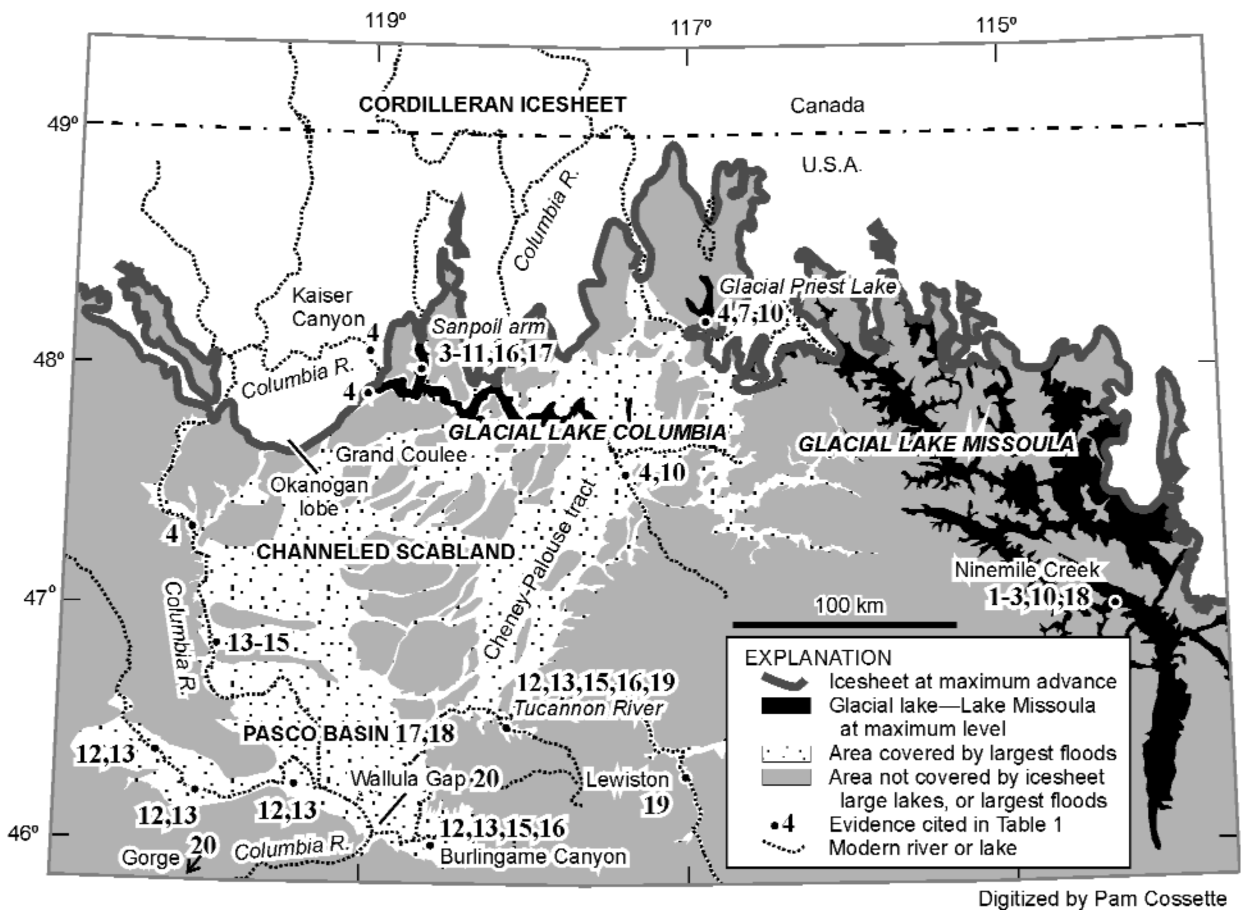


Figure 2. Index map. Modified from Waitt and Thorson (1983) and Atwater (1986, Plate 1).

