyond Entiat (Fig. 4) but farther up disappears beneath glacial outwash and moraines—which thus are younger. From such geomorphic relations I infer the enormous flood(s) past Wenatchee came early in the Missoula-flood sequence, before advancing Okanogan ice blocked off the Columbia's ‘great bend’ (Waitt, 1987).

Moses Coulee floods

Once the ice sheet blocked the Columbia, Missoula floods diverted south not only down Grand Coulee but also up Foster Creek and across divides into the heads of a southward valley (Hanson, 1970). Immense floods quarried its lower reaches wide and deep into Moses Coulee. From the coulee's mouth 25 km below Wenatchee, the floods built an enormous gravel bar across the Columbia, expanding downvalley and up, filling the valley 40–95 m deep (Figs. 4, bars ‘mc’; 5B; 7A). This *basaltic* bedload lies 170 m below the top of the great Pangborn bar.

An upvalley part of Moses Coulee bar—Rock Island bar—comprises five separate floodlaid sand-gravel beds each overlain by slackwater silt and lake varves (Fig. 8A). This stratigraphy reveals at least five separate gigantic floods down Moses Coulee spread into Columbia valley (Waitt, 1980, 1982, 1985). Each one backflooded deeply northwest up the Columbia through Wenatchee.

Grand Coulee floods

Advancing farther south, the Okanogan lobe buried Foster Creek and upper Moses Coulee. The westmost floodway became huge Grand Coulee that empties south into Quincy basin. Filling Quincy basin, the largest floods spilled west from as high as altitude 412 m through three cataracts to Columbia valley and so backflooded 50 km to Wenatchee. During a maximum flood this huge backflood in Columbia valley deepened to surface-altitude 340 m or more. (A robust 2-D hydraulic model by Denlinger and O'Connell (2010) shows this backflood at 27.3 h cresting at altitude 346 m.) Overlying the five Moses Coulee floodbeds at Rock Island bar, thickly bedded silt lie as high as 229 m (Figs. 7A and 8A). These deposits of far lower energy than those from Moses Coulee must record many such long-distance backfloods. They could only have come from catastrophic flood spillovers from Quincy basin. Slackwater deposits lie as high as altitude 323 m atop the low eastern end of Pangborn bar and other surfaces in Columbia and lower Wenatchee valleys (Waitt, 1985) but not high parts of Pangborn bar (altitude 366–387 m).

Several dozen Missoula floods swept down Grand Coulee when it was the farthest-west conduit. But as the Purcell Trench lobe gradually thinned, it dammed smaller and smaller lakes and the Missoula floods came smaller and more frequently (Waitt, 1985, 1994; Atwater, 1986, 1987). From Quincy basin these later floods could overflow westward less and backflood to Wenatchee less. The last few dozen smaller Missoula floods probably left Quincy basin only by lower Crab Creek.

Late floods and source lakes

After the last Missoula flood, glacial Lake Columbia remained dammed by Okanogan ice for another two to four centuries (Atwater, 1987). As this ice receded west downvalley and a lobe also backed north up the upper Columbia, the lake's length and volume grew until it held 60 km^3 of water, all of it drainable.

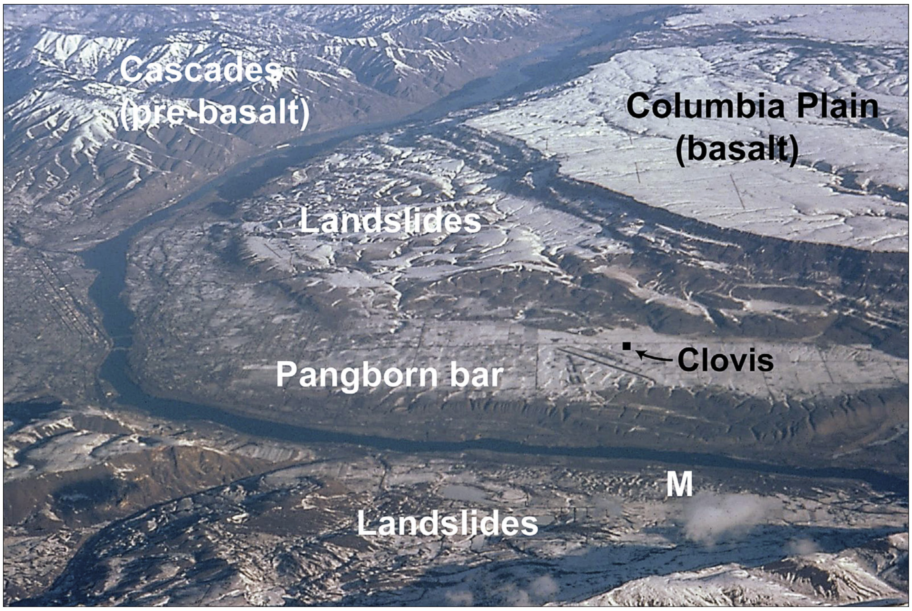


Figure 6. Oblique aerial photograph northward of Pangborn bar showing giant current dunes across its top, as between airfield runways. A lower, later Malaga bar (M) also with giant ripples. Land grid visible at and left of airport is 1 mile (1.6 km) on a side. Platted city of Wenatchee at left west of Columbia River. Photograph February 1972 by R.B. Waitt.

