Classic localities explained 5

Lake Missoula and the Scablands, Washington, USA

Gigantic floods that, for just a few days, had flow rates many times greater than the combined flows of all the other rivers of the world put together. Sounds ridiculous, and it's almost inconceivable, but it's real, and it all happened at the end of the last Ice Age. The water came from Lake Missoula, which exists no more, but the effects are still to be seen in the landscapes, most notably in the vast scablands of eastern Washington.

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Ice-dammed Lake Missoula

During the last great stage of the Ice Ages (the main Devensian, or Dimlington, in Britain, known as the Pinedale stage in America), the huge Cordilleran ice sheet extended south along the Canadian Rockies and all the Coast Ranges, and just reached into the United States. Its ice reached thicknesses of over 3000 m. As with any large ice sheet, its morphology was complex, with major flows concentrated within 'ice streams' that were largely directed along pre-existing valleys in the buried landscape. Few were greater than the Purcell ice stream, developed in the great fault-bound trench of the same name, which gathered ice in the heavy snowfall zone along the western slopes of the Canadian Rockies.

With its powerful feed, the Purcell ice extended into a lobe reaching that much further south into lower terrains. And there it completely blocked the valley of the Clark Fork, a major tributary of the Columbia River, where it flowed through what is now the narrow northern neck of Idaho. Ice flowed about 20 km both upstream and downstream in the Clark Fork valley, and extended south to wrap around some smaller mountains. This was a massive ice dam, and the river had no way past (Fig. 1).

Fed by snowfall and glacier meltwaters from the

Fig. 1. Simplified map of Lake Missoula, the scablands and the temporary lakes alongside the margin of the late Devensian ice sheet.

Fig. 2. Giant ripples of the Camas Prairie, formed beneath standing waves as Lake Missoula drained out. The farmhouse beneath the trees gives scale.

Rockies of Montana, the Clark Fork was ponded behind its ice barrier to form Glacial Lake Missoula. This was huge, reaching more than 250 km towards the southeast, and backing up along its many tributaries, but nowhere finding an overflow route through the high Bitterfoot Range. Filling the deep mountain valleys, the lake had no great area, but much of it was 600 m deep, such was the thickness of the Purcell glacier that held it in place. Consequently, the volume of water in Lake Missoula reached about 2170 km^3, a little more than the combined volumes of Lakes Erie and Ontario today.

No ice dam is permanent. Exactly how the Purcell dam failed is not known for sure. It was most likely due to its ice floating and lifting off the bedrock due to the combination of rising water pressure in Lake Missoula and thinning of the ice as climates ameliorated. This is how most modern ice dam failures occur, including the floods from Lake George due to failures of the Knik Glacier in Alaska, which were annual events until 1967. But failure of the Purcell ice dam could also have been triggered by jokulhlaup floods draining down from sub-glacial basins further north beneath the ice sheet; these would have contributed huge flows to the subsequent floods that were on an almost unaccountably gigantic scale. With or without the water from the north, the escaping water rapidly undermined and destroyed the toe of the glacier, to turn a major leak into a wholesale flood.

The great flood

When the ice dam failed, a truly enormous flood pulse was generated as Lake Missoula completely drained out. It is difficult to conceive the scale of this flood. The flow down the Clark Fork valley has been assessed at the Eddy Narrows, where water velocity is estimated from the sizes of transported boulders, and the cross-section is indicated by the level to which soil was stripped off the valley sides. The result is an incredible 38 cubic kilometres of water per hour, which is about 600 times the mean flow of today's River Amazon, and it reached speeds of about 80 km/h. This flow would have waned from an early peak, so it is likely that it took nearly a week to empty Lake Missoula.

Elsewhere within the lake site, this catastrophic outpouring had some spectacular effects. Where a northern arm of Lake Missoula emptied over a low col that was nearly exposed, giant standing waves were created just downstream within the massive flow. These waves shaped huge ripples within the bed load of gravel and cobble-size sediment, and the ripples, 30 m high and 100 m apart, still survive across a basin known as the Camas Prairie (Fig. 2).

The floodwaters from Lake Missoula could not reach the lower Clark valley, which was still blocked by ice. So they poured away to the south, dumping gravel and debris in a basin before overtopping a col, and cascading into Glacial Lake Columbia (Fig. 1). This was another very large ice-dammed lake, created where the Okanogan lobe of the Cordilleran ice sheet blocked the valley of the Columbia River. Its overflow was down the Grand Coulee, then only a small predecessor of that seen today. A coulee is the local name for a rocky gorge carved by meltwater and now largely dry.

Fig. 3. Palouse loess standing 100 m high above a wide channel through the Cheney-Palouse Scablands.

Fig. 4. The rocky terrain known as scabland contrasts with the smooth profile of the loess hill beyond, in the heart of the Cheney-Palouse Scablands.