TABLE 1. EXAMPLES OF EVIDENCE FOR DOZENS OF COLOSSAL FLOODS FROM GLACIAL LAKE MISSOULA

| **Evidence** | **Interpretations in reports where the evidence was first presented** | **Treatment by Shaw *et al.* (1999)** |
|---|---|---|
| ***1-3. Varved evidence that glacial Lake Missoula filled gradually and was lowered rapidly, dozens of times*** | | |
| **1.** At Ninemile Creek, in each of at least 34 rhythmic units deposited in Lake Missoula, basal sand and silt are overlain by varves that thin upward (Chambers, 1971, p. 46; Waitt, 1980, p. 673-674)<br>**2.** The uppermost varves are desiccated and cracked in at least 10 of these units (Fritz and Smith, 1993) and in as many as 22 of them (Chambers, 1984, p. 191, 194). Chambers (personal communication, 1994) observed this evidence soon after it was first exposed in a deep cut for an interstate highway | At least 34 times, Lake Missoula filled gradually for a few decades (**1**), then was lowered rapidly—to a level that sometimes exposed much of the lake bottom (**2**)<br>Turbidity currents deposited sand and silt beds soon after the lake was suddenly lowered, whether or not the lake bed had just been exposed (Fritz and Smith, 1993) | Interpretations made: Basal silt was deposited by turbidity currents from floods into Lake Missoula. These floods periodically interrupted "normal varve sedimentation" (p. 606), and they were independent of floods into glacial Lake Columbia and Pasco Basin (p. 608) |
| **3.** Unlike varves of glacial Lake Missoula, varves of glacial Lake Columbia do not repeatedly thin upsection, nor do they contain evidence for subaerial exposure (Atwater, 1986, Figs. 7, 13-15, 20, 25B). And unlike Lake Missoula's ice dam, Lake Columbia's usual outlet was unfloatable—a rock spillway formed by the upper Grand Coulee (Atwater, 1986, p. 4-6) | Lake Missoula's ice dam became unstable when water rose high behind it (Clarke *et al.*, 1984). By contrast, Lake Columbia usually maintained a level close to that of its unfloatable rock spillway and too low to destabilize this lake's ice dam (**3**) | Evidence ignored: upward thinning of varves (**1**), weathered varves (**2**), contrast with varves of Lake Columbia (**3**), and evidence for correlation with deposits of Lake Columbia and Pasco Basin (**10, 16-18**) |
| ***4-6. Evidence for dozens of periodic floods into lakes on the north and west margins of the Channeled Scabland*** | | |
| **4.** Flood deposits regularly alternate with varves of three different lakes downstream from Lake Missoula (Waitt, | Floods flowed periodically into already existing lakes downstream | Interpretations made: Sage Trig section is "central to the |

| Evidence | Interpretations in reports where the evidence was first presented | Treatment by Shaw *et al.* (1999) |
|---|---|---|
| 1984; 1985, p. 1275-1277; Atwater, 1984, 1986, 1987)<br>**5.** The deposits of one of these lakes, glacial Lake Columbia, contain at least 89 flood beds regularly intercalated among 2000-3000 varves in a section 115 m thick (Atwater, 1986, Plate 2). This section was deposited in Lake Columbia's Sanpoil arm, near Manila Creek<br>**6.** A few kilometers from the Manila Creek section, the much shorter and less complete Sage Trig section contains seven flood beds. These beds, separated from one another by sets of varves, contain examples of turbidites and debris-flow deposits (Atwater, 1986, figs. 6, 8C, 26) | from Lake Missoula (**4, 10**)<br>At least 89 such floods entered glacial Lake Columbia, and seven of these are recorded in the Sage Trig section (**5, 6**)<br>The Sage Trig section is notable mostly for its examples of turbidites and debris-flow deposits. Seven floods are recorded at Sage Trig, but a much fuller record of floods is present in the Manila Creek section (**5, 6**) | debate of multiple versus single floods" (p. 605) and is "well explained" by "a single flood with multiple pulses" (p. 608)<br>Evidence ignored: flood deposits at sites other than Sage Trig section (**4, 5**), interflood varves in Sage Trig section (**6**)<br>Inconsistency: Shaw *et al.* (p. 608) infer, from bottom sediments of Lake Missoula, periodic floods into that lake; yet they do not acknowledge the occurrence of any such floods into Lake Columbia, despite their citation of reports that present points **4-6** |
| ***7-10. Evidence that these floods (points 4-6) came from glacial Lake Missoula*** | | |
| **7.** Ripple laminations record initial flood currents directed northward—away from Lake Missoula and toward the Cordilleran icesheet—in varve-bounded flood beds. Nine examples were deposited in glacial Priest Lake (Waitt, 1984, Fig. 4), seven were correlated between two sections deposited in the Sanpoil arm of glacial Lake Columbia | The main floods into glacial Priest Lake and glacial Lake Columbia came from glacial Lake Missoula (**10**)<br>In Lake Columbia's Sanpoil arm, water of each of these floods first | Interpretations made: The Sage Trig section records a "single flood with multiple pulses" and "powerful flows from the north"—from a northerly source beneath the |