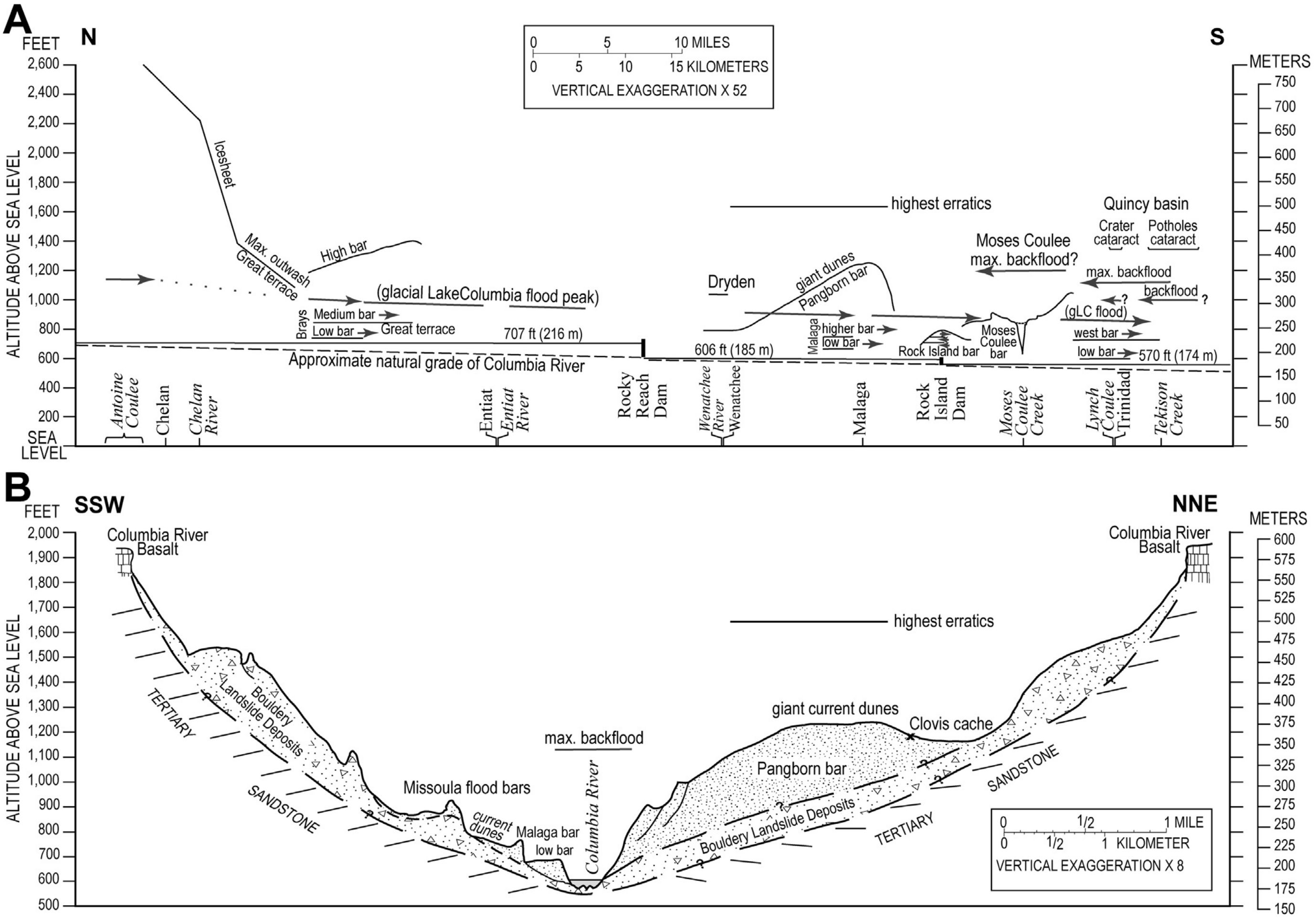


Figure 7. Sections through Columbia valley near Wenatchee. A, Longitudinal profile Chelan to Potholes cataract; glacial limit, outwash, and flood bars projected from both sides. Former low-water grade of river beneath reservoirs approximated by line drawn through tailraces of dams. Arrows distinguish downvalleyward from upvalleyward (backflood) floodflow. B, Cross section through Pangborn and Malaga bars.

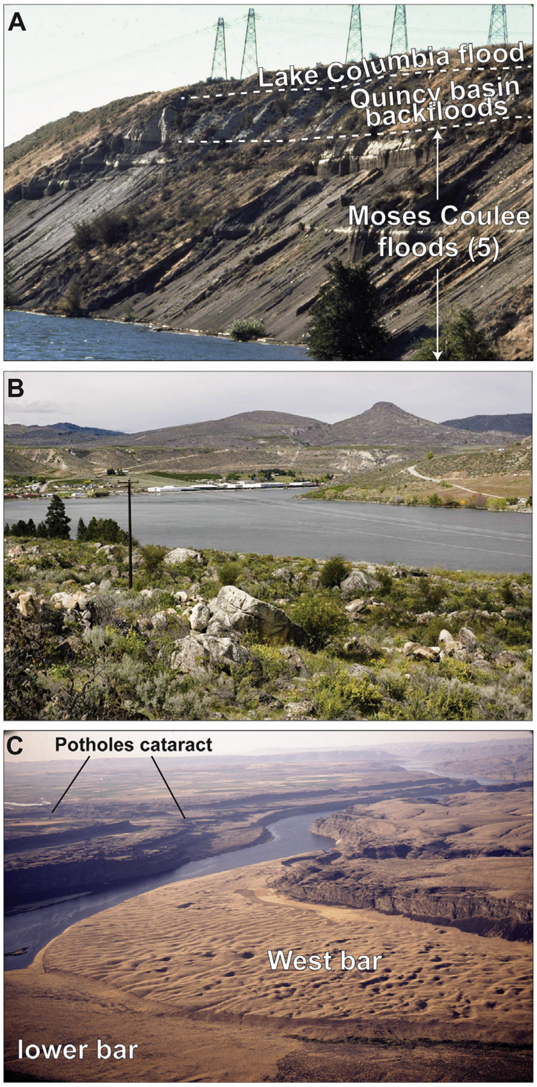


Figure 8. Photographs showing stratigraphic and geomorphic evidence of sequence of floods along Columbia valley past Wenatchee. A, Rock Island bar: five basalt-gravel beds flooded from Moses Coulee, overlain by slackwater beds from Quincy basin backfloods, overlain by duned gravel from glacial Lake Columbia flood; contacts between these three beds plotted on Fig. 6A. B, Boulders from Lake Columbia flood run up on outside bend of Columbia valley just below mouth of Methow River. C, West Bar. Photographs by R.B. Waitt.

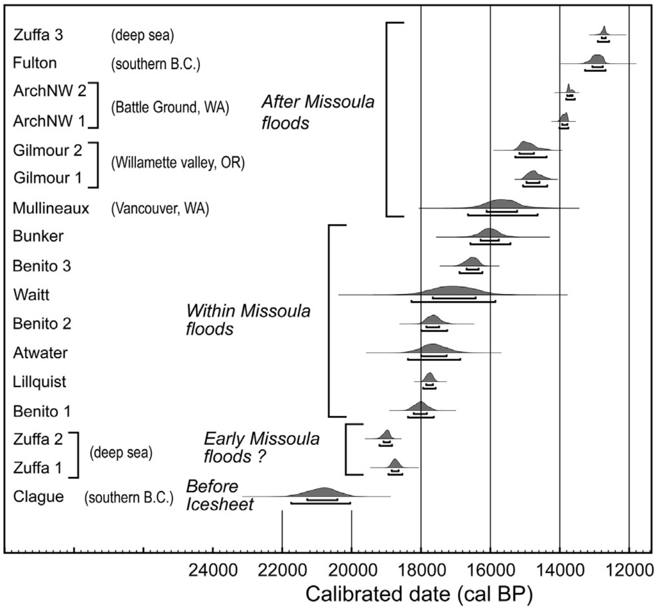


Figure 9. Probability plot of calibrated radiocarbon dates limiting timing of Missoula floods showing 1σ and 2σ confidence ranges. Calibrated with OxCal v. 4.2.3 (Bronk Ramsey, 2009) with IntCal13 curve (Reimer et al., 2013).

Eventually the Okanogan lobe retreated enough to unblock the Columbia and return the river to the great bend past Chelan and Wenatchee. At least two floods smaller than most Scabland floods swept down this reopened Columbia valley from sources other than glacial Lake Missoula (Fig. 4, bars ‘m’ and ‘l’).