Arrival of the huge volume of Missoula water instantly raised Lake Columbia to unprecedented levels. The inevitable overflow created new outlets, notably across the lowlands to the south; and so the scablands were formed.

Scablands and Coulees

South of Glacial Lake Columbia, a huge sweep of open country stands on the massive plateau of the Columbia River Flood Basalts (all created back in late Tertiary times). During Pleistocene glaciations much of the basalt terrain was covered by the Palouse loess, wind-blown silt mostly 30–80 m thick and largely derived by deflation from plains of glacial outwash during the Pleistocene. When the Missoula floodwater overflowed from Lake Columbia across this great plateau, the broad channels that carried the main flood flows were almost instantly stripped down to basalt bedrock, while the loess survived in long strips and lenses on the slightly higher ridges (Fig. 3).

When farmers settled the region in the late 1800s, they soon appreciated the rich loam soils that formed on the loess, and their patchwork of fields are still highly productive today. But the farmers also recognised that, between the rich loess hills, the strips of flood-scoured basalt were almost useless, and they called these the scablands (Fig. 4). These are floored by broken basalt, chaotic blocks and only meagre soils.

That first great flood from Lake Missoula scoured the southeastern half of the scablands, roughly those south of Interstate 90 (Fig. 1); these are known as the Cheney-Palouse Scablands. It appears that the northwestern scablands were not formed in this first event, probably because the Columbia ice lobe then extended further south, almost cutting Lake Columbia

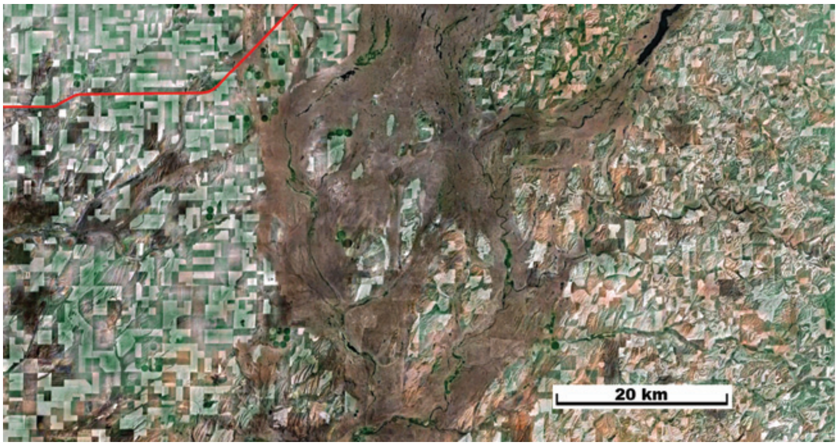

Fig. 5. Satellite image of a small part of the Cheney-Palouse Scablands midway between Spokane and Pasco, with interstate 90 cutting across the northwest corner, marked in red. The grid pattern of cropped fields identifies the areas of loess, while the brown scablands are textured by stream channels both dry and active. (Photo: USGS).

Fig. 6. Palouse Falls, dropping into the greatly oversized plunge pool that is a relict of much larger flows during the flood pulses from Lake Missoula.

Fig. 7. Stratified silts and clays exposed along Latah Creek, south of Spokane, were deposited in an arm of glacial Lake Columbia, and include a conspicuous bed of gravel that marked the arrival of a huge flood pulse from Lake Missoula.

into two and reducing the impact of the flood on its western half. But south of Spokane, these scablands remain as testimony to that enormous flood hurtling southwards. They are often referred to as the channelled scablands because of their braided channels between islands of loess, some of which are re-deposited material left by the waning floodwaters (Fig. 5).

Within the scablands, the floods cut some channels deeper into the basalt, to form coulees of various sizes. The old course of the Palouse River was enlarged to form the long, but not very deep, Washtucna Coulee. But floodwater also overflowed the interfluve ridge to the south and took a short cut into the deep valley of the Snake River. This route took such a flow that it was entrenched into a deep gorge, which then carried the Palouse River forever after the wane of the floods. Midway along its course, the river drops 60 m over the Palouse Falls (Fig. 6). This splendid waterfall is an obvious underfit within the giant plunge pool into which it drops, because its modest modern flow is as nothing compared to the huge Missoula flood that scoured the rock basin and its downstream canyon.

Farther west, the existing outlet from Lake Columbia, the Grand Coulee was probably enlarged by a proportion of the Missoula floodwater that found its way past the Columbia ice lobe. But such was rather masked by later events.