| Evidence | Interpretations in reports where the evidence was first presented | Treatment by Shaw *et al.* (1999) |
|---|---|---|
| (Atwater, 1986, Figs. 6, 9, 24; Plate 2), and others accumulated in an arm of Lake Columbia that adjoined the icesheet's Okanogan lobe (Atwater, 1987, Table 1, Kaiser Canyon section) | flowed northward, backing up the Sanpoil valley toward the Cordilleran icesheet (**7, 8**); then this floodwater drained southward (**9**) | Cordilleran icesheet (p. 606, 608)—but it also records "backwater" (p. 608). Floodwater issued southward from beneath the icesheet's Okanogan lobe (p. 607) |
| **8.** Additional sign of initial northward flood flow in Lake Columbia's Sanpoil arm: Northward fining of three flood beds correlated for 13 km (Atwater, 1986, Figs. 9, 14B, 24). This trend contrasts with southward fining and thinning of sand layers in interflood varves (Atwater, 1986, Figs. 9, 14B) but this evidence comes only from inspection under a hand lens | | Evidence ignored: indicators of initial northward flow, even close to the Okanogan lobe (**7, 8**); typical stratigraphic position of southward current indicators (**9**); similarities in varve counts (**10**) |
| **9.** Most of the southward current indicators in flood beds of the Sanpoil arm are ripples at the upward transition from sand to silt (Atwater, 1986, Plate 3). Others are in places where Missoula floods likely produced eddies | | Evidence asserted without supporting data: Shaw *et al.* (1999) say that flood-deposited sand in the Sanpoil valley lacks grains from the south. But they present no petrographic data from either flood-bed sand or varve sand. Does flood-bed sand in the Sanpoil valley contain more lithic grains than does the varve sand derived from the north (Atwater, 1984, p. 464-465)? |
| **10.** About 30-50 varves accumulated between disturbances to each of three lakes: between each of at least 8 floods into glacial Priest Lake (Waitt, 1984, Fig. 4), between each of at least 20 of the floods into glacial Lake Columbia (Atwater, 1986, his Table 1, Fig. 17, and Plate 3), and during at least 20 of the fillings of glacial Lake Missoula (Chambers, 1984, Fig. 2) | | |

| Evidence | Interpretations in reports where the evidence was first presented | Treatment by Shaw *et al.* (1999) |
|---|---|---|
| ***11. Evidence for smaller floods from a source other than glacial Lake Missoula*** | | |
| **11.** High in Lake Columbia's Manila Creek section, sets of about 25 varves alternate with flood beds 15-100 cm thick. Several of these sets of varves contain graded beds several centimeters thick that alternate rhythmically with a few varves. About 45 such beds accumulated in 91-142 varve years (Atwater, 1986, p. 17, Plate 3) | About 45 periodic floods from a non-Missoula source entered Lake Columbia every two or three years, during a time when larger floods from Lake Missoula occurred at intervals close to 25 years (**11**) | Evidence ignored: previously reported signs of non-Missoula floods into Lake Columbia (**11**) |
| ***12-17. Evidence for subaerial exposure after each of dozens of floods into Pasco Basin*** | | |
| **12.** Two ash layers are widely present in silt that caps a flood bed, and third ash layer is present locally in silt that caps the underlying flood bed (Waitt, 1980, p. 664-667; Waitt, 1985, p. 1273-1274) | Intervals of subaerial exposure separated floods that account for rhythmic beds in Pasco Basin and vicinity (**12-15**) | Inferred from the many flood beds (**12-15**): pulses in one flood (p. 607, 608), as previously proposed by Baker (1973, p. 46-47) |
| **13.** Many flood beds are capped by deposits interpreted as loess (Waitt, 1980, p. 663; Smith (1993, facies NA), mixed loess and colluvium (Smith, 1998, facies NB), and non-flood alluvium (Smith, 1998, facies NC) | These intervals probably correlate with the decades of varve deposition in lakes to the north (**10, 16, 17**) | Evidence summarily dismissed: details about ash layers (**12**), non-flood facies (**13**), and bioturbation (**14**). Shaw *et al.* (p. 606) discount the bioturbation as possibly modern. They cite negative evidence from unnamed observers of an unstated number of beds, and they say |
| **14.** Rodent burrows with semi-consolidated fills are present in most flood beds to the bottom of a 30-m-tall section exposed in a nearly vertical slot cut in 1922 (Waitt, 1980, p. 667; Waitt, 1985, p. 1273; O'Connor and Waitt, 1995, p. 102). Among 12 other measured sections, over half of 186 flood beds show bioturbation, and in most of these the measured degree of bioturbation typically increases | | |