Evidence of large post-icesheet flood down Columbia's great bend include huge boulders and high gravel bars about the mouth of the Methow (Fig. 8B), Alta and Antione Coulees choked by bars and chaotically hummocky-gravel ice-jam deposits, channels and bars atop outwash above Chelan, and flood-scoured and boulder-strewn ‘great-terrace’ outwash below Chelan Falls as high as 100 m above the river's natural grade (Fig. 7A) (Waitt, 1985, 1987, 1994; Waitt et al., 2009). This flood seems the demise of glacial Lake Columbia—as Waters (1933) had postulated but Flint (1935) dismissed.

While diverted upper Columbia River flowed through Grand Coulee for millennia, the river past Wenatchee was much reduced. Below Wenatchee the valley had been obstructed by the huge bar repeatedly flushed from Moses Coulee. Through this narrowed reach the flood from glacial Lake Columbia overtopped upstream parts of the Moses Coulee bar built by *up*-Columbia currents. Lake Columbia's flood reworked the bar's surface with *down*-Columbia current dunes. It overlay the dark basaltic sand and gravel from Moses Coulee with bright crystalline-rock gravel from up the Columbia (Fig. 7A). Lake Columbia's flood also formed a giant-rippled bar at Malaga below Wenatchee (Figs. 4, bars ‘m’; 5A; 6; 7A). At ‘Bray's bar’ above Entiat, Glacier Peak tephra overlies such higher-level postglacial flood deposits that I attribute to glacial Lake Columbia (Waitt, 1982, 1987).

West bar (Figs. 5C and 8C) lies on the inside of a sharp bend where a bar would re-form under each great flood. The last Missoula floods through this reach backflowed from Quincy basin *up*valley, carrying sand and silt into this backwater. But West bar's asymmetric giant current dunes reveal *down*valleyward flow (Fig. 8C) and its bouldery cobble gravel isn't capped by slackwater silt. While West bar is usually attributed to Missoula flood, it lies at similar height above the river as four bars upvalley (Brays, Malaga, Rock Island, north Moses Coulee). West bar would have re-formed under a great flood downvalley from glacial Lake Columbia, and this seems best to explain its present form (Fig. 8A, B).

Along the Columbia lie still-lower gravel bars of diverse crystalline rocks derived upvalley (Fig. 4, bars ‘l’). These round-topped barforms display huge boulders or giant current dunes revealing their deposition by megaflood. The lowest two ‘Bray’ bars above Entiat are capped by much less windblown silty sand than higher ones, and they lack the Glacier Peak ash that tops higher bars. So these lowest bars, no higher than 35 m above the river, must long postdate deposits of Lake Columbia's flood. Since my field investigations in the 1980s–1990s much of this area has been developed into housing, much of the land extensively regraded.

Downvalley such sporadic low-level deposits include riverward of giant-duned Malaga bar a low bar that contains boulders as large as 3 m (Figs. 6 and 7A, B), and a similar bouldery bar riverward of West Bar (Fig. 8C). Potential sources of these last floods are several glacial lakes dammed in the Columbia and its tributaries as lobes of

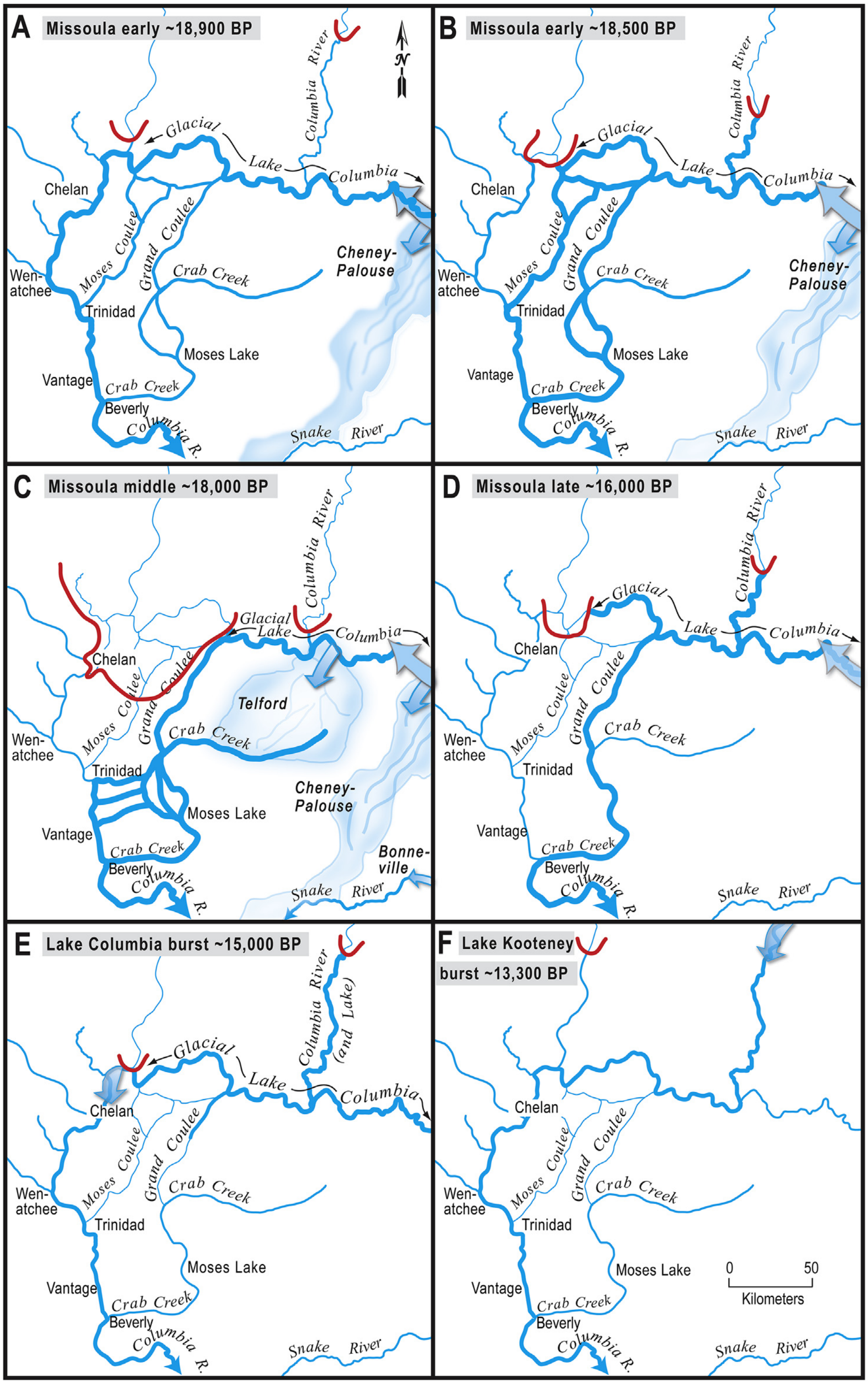


Figure 10. Synoptic routings of Missoula and other great floods through northwest Columbia valley and major coulees. Timings inferred partly from Figure 13 summary.