Floods repeated

With Lake Missoula gone, and the Clark Fork reduced to a modest river, the Purcell ice lobe could advance again, back over the site of its earlier collapse and destruction. And so the ice dam was re-created, and a new Lake Missoula started to fill up. Until the dam failed again. And the whole cycle, of filling and emptying, was repeated over and over. Evidence for this comes from sediments of Lake Columbia exposed along Latah Creek, just south of Spokane, where a thick sequence of varved lake silts and clays is interrupted by 16 gravel horizons, each of which marks a pulse of flood water in from Lake Missoula (Fig. 7).

It also appears that each filling of Lake Missoula only reached a level a little below that of its predecessor, perhaps as a result of the slow thinning of the Cordilleran ice sheet and its outgoing ice lobes through the later years of the Devensian. Such is the story told by the ladders of terraces on hillsides above the city of Missoula that were repeatedly inundated by the lake (Fig. 8). More than 30 terraces can be counted, each so modest that it was formed within only a few years, and each so fragile that it cannot

Fig. 8. A hillside overlooking the edge of town in Missoula is gently scored by the multiple terraces that were shorelines on successive stages of its Ice Age lake.

Fig. 9. Part of the varved sequence of silts and clays that accumulated in a northern arm of glacial Lake Columbia.

Fig. 10. The upper end of Grand Coulee. The Columbia River crosses the top of the view with the Grand Coulee Dam across its narrowing near the right edge. Grand Coulee extends from there to the lower left, with most of its floor covered by Banks Lake, a holding pond for irrigation water diverted to the south. The basalt cliffs along the coulee are over 250 m tall. The cropped fields in the lower right are on loess, while the scatter of fields upper left are on glacial till.

have been covered by a subsequent lake. Counting the annual varves across disjointed exposures is never easy, but more than 2000 are recognized in the sediments left in one northern arm of Lake Columbia (Fig. 9). And within this, there are more than 80 gravels, each of which may represent a flood pulse in from a newly failed Lake Missoula.

Within these varved sediments, a few dated horizons of volcanic ash and shell sand constrain a timetable for the succession of lakes that filled and drained in the Missoula valleys. The first was at about 15 300 years BP (before present), while the last was at about 12 700 years BP. Sediment sequences inside the lake site suggest that Lake Missoula existed for a total of about half this period. Counting the Missoula varves suggests that the lake was filled for periods of about 50 years during each of the earlier events, but only for about 10 years in the later events when the ice dam was not so large. Meanwhile, Lake Columbia survived throughout this long decline of the main Devensian ice.

In part, the subsequent floods repeated the effects of the first great flood pulse across the scablands. But the later events added more to the story. They were largely responsible for the northwestern half of the scablands (north of I-90), after the Columbia ice lobe had retreated to allow access to these slightly lower areas. The big event was the enlargement of 80 km long Grand Coulee by the gigantic floods that poured through it. For short periods, these floods hugely increased the power of the waterfalls along its course, which plucked easily into the layered columnar basalts so that they retreated rapidly upstream to create the huge gorge. The upper part of Grand Coulee lay almost along the edge of the ice sheet, starting 170 m above the Columbia River just upstream of its dam created by the Okanogan ice (Fig. 10); so Lake Columbia was at least that deep. At the same point, the Grand Coulee Dam now impounds a much smaller reservoir, diverting some water through lakes within the coulee and then into canals to irrigate farmland far to the south.

Grand Coulee was the outlet from Lake Columbia through most of its Ice Age lifetime, but much of it was carved out by the short-lived Missoula floods. A major waterfall was initiated where it dropped off the basalt plateau at its downstream end. This then deepened the lower part of the coulee by retreating 30 km upstream. Its retreat stopped only when the coulee was left dry with the ice retreating from the main channel of the Columbia River, and it then left the dry waterfall now known as Dry Falls (Fig. 11). This was a spectacular cascade for thousands of years, but it grew to enormous proportions, over 120 m high and 5 km wide (many times the size of Niagara Falls), for the few weeks that each of the Missoula flood pulses swept through.

Parallel to Grand Coulee, and only a little smaller, the splendid Moses Coulee is up to 200 m deep between cliffs 2 km apart for much of its 70 km length (Fig. 12). It was probably a parallel outlet during many of the Missoula floods, but its upper end is now plugged and buried under moraine. This was left by a late expansion of the Okanogan ice lobe, which never quite reached into Grand Coulee.

Downstream lakes

From the scablands and the coulees, the Missoula floods finally poured out into the ice-free valley of the Columbia River. But even there they faced more barri-

Fig. 11. The western half of Dry Falls, seen from the Visitor Centre overlook. The curved cliff on the left was the main waterfall, 120 m high, which poured into the head of the lower Grand Coulee extending off to the right.

ers. Where the great river turns west, it flows through the Wallula Gap (Fig. 13), cutting though an anticline in the Columbia basalts that rose slowly enough for the river erosion to keep pace and maintain its channel. Though the Gap is more than a kilometre wide, it could not take the enormous flood pulses from Lake Missoula without backing up enough to drive the water through on a steeper gradient.