| Evidence | Interpretations in reports where the evidence was first presented | Treatment by Shaw *et al.* (1999) |
| --- | --- | --- |
| upward within each bed (Smith, 1993, Figs. 3, 4; p. 88). Lamination commonly disappears laterally into silt and fine sand that are massive from bioturbation<br>**15.** Mudcracks are preserved in the uppermost part of a flood bed (Smith, 1993, Fig. 7B)<br>**16.** Dozens of flood beds formed about 14,000 $^{14}$C yr B.P. both in Lake Columbia, where they are separated by varves (Atwater, 1986, p. 29), and in Pasco Basin (Waitt, 1985, p. 1284), where the evidence for intervening non-flood intervals is less obvious but still present (**12-15**)<br>**17.** The number of flood beds deposited in Pasco Basin (probably over 60; Waitt, 1985, p. 1284) is consistent with the number deposited in Lake Columbia (at least 89; **5**) | | that silt and fine sand were deposited massive by "suspension settling"<br>Evidence ignored: mudcracks (**15**; termed "absent" on p. 606); similarities in age and number of flood beds that imply correlation between flood beds of Pasco Basin and varve-bounded flood beds of Lake Columbia (**16, 17**) |
| ***18-20. Evidence that many last-glacial floods in and below the Channeled Scabland were colossal outbursts from Lake Missoula*** | | |
| **18.** The number of flood beds deposited in Pasco Basin (probably over 60; **17**) is also consistent with the number of rhythmic units from gradual filling and rapid lowering of Lake Missoula (at least 34; **1-3**)<br>**19.** Along the lower Tucannon River, deposits of about 20 last-glacial floods contain coarse sand that records repeated, high discharges across a high divide at the south end of the Cheney-Palouse scabland tract (Smith, 1993, p. 96-97; Waitt, 1994, p. K56-K59). At least 21 flood beds are present at Lewiston, a site too high for passive | Dozens of colossal floods came from Lake Missoula during the last glaciation (**18-20**)<br>Though termed "low energy" (Baker and Bunker, 1985, p. 28-29), many of the so-called slackwater deposits in Pasco Basin were produced by fast-moving flood currents (Smith, 1993, p. 96-97; Waitt, 1994, p. K59). Of the last-glacial floods into | Interpretation made: the main last-glacial flood (or floods) came from a huge reservoir inferred to have underlain the Cordilleran icesheet, especially north of its Okanogan lobe (p. 607-608)<br>Evidence ignored: similarities in number and frequency of floods among Lake Missoula, |

| Evidence | Interpretations in reports where the evidence was first presented | Treatment by Shaw *et al.* (1999) |
|---|---|---|
| inundation by a hydraulically ponded lake in Pasco Basin (Waitt, 1985, p. 1277-1278) | Pasco Basin, about 20 surmounted a high divide at the south end of the Cheney-Palouse scabland tract (**19**) | Lake Columbia, and Pasco Basin (**10, 17, 18**); records of repeated, high discharges from the Cheney-Palouse scabland tract (**19**), which would be bypassed by floods running southward from the Okanogan lobe; high discharges calculated for multiple floods in Columbia River Gorge (**20**) |
| **20.** In several flood-deposited bars in the Columbia River Gorge, cobble gravel alternates with beds of sand and silt, some of which are probably eolian. Floods that covered the bars probably exceeded 6 x $10^6$ $m^3/s$, as estimated by step-backwater methods (O'Connor and Waitt, 1995, p. 76, 110). The similarly modeled maximum discharge is 10 x $10^6$ $m^3/s$ for Wallula Gap (O'Connor and Baker, 1992, Figs. 3, 9) and for a 200-km reach of the Columbia River Gorge that includes the above-mentioned bars (O'Connor and Waitt, 1994, p. 55). | At least six last-glacial floods in the Columbia River Gorge approached the maximum discharge estimated for this area (**20**) | Estimate apparently misread by a factor of ten: Shaw *et al.* (1999, p. 608) give the maximum modeled discharge below Pasco Basin as 1 x $10^6$ $m^3/s$ (**20**) |

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