Cordilleran ice receded north into British Columbia. Let us scan possible sources—Okanogan valley, mainstem Columbia, and two upper-Columbia tributaries.

Some have speculated that late-Wisconsin floodwater descended Okanogan valley (Shaw et al., 1999). But there's no direct field evidence for it. Having several times since the 1970s reconnoitered the south 130 km of Okanogan valley's floor, I find there abundant conventional glacial features—ice-moulded bedrock, ice-marginal channels, small moraines, kettled kames, outwash terraces. But one finds no boulderstrewn whalebacked gravel bars, no high-eddy bars, no large scours around rock obstacles, no fields of large boulders below bedrock obstacles, nor other features that abound along Missoula megaflood routes like the lower Flathead, Clark Fork, Spokane, lower Snake, and

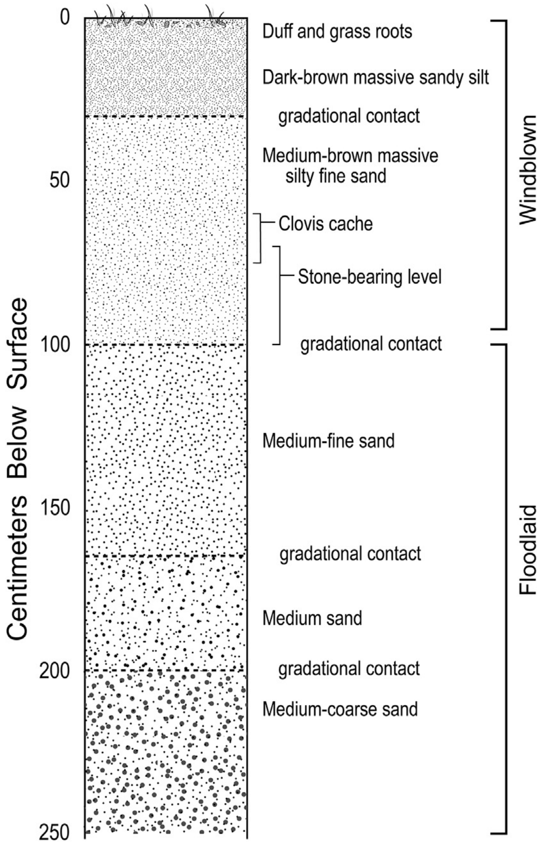


Figure 11. Stratigraphic sketch at East Wenatchee Clovis site. Assembled from whole excavation, but elements below 1 m from two pits 3–8 m southwest and southeast of main excavation.

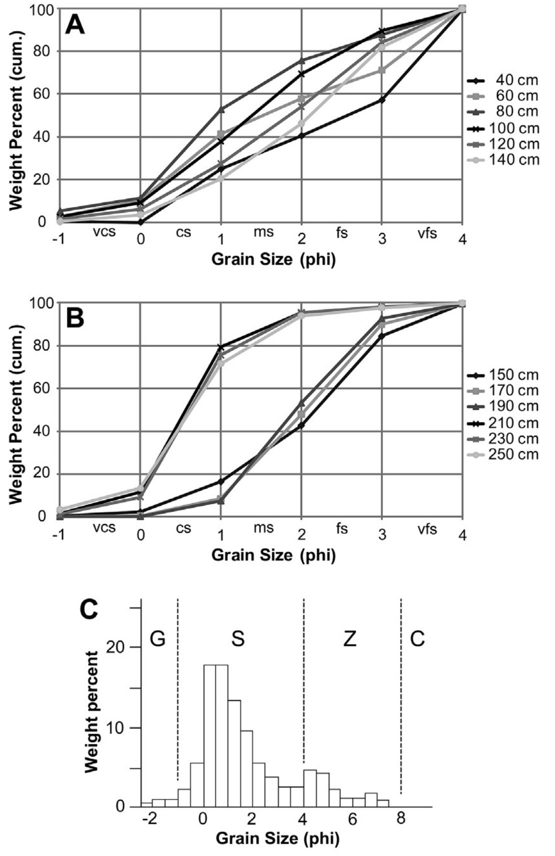


Figure 12. Cumulative grainsize distributions for samples sieved a 1-φ intervals. Unanalyzed pan fraction (finer than 3 φ) arbitrarily plotted at 4 φ. Some clasts coarser than −1 φ omitted. Sample numbers are depth (centimeters) of sample below surface. Letter code on abcissa are Wentworth designation of sand sizes: vc = very coarse, c = coarse, m = medium, f = fine, vf = very fine. Recalculated from data supplied by R.M. Gramly. A. Top of flood bar (140–80 cm depth) and overlying eolian deposit (60–40 cm depth). B. Flood bar: coarser layer (250–210 cm depth) and overlying finer layer (190–150 cm depth). C. Grainsize histogram redrawn from the detailed sieving in Mehringer (1989b). From his sediment column II, sample 3 is 65 cm below surface and 12 cm below artifact layer. Gravel, sand, silt, and clay fields indicated. Example selected from 65 histograms.

Columbia gorge. Midvalley rock monoliths and salients along the lower Okanogan 6–50 m above the river lack adjacent fosses, pendant bars, and angular boulders that characterize megaflood-swept valleys (Bretz, 1928; Baker, 1973; O'Connor, 1993; Carling et al., 2002; Waitt, 2002; Benito and O'Connor, 2003). Once deglaciated and restored to an open channel, southern Okanokan valley passed no megaflood.

Exploring long reaches of Columbia valley in British Columbia below the Rocky Mountain Trench, Robert Fulton found no features suggesting the upper Columbia had passed a huge flood—including promising reaches like Big Bend (before Mica Dam) and the narrows above Burton (Fulton and Achard, 1985; Fulton et al., 1989; RJ Fulton, pers. commun., 2009). Receding ice had dammed glacial Lake Clark in Columbia tributary Pend Oreille River (Waitt, 1980, 1984; Waitt et al., in press). But lower reaches of this valley bear no low-level boulder fields, no pendant bars on insides of bends, no run-up boulders on outsides of bends—no evidence the valley passed a large flood. And the extremely narrow and crooked gorge where Boundary Dam lies (south of the international boundary) is too tight a valve to have passed huge discharge.