On the largest floods the back-up reached a depth of some 250 m, creating the enormous Lake Lewis, with an extra arm up the Yakima Valley (Fig. 1). This lake was very temporary, and probably drained out within a matter of weeks, as it had no permanent barrier—it was only held there until its waters could squeeze out through the Wallula Gap. But Lake Lewis re-formed with the arrival of each flood pulse from Lake Missoula. Sediments left in one of its backwaters are exposed in the isolated Burlingame Canyon (the result of an accidental breach of an irrigation canal in the 1930s). These have 39 cycles of silts and clays (Fig. 14); each cycle is capped by an erosion surface and represents a single lake filling and emptying.

Once through the Wallula Gap, the Missoula floods were next held up by the bottleneck of the Columbia Gorge. Lake Condon became another temporary feature on each flood pulse, sometimes reaching depths of more than 250 m so that it backed up into Lake Lewis. And the gorge itself was substantially entrenched by the massive flows that roared through.

Downstream of the gorge, the main flood pulses poured through the Portland Basin with depths of over 100 m, and water overflowed into the Willamette Valley (Fig. 1). Again this huge lake was only short-lived on each event, but its sediment-laden floodwaters contributed greatly to the excellent loessic soils that now floor the valley. And among the loess are isolated erratic boulders, whose angular profiles indicate that they were dropstones from icebergs, chunks of floating ice that had ridden the flood for 800 km from their sources in Lakes Columbia or Missoula.

Fig. 12. The dry channel of Moses Coulee, crosses by the main road east of Dry Falls.

From Portland, the Missoula floods dissipated more easily down the wider Columbia valley, finally reaching the Pacific Ocean well beyond the present coastline, when the Devensian sea levels were about 100 m lower than they are now. Such was the end of the truly massive floods from Glacial Lake Missoula.

A story of disbelief

The story told above is very much a simplification of a complex series of events related to Lake Missoula, so it all seems to hang together and make sense. But the first geomorphologists into this dramatic landscape had a hard time deducing the story from the widely scattered field evidence, and they also met with major opposition.

The terraces of Lake Missoula were first recognized in 1886 by a Professor T.C. Chamberlain—after he had read about Scotland's three comparable features known as the Parallel Roads of Glen Roy. Then in 1909, Joseph Pardee took the story further by mapping the extent of the lake and identifying its one-time ice dam south of the Purcell Trench. J. Harlen Bretz was a meticulous geomorphologist who studied his Channelled Scablands for many years and was the first to recognize them as the result of a gigantic flood, but from where it came he knew not. So when he presented his papers to the Geological Society of

Fig. 13. The Wallula Gap, where the Columbia River heads west between high cliffs of basalt.

Fig. 14. Layered silts, with each bed nearly a metre thick and representing a single short-lived filling of Lake Lewis, exposed in the wall of Burlingame Canyon.

America in 1923 he was ridiculed; catastrophism was geological heresy in those days, and the establishment would not believe him, though none of his main detractors had ever seen the Washington scablands. Bretz never visited Montana, so it was left to Pardee to establish the link between Lake Missoula and the scabland floods, with a paper published in 1942. But still many would not believe in such massive floods, and Bretz was left out in the cold. Then in 1962, a field trip from the Quaternary Research Congress took many senior participants to the scablands. Bretz was too ill to attend, but at the end they sent him a telegram to say he was right.

Bretz's great flood was finally believed, and the story was modified through the years only to encompass a great series of giant floods. It is not easy to date erosional events, and there is still ongoing debate over the sequences of landforms and the floodwaters responsible for each. But the scablands of Washington will long remain as a great example of catastrophic events in geology; just think of Grand Coulee (Fig. 15) being largely formed within a matter of weeks!

Visiting the scablands

With a name like that, the scablands have to be a great holiday destination. Maybe not with the deckchair, but well worth it for any geologist who happens by the region. The best of the scablands are seen by taking any road southeast from I-90 within an hour's drive west from Spokane, and the Columbia Gorge is an obvious attraction along I-84. Dry Falls and Palouse Falls are both accessible state parks, and the western approach to the former crosses the finest part of Moses Coulee. Burlingame Canyon is on private land with no access, but the Latah Creek section is visible from highway US-195, and there are many other flood landforms that can be traced with local guidebooks. The terraces of Lake Missoula are visible on various hillsides overlooking its namesake town, and the Camas Prairie ripples can be seen from road 382 just north of Perma.

Suggestions for further reading

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Fig. 15. Grand Coulee, where it is 4 km wide between cliffs 250 m high—the finest of the landforms left by the floods from Lake Missoula.