As Cordilleran ice receded north up the Purcell Trench in southern British Columbia, glacial Lake Kootenay lengthened in the trough now holding Kootenay Lake (Fig. 1). The receding Columbia River glacier tongue meanwhile blocked lowermost Kootenay valley, damming glacial Lake Kootenay to volume as much as 70 km^3, about 45 km^3 of it drainable (Waitt, 2009; Peters, 2012, Table 6.2). The lower western reach of valley bears evidence of megaflood. Through Grohman narrows below Nelson, the lower 120 m of the sides of Kootenay valley are largely bare of glacial drift—as if rinsed off by torrent. Though bedrock is granite-gneiss rather than basalt, the valley floor is quarried into a crooked dalles-type channel (e.g., Bretz, 1924) whose intervening islands and peninsulas display etched-out joints, cataracts, scabland channels, and ragged potholes both deep and wide. Lower Kootenay valley resembles at smaller scale valleys carved in crystalline rocks that were scoured by Missoula floods—narrow reaches of the lower Clark Fork, lower Flathead, and narrow reaches of Columbia valley between Chelan Falls and Wenatchee. Below Grohman narrows a high bar several kilometers long across Slocan valley is littered with large subangular boulders—seemingly of catastrophic flood. This field evidence is scarcely explored, yet glacial Lake Kootenay seems the likely source of flood(s) down the Columbia past Chelan and Wenatchee after the Glacier Peak ashfall.

Timing and routings

Timing of Cordilleran ice and the Missoula floods has been from time to time reviewed in uncalibrated radiocarbon time (Atwater, 1986; Benito and O'Connor, 2003; O'Connor and Benito, 2009; Waitt et al., 2009). I summarize essentials here in calibrated (calendar) time.

Table 1
Selected radiocarbon dates for Missoula-flood deposits.

No	Source	Where	Strat signif	Material dated	Raw mean (yr BP)	Uncert (±)	Calibrated range[a] OxCal (2σ)	Median
1	Clague, 1980	Columbia R., BC	Pre-Miss floods	Spruce wood	17240	330	21740–20040	20840
2	Zuffa et al., 2000 (1)	Pacific, Escanaba trough	Missoula-flood influencing deep sea	Hemipelagic	15482	100	18937–18539	18744
3	Zuffa et al., 2000 (2)	Pacific, Escanaba trough	Missoula-flood influencing deep sea	Pinecone	15750	70	19197–18833	18994
4	Benito and O'Connor, 2003 (1)	Columbia gorge	Clast in MF sed	Organic clast	14795	150	18374–17631	18009
5	Lillquist et al., 2005	Moxee mammoth	Within high flood	Mammoth bone	14570	50	17936–17576	17753
6	Atwater, 1986	Sanpoil	In floodbed	Wood	14490	290	18376–16867	17636
7	Benito and O'Connor, 2003 (2)	Columbia gorge	Clast in MF sed	Humic acid extract	14480	145	17993–17244	17645
8	Waitt, 1985	Mabton	Within flood rhythmites	Shells	14060	460	18275–15855	17061
9	Benito and O'Connor, 2003 (3)	Columbia gorge	Clast in MF sed	Dung	13695	95	16890–16231	16532
10	Baker and Bunker, 1985	Mabton	Within flood rhythmites	Shells	13325	185	16577–15421	16023
11	Mullineaux et al., 1978	Vancouver (Manor)	Flood channel	Bottom-bog peat	13080	300	16645–14636	15662
12	Glimour et al., 2015 (1)	Willamette Valley	Minimum-limiting big flood	Bison bone	12500	40	15058–14359	14745
13	Glimour et al., 2015 (2)	Willamette Valley	Minimum-limiting big flood	Mammoth bone	12610	100	15281–14378	14929
14	Archeol. Invest NW, 2015 (1)	Near Dollar Corner	Minimum-limiting big flood	Plant frags	12020	40	14008–13753	13867
15	Archeol. Invest NW, 2015 (2)	Near Dollar Corner	Minimum-limiting big flood	Seeds	11910	40	13815–13566	13731
16	Fulton, 1971	Columbia valley, BC	Minimum-limiting big flood	Bottom bog peat	11050	180	13272–12681	12930
17	Zuffa et al., 2000 (3)	Pacific, Escanaba trough	Post Missoula-flood deap sea	Hemipelagic	10822	85	12903–12577	12728

[a] Calibrated by OxCal v. 4.2.3 (Bronk Ramsey, 2009) with IntCal 13 (Reimer et al., 2013).

Table 1 and Figure 13 contain only selected least-problematic dates. Most of them, done many years ago by conventional method, have large 2σ error ranges. Omitted here are many dubious ages that seem much "too old" or much "too young" and those later done by non-radiocarbon methods but not yet reconciled to radiocarbon time scales.

These are the real numbers. But so narration can be clean and understandable, the text mentions only approximate round-number median dates (Table 1 and Fig. 9 has the details). Almost all dates are from clasts within floodlaid sand and gravel and can serve only as maximum-limiting ages of the floodbeds. For their 25 dates from the Columbia gorge, Benito and O'Connor (2003) elaborate why all but a few are much "too old"—why only the youngest dates limit flood ages fairly closely. Here I include only their youngest three dates (Table 1 and Fig 9).

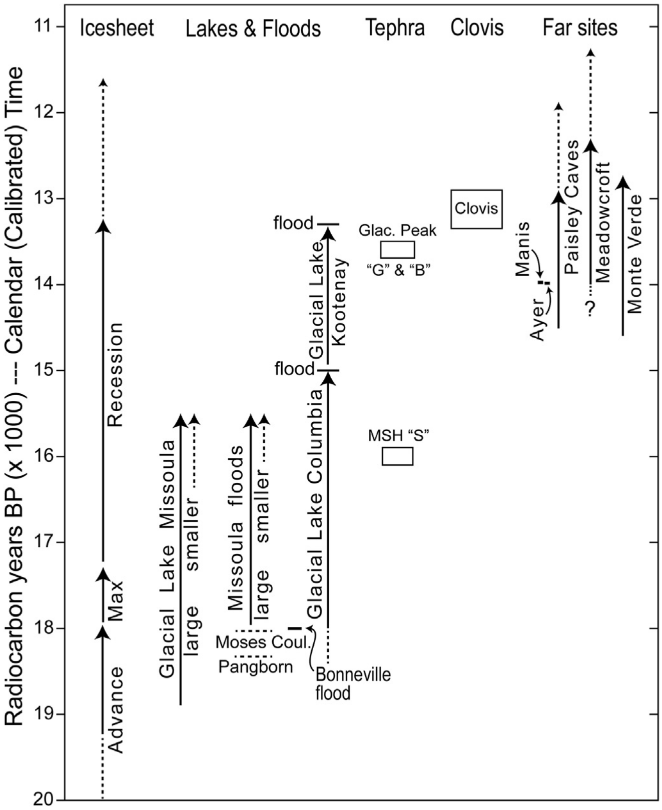


Figure 13. Schematic, interpretive time relations of geologic events and deposits and Clovis occupation plotted in calibrated radiocarbon time.

Direct radiocarbon dating of Missoula floods includes a stick at roughly 17,600 cal yr BP in the lower-middle of the detailed section in Sanpoil valley (Atwater, 1986); a mammoth tusk dated about 17,700 yr ago within high backflood deposits in Yakima valley (Lillquist et al., 2005); shells from three rhythmites below the Mount St. Helens S tephra in lower Yakima valley dated roughly 17,000 yr ago with large uncertainties (Waitt, 1985) or 16,000 yr ago (Baker and Bunker, 1985); and many dates from Columbia-gorge megaflood deposits, the youngest about 18,000, 17,600, and 16,500 yr old (Benito and O'Connor, 2003). Deep-sea turbidites thought to stem from the Missoula floods radiocarbon date to about 18,900 yr ago (Zuffa et al., 2000). All the dates (even from a mammoth skeleton) being from clasts, they are technically maximum-limiting. The Lillquist, Waitt, and Bunker would be closely limiting, the others potentially a little older than the flood whose bed the clast lies in. Relevant tephras are: Mount St. Helens S now thought 16,000 years old (Clague et al., 2003; Clynne et al., 2008) that lies upsection in flood slackwater beds (Waitt, 1980, 1985; Waitt et al., 2009), and postflood Glacier Peak ash about 13,600 yr ago (Kuehn et al., 2009).

Reckoned from maximum-limiting and minimum-limiting dates (Oviatt, 2015), the Bonneville flood swept down about 18,000 yr ago. Bonneville-flood deposits with no discernible soil directly underlie at least 22 rhythmic beds from Missoula floods that backflooded far up Snake valley to above Lewiston (Waitt, 1985).

Minimum-limiting dates on the last of the huge Missoula floods include a bottom-bog date of about 15,600 yr from a flood-scoured trough north of Vancouver, Washington (Mullineaux et al., 1978), the oldest composite date (about 14,800 yr) from mammoth bones in Willamette valley (Gilmour et al., 2015), and postflood organic sediment (about 13,900 yr) west of Battleground, Washington (Archaeological Investigations Northwest, 2015).

In southern British Columbia several radiocarbon dates on the Columbia River ice lobe delineate a wider envelope of time—preglacial dates as young as roughy 21,000 yr ago and postglacial dates as old as about 13,000 yr (Table 1, Fig. 9)

(Clague, 1980, Tables 3 and 4; Clague, 1981). Only well inside these broad limits could the Purcell Trench lobe and Okanogan lobe exist farther south to dam glacial Lake Missoula and divert Columbia River.

All considered within the present limits of dating, the Missoula floods must have occurred between roughly 19,000 and 15,400 yr ago. In the Chelan-Wenatchee-Trinidad reach of Columbia valley, the high flood bars early in the overall flood sequence must date to about 18,800 yr or so (Fig. 10A). The Moses Coulee floods came later but also before the glacial maximum, 18,500–18,000 yr (Fig. 10B). Grand Coulee transmitted all Missoula floods, but it became the westmost floodway just before, during, and after the glacial maximum, about 18,000 to 17,000 yr (Fig. 10C). It was probably the only conduit for a few dozen late, smaller Missoula floods 16,500 to 15,400 yr ago (Fig. 10D). After the last Missoula flood, glacial Lake Columbia lingered as long as four centuries, growing larger behind ice tongues retreating upvalley and downvalley. The lake's demise by flood thus occurred about 15,000 yr ago (Fig. 10E). From an up-Columbia source, probably glacial Lake Kootenay, the last flood(s) for which there is clear field evidence swept past Chelan and Wenatchee after Glacier Peak's eruptions about 13,600 yr ago (Fig. 10F). Well above the Columbia valley floor upvalley of Castlegar, BC, a bottom-bog date of about 13,000 yr (Fulton, 1971; Clague, 1980) suggests the Columbia River lobe dammed lower Kootenay valley below Castelgar till roughly 13,300 yr ago.

Deposits of East Wenatchee Clovis site

The huge early Pangborn floodbar of mixed-lithology gravel is surfaced by giant current dunes. The East Wenatchee Clovis cache lies 250 m north-northeast of the bar crestline and faces a fosse that bottoms 500 m farther north at the base of bluffs of basaltic landslides the bar overlies (Figs. 2A, 4, 6 and 7B). The Clovis cache is in a swale between giant current-dune crests. The bar is capped by ¾ to 1½ m of massive silty sand and sandy silt, eolian material blown from the bar crest and nearby areas.

The cache lay 50–70 cm below the surface, low in the eolian blanket (Figs. 3 and 11). The 1990 excavations showed it monotonously compact brownish-gray silty sand—no obvious strata or laminations, no sharp variations in color or texture, no obvious human-made surface.

Flood deposit

Two square-meter pits dug in 1990 outside the artifact area (Fig. 2B) bottomed 2–2.5 m deep in the top of the great flood bar. That sediment is moderately sorted coarse to medium sand—the uppermost fine part of gravel 200 m thick whose upper few meters, as exposed in an old broad pit 1.3 km southwest, is pebble gravel. At lower levels the south face of the cobble-boulder gravel bar, exposed on S. Nile Road 2 km southwest of Pangborn airfield, contains boulders as large as 2.5 m within tall downvalley-dipping foreset beds. The varied stone types in all these deposits—diverse granite, gneiss, schist, and many others derived upvalley—show the flood(s) depositing this bar swept down Columbia valley.

Stone-bearing sand layer

Gradationally overlying the coarse sand at depths 120 to 70 cm (Fig. 11), silty medium-coarse sand grades up to medium-fine sand. This obscurely layered sand consists two-thirds grains of light-colored quartz, feldspar, and crystalline-rock fragments and a third of dark basalt-rock grains. A coarse-sand fraction consists almost entirely of light-toned quartz and feldspar grains, only 3 percent basalt grains—this too then a deposit of flood from upvalley. At depths 100–70 cm this layer contains sparse outsized stones, most of them very angular to angular basalt pebbles and cobbles as large as 16 cm. A few are subangular pebbles of granite or gneiss. The stones rest incongruously in the sand matrix—some alone, others bunched. Vague wisps of lamination show this layer also waterlaid.

Most clasts resemble angular stones fallen from basalt cliffs and show no evidence they've been worked. In two pits meters from the artifact area (Fig. 2B), the basalt stones lie at the same depths in even greater abundance. They cannot be from early people.

At low levels downvalley, sand from Moses Coulee flood is almost all basalt grains. The sand at the high level of the Clovis site is mostly quartz and feldspar, from upvalley. The bar's giant transverse dunes also show downvalley currents. At this high level lie no graded sand-silt beds that across the flooded region are the hallmark of backflood (Waitt, 1980, 1985). Such beds do lie 43 m lower on the southeast end of the bar. The great Moses Coulee floods apparently did not backflood deeply enough to reach high on Pangborn bar. Backfloods from Quincy basin—entering farther down Columbia valley and lower than the Moses Coulee floods—also couldn't reach high levels at Wenatchee.

The steep east-facing sides of the giant transverse dunes atop Pangborn flood bar (Fig. 6) record downvalleyward floodflow. Except for their outlandish size they resemble ordinary current ripples (Allen, 1969; Pettijohn et al., 1972). The early burst(s) of the Missoula-flood sequence swept downvalley over the landslides of fragmented basalt. The basalt stones in the Clovis site are coarse and angular because the source lay only 0.7–4 km upcurrent across a bed of scarcely abrasive sand.

Eolian deposit and plow zone

Overlying the waterlaid sand at depths as much as 75 cm is nearly structureless, stone-free, brown sandy silt to silty sand, apparently windblown (Fig. 11). The dominant sand component at the Clovis site probably came from the bar top only meters to tens of meters away. The contact with the fine top of underlying floodlaid sand is vague. Several centimeters of this windblown material had accumulated before the Clovis cache was placed, and more than half a meter fell later. This eolian blanket accumulated from more than 16,000 yr ago to the present. Windstorms still occasionally cloud the air with fine silt.

The walls of the excavation, mostly only a meter deep, showed no obvious contacts, no abrupt increase or decrease in grain size. From the eolian layer, the transition down into the top of waterlaid sand is a gradual increase in grain size and looseness.

At Washington History Research Center in Tacoma I reexamined latex peels that Mehringer had taken in 1988—four from the archaeologic excavation, five from the northern backhoe trenches 23, 10, 8, and 6 (Fig. 2A). Peels from the excavation show structureless dark-brown sandy silt that grades up from silty sand at 110 cm to slightly sandy silt among grass roots at the top. One peel retains an angular basalt pebble at depth 90 cm, the stoney layer discussed above. Coarse sand grains at the base are bright quartz and feldspar encased in dark-brown silt. The peels repeat the brown structureless walls of the excavations. Peels from the north trenches likewise show no discernible bedding, but the brown eolian blanket thickens into that fosse.

The lack of evident disturbance or grain-size difference in the excavation at and above the level of the artifacts suggests the tools had been laid on the surface only slightly buried if at all. The 55–65 cm of overlying massive silty sand seems gradual eolian fall. The upper 20–30 cm is a slightly deeper brown, evidently plowed during dry wheat farming in the 1920s–1960s. The surface few centimeters of stratified sand and silt, organic duff, and grass roots stem from orchard and irrigation in the 1970s and 1980s.

Grain size

Gramly provided a digest of data from 94 samples from the 1990 excavation. But they'd been screened at whole-phi (φ) intervals, and the unanalyzed pan fraction (finer than 3 φ) held 15 to 45 percent of the samples. These data are sparse. Samples from the trench m north of the artifact area and from the deeper pits several meters away (Fig. 2B) show the general character of the sand fraction. Below 140 cm the deposit is vaguely layered, clearly waterlaid. A coarse-sand layer at 210–250 cm depth is overlain by medium-fine sand at 190–150 cm (Fig. 12B), all moderately well sorted. Between 250 and 80 cm the upsection fining accords with the top of a bar accumulating during waning flood (Fig. 12A). The top of the flood bar and the overlying eolian blanket (at 60 to 40 cm) is medium to fine sand. Mehringer (1989b) had sampled the shallower 1988 excavation at half-centimeter intervals, sieved and pipetted samples at half-phi intervals from granule to clay sizes and plotted the data as histograms. This much closer sieving shows a major coarse-sand mode (0.5 φ) and a minor coarse-silt mode (4.5 φ) (Fig. 12C). The silt mode grows stronger upward in the eolian blanket. Even this detailed analysis shows grain-size changes upsection only gradually.

Stratigraphy

The Clovis cache lies atop the great Pangborn bar built by one or more immense debâcles down the Columbia early in the sequence of last-glacial Missoula floods. Deposits of later Missoula floods—via Moses Coulee and Quincy basin that backflooded up the valley—didn't pond as high as the cache, thus no direct stratigraphic relation between them. Some Clovis points excavated in 1988 overlay grains of Glacier Peak ash, visible only in lab samples. So the tools postdate the ash (Mehringer and Foit, 1990) now dated to 13,600 yr ago (Kuehn et al., 2009).

In the grain-size plots (Fig. 12A), the subordinate coarse-silt mode in the bar top grows dominant upward in the eolian deposit. Windstorms must have winnowed finer particles from the crests of the giant dunes and deposited in adjacent troughs where wind eddies. As the dune crests lost finer material and armored in coarser sand—increasing vegetation further restricting this source—accumulation rate would diminish and a higher share be silt blown from farther away.

The Clovis artifacts two-thirds kilometer northeast of the top of Pangborn bar are buried by 55–65 cm of eolian silt. Downslope ½ km north—deeper into the fosse along the bar's side—postflood deposits thicken to 2 m and more, shown in the 1988 backhoe trenches (Mehringer, 1989b, Figs. 13, 17 and 25). The fosse, 6–9 m lower than the archeologic site and 20–24 m below the bar's top, is apparently enough calmer that airborne silt settles and accumulates.

The Clovis cache is buried by most of the eolian blanket and which accumulated on average only 1 cm in 250 yr. Its thickening into the fosse shows that windborne silt blows past the Clovis site as much as settles. Where eolian accumulation is so slow, the roots of such plants along with burrowing insects and rodents can over time homogenize a sequential accumulation.

The stone tools had been anciently scattered, and within the 1990 excavation lay an anciently disturbed sediment mass rich in bone shards. Several of the bone rods had been gnawed, and one of them devoured and defecated—by wolverine, Gramly (1991, 1993a) infers.

Source of Clovis lithic material

The Clovis stone artifacts resemble jasper, brownish chalcedony, and pale agate that fill voids in the bases of several flows of Columbia River Basalt that crops out across the region (Tabor et al., 1982, 1987). Potential source sites of chalcedony and agate are many. D.C. Waldorf and I in late 1990, and I alone in 1991, examined a few. Forty kilometers east of the cache, stream gullies off Badger Mountain anticline northward to Sagebrush Flat carry brown chalcedony that visually resembles some of the stone artifacts. Such pebbles in the gullies mean bedrock sources lie upslope within the Columbia River Basalt.

Debitage and discarded rubble about ancient quarry sites a few tens of kilometers farther east (no exposed rock) includes chalcedony and agate resembling that of blades in the Clovis cache. Bits of yellow-brown palagonite in the quarry rubble suggest the silica had filled voids in pillow basalt at the base of a lava flow. Much of the lithic material of the Clovis-cache tools seems from local sources. At the time of their cache the Clovis weren't passing up or down the Columbia for the first time but had resided long enough to discover and exploit quality lithic sources.

Ashfall and Clovis cache

Ash was invisible in the excavations, but microscopically discovered grains of Glacier Peak pumice lay just beneath some of the Clovis points, little or none of it above (Mehringer, 1989; Mehringer and Foit, 1990). Silica that had encrusted the undersides of points could only have dissolved from the pumice ash. Clovis age was then thought 10,900 to 11,500 ^{14}C yr BP (in raw uncalibrated time) while Glacier Peak ash dated to about 11,200–11,250 ^{14}C yr BP (Mehringer et al., 1977, 1984). Mehringer and Foit (1990) conclude, "… Clovis people placed their points on patches of pumice soon after Glacier Peak erupted ca 11,250 BP" Further dating reafirmed Glacier Peak ash to be around 11,200 ^{14}C yr BP (Foit et al., 1993). Yet this call discounted three organic samples stratigraphically near the Glacier Peak that dated centuries older.

A modern study including trace-element analyses closely distinguished Glacier Peak ash and its largest layers, G and B (Kuehn et al., 2009). Selecting only stratigraphically reliable dates, they show through statistical filtering that Glacier Peak ash is about 11,600 ^{14}C yr BP. And Waters and Stafford (2007) using only the most reliable dates including many new ones at 11 stratigraphically secure sites narrowed provable Clovis age in western U.S. to 10,800 to 11,050 ^{14}C yr BP (unclaibrated). The redatings made Glacier Peak ash centuries older than thought in 1990, and Clovis occupation somewhat younger.

Stratigraphy in the East Wenatchee excavations remains unchanged since the 1988–1990 excavations. Glacier Peak ash (seen only microscopically) lay beneath the points and apparently not above. The ash predates the cache. This ash dated elsewhere can be only a maximum-limiting proxy age of the East Wenatchee artifacts. In calibrated time, Glacier Peak ash is 13,410 to 13,710 cal yr BP (Kuehn et al., 2009) while western North American Clovis is 13,125 to 12,975 cal yr BP (Waters and Stafford, 2007). Glacier Peak seems to have erupted centuries before the Clovis left their cache of tools.

Some papers seem to misunderstand the ash's stratigraphic context for the Clovis cache. Haynes (2005, p. 127–128) as storyteller spins a tale how generations of people explored south from Alaska. So near East Wenatchee "a band came under an ash fall of the Glacier Peak eruption." Yet Haynes as archaeologist knows only that Glacier Peak ash underlay some of the stone tools. Any notion that these Clovis people actually experienced ashfall is imagination.

Figure 14. Luther Cressman (1960, Fig. 27) ‘knife,’ curated at University of Oregon Museum of Natural and Cultural History, examinination in August 2008. Photograph by C. Melvin Aikens.

Haynes (2008, SI Table 3, site 83) calls the horizon just above the East Wenatchee tool cache “colluvium” and the one just below “ash.” But the very gentle top of a porous and permeable flood bar far out from the valley side isn't a colluvial environment. The silty sand both above and below the stone tools is apparently wind-blown silty sand—but that just below fairly rich (microscopically) in Glacier Peak ash.

Haynes' falling-ash story may have been plausible when the age of the ash seemed within the supposed range of North American Clovis occupation. But after the ash redated to centuries older than had been, and Clovis age redated to somewhat younger than had been, the story isn't so plausible. Yet some have repeated Haynes' story, equated the age of Clovis with the age of the ash, and suggested that the East Wenatchee Clovis cache dates to 13,600 cal yr BP (Fiedel, 2006, p. 43; Hamilton and Buchanan, 2007, Table 1; Morrow et al., 2012, p. 3680). Haynes' whimsical tale grows to outpace actual data.

Did people witness the huge ice-age floods?

Missoula floods swept down the great bend of Columbia River before the Okanogan ice lobe sealed off the valley by about 18,500 yr ago (Figs. 10 and 13). For another 2½ millennia dozens of Missoula floods reached Wenatchee by backflood from Moses Coulee and Quincy basin. Waters and Stafford (2007) Clovis range between about 13,100 and 12,800 cal yr BP is about five millennia after the great Pangborn-bar flood(s). The Clovis cached their tools two millennia after the last (and by then small) small Missoula flood. *These* people didn't witness any of them. The cache also came some 15 centuries after the flood from glacial Lake Columbia, and seemingly 5 to 8 centuries after the 13,600 cal yr BP Glacier Peak ashfall.

In August 2008, five veteran University of Oregon archaeologists (Mel Aikens, Don Dumond, Tom Connolly, Pam Endzweig, Dennis Jenkins) and I met at the Museum of Natural and Cultural History in Eugene to reexamine claims of humans in Columbia gorge before the Missoula floods (Cressman, 1960, pp. 63–66, 1977, pp. 50–51, 71). We studied the stone ‘knife’ Cressman had in 1953 plucked from cemented Missoula-flood gravel. “Doubt hung heavy in the room,” as Mel Aikens puts it. One edge of the stone is crudely chipped but large flat areas wholly unworked (Fig. 14). None of us thought it a knife. It seems a fortuitously flood-bruised basalt pebble—what archaeologist may call a geofact. Nothing about the broken and worn pebble suggests a human touch before Cressman's.

Of allied 1955 materials collected by Sam Sargent farther down the Columbia in excavations for the navigation lock at The Dalles Dam, only two are clearly artifacts. Yet no stratigraphic, descriptive, or photographic documentation of their context exists, and the site has since lain behind concrete. Except for Cressman (1960, p. 65) hearsay of Sargent's vague say-so, nothing links these materials to Missoula-flood deposits. Cressman's claim of preflood humans along Columbia gorge lacks a foundation. (Aikens et al., [2011, pp. 153–154] elaborate an archaeological view of these 1953–1955 collections.)

Did humans witness the immense debâcles down the Columbia? There's no direct evidence. The East Wenatchee Clovis tools were apparently cached much later. The oldest radiocarbon dates for pre-Clovis humans in the Pacific Northwest are about 14,400 cal yr BP at Paisley Caves in southern Oregon (Gilbert et al., 2008; Jenkins et al., 2012), and in northwest Washington about 13,860 for the Ayer Pond bison (Kenady et al., 2011) and 13,960 for the Manis mastodon (Waters et al., 2011). (Doubt lingers that the Manis projectile is manmade [Grayson and Meltzer, 2015; Grayson, 2016].) These are two millennia younger than the *last* Missoula flood, a millennium younger than the burst ending glacial Lake Columbia. Across the continent, Meadowcroft rockshelter's stratigraphically ordered radiocarbon dates affiliate with artifacts down to about 14,000 years ago (Struckenrath et al., 1982; Adovasio and Page, 2002; Meltzer, 2009; Adovasio and Pedlar, 2012; Waters and Stafford, 2014). In southern Chile, Monte Verde's diverse artifacts affiliate with radiocarbon dates back to 14,600 cal yr BP ago (Dillehay et al., 2008; Erlandson et al., 2008; Waters and Stafford, 2014). But such pre-Clovis sites lie thousands of kilometers from Wenatchee and Columbia River, and even those occupational dates postdate the Missoula floods by a millennium and more (Fig. 13).

The two lowest and youngest flood bars in the Chelan–Wenatchee reach of Columbia valley clearly postdate Glacier Peak ash. Clovis people *could* have witnessed these relatively small flood(s) from British Columbia. Of the many ice-age watery cataclysms down the Columbia, only the last from southern British Columbia not long before 13,000 years ago are likely to have been witnessed.

Acknowledgments

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