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Ice water land and time: A partial story of Glacial Lake Missoula and the Missoula floods

Daniel Peter Berger
The University of Montana

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ICE, WATER, LAND, AND TIME:
A PARTIAL STORY OF GLACIAL LAKE MISSOULA AND THE MISSOULA FLOODS

By
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B.A. Syracuse University, New York, 1996
presented in partial fulfillment of the requirements
for the degree of
Master of Science
The University of Montana
May, 2002

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During the end of the last ice age, an ice dam in northern Idaho blocked the Clark Fork River creating Glacial Lake Missoula, which spanned from the Montana/Idaho border nearly 200 miles east to Drummond, Montana. When the dam burst, 500 cubic miles of water rushing at speeds of up to 65 miles an hour ripped across eastern Washington in three braided channels, rejoined at Walulla Gap on the Columbia River, then tore through the Columbia River Gorge to the Pacific Ocean. This lake, North America's largest freshwater inland sea, was said to have flooded and filled between 40 and 100 times, each break releasing up to ten times the current total flow of all of Earth's rivers. These cataclysmic floods scoured the soft, fleshy earth of eastern Washington right down to the bare basalt, creating the channeled scablands and dry coulees, including the 700-foot deep Grand Coulee.

The phenomenon was unlike anything anyone has ever seen. The National Park Service has joined with the non-profit Ice Age Floods Institute and a host of local communities to display and interpret the lake and flood features, visible from Missoula, Montana to Portland, Oregon, in a proposed National Ice Age Geologic Trail. In a study released in the fall of 2001, the Park Service proposed the four-state trail though Montana, Idaho, Washington, and Oregon, which would include spur trails, roadside kiosks, and visitor centers, to celebrate the events and to weave the story of the glacial lakes and their floods back into the lives of those living or visiting the Northwest. The trail is unique for the Park Service because it would acquire no new land but would instead work with local, state, and other national agencies and private landowners to manage interpretation and preservation of the lake and flood features.

Today you can see the dramatic effects of the lake and the flood on the Clark Fork, Columbia, Snake and Yakima Rivers, on the channeled scablands in Oregon and Washington and in other places such as Mount Sentinel in Missoula and the Camas Prairie near Dixon, Montana.
Ice, Water, Land and Time: A Partial Story of Glacial Lake Missoula and the Missoula Floods

Table of Contents:

Abstract ......................................................................................................... ii
Acknowledgements ................................................................................... iv
Prologue ....................................................................................................... v
Map 1 .......................................................................................................... viii
Introduction ................................................................................................ 1
The Floods .................................................................................................... 7
The Lake ...................................................................................................... 46
As Ice ......................................................................................................... 62
Soil .............................................................................................................. 76
Designation ............................................................................................... 86
Field Trip .................................................................................................... 100
A Plea ........................................................................................................ 117
Bibliography ............................................................................................ 118
Map 2 ........................................................................................................ end

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Prologue

*It is supposed* that during the end of the last ice age, an ice dam in northern Idaho blocked the Clark Fork River in Montana creating glacial Lake Missoula, which spanned from the Montana/Idaho border nearly 200 miles east to Drummond, Montana. When the dam burst, 500 cubic miles of water rushing at speeds of up to 65 miles an hour ripped across eastern Washington in three braided channels, rejoined at Walulla Gap on the Columbia River, then tore through the Columbia River Gorge to the Pacific Ocean. This lake, North America's largest freshwater inland sea, was said to have flooded and filled between 40 and 100 times, each break releasing up to ten times the current total flow of all of Earth's rivers. These cataclysmic floods scoured the soft, fleshy earth of eastern Washington right down to the bare basalt, creating the channeled scablands and dry coulees, including the 700-foot deep Grand Coulee.

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Figure 1. Regional (A) and local (B) index maps for the lower Sanpoil River valley and surrounding areas. The map areas correspond to those in plates 1 and 2A, respectively, which show glacial-age paleogeography. Crosses in 1B show locations of stratigraphic sections.

Pleistocene Glacial-Lake Deposits of the Sanpoil River Valley, Northeastern Washington
We must begin by remembering beyond history.

—Paul Shepard, *Coming Home to the Pleistocene*

It was the biggest flood in the world for which there is geologic evidence; it was so vast a geologic event that the mind of man could only conceive of it but could not prove it until photographs could be taken from earth satellites.

—Norman Maclean, *A River Runs Through It*

There seems, indeed, to be more than a little of the humanities in this subject.

—John McPhee, *Basin and Range*
Introduction

The chaos and the incongruities, it turns out, are part of the truth.
—Jonathan Rosen, *The Talmud and the Internet*

The Clark Fork and Bitterroot rivers meander through the Missoula Valley until they finally meet in an arbitrary spot. The city of Missoula, in contrast, is an organized grid. Streets run north-south and east-west. My house lies at the corner of Fifth Street—five blocks south of the Clark Fork River above the confluence—and Cottonwood Street—10 blocks west of the base of Mount Sentinel.

On the face of it, Mount Sentinel, viewed from my backyard, is a herald into its own past. That is, you can see clues of nearly everything it's been just by observing its surface. One Sunday during my first month in the house, while I was cutting the lawn, Mount Sentinel caught on fire. Matt O'Brien and Brian Priest, two of the guys I shared the house with then, came outside to watch. We pulled up lawn chairs, opened a case of Hamms Beer and sat and watched our mountain burn. I wasn't there four weeks, and already the landscape around me was visibly changing. That day, a patch of invasive knapweed burned, and, in the coming weeks, a dark patch of native grasses grew in its place.
A changing landscape: this seemed to be a theme here in Montana. It has become a metaphor for life: the changing rural landscape, the changing economic landscape, landscape that has been changed by resource extraction. And maybe it works as a social term, but geomorphically, it is a redundant statement, like saying a flowing river. Inherent in a landscape is that it changes, regardless of the source of that change. And embedded in the physical shape and ecological make-up of Mount Sentinel, you can see change as it happened over the last several thousand years, including the marks left by glacial Lake Missoula.

Sitting again on my back porch two and a half years later, I have just finished a wonderful little book titled *The Talmud and the Internet*, in which the author, Jonathan Rosen, draws a parallel between the ancient book of Jewish wisdom and the infinitely large world of virtual information. “Vastness and an uncatagorizable nature are in part what define them both,” he writes. Rosen calls himself an amateur scholar of each, and he uses them in their own ways to eke out something whole, some way of understanding his past and present in a manner complete enough to satisfy himself and his soul.

I am a scholar of neither the Talmud nor the Internet, but I, too, am looking for something vast from which I can extract my own holistic sense of the world. For me, that is landscape, and in that I have become an amateur scholar. In this case, the landscape I am studying is that of an ancient giant lake and the vast path of its likely floods. Like arguments in the Talmud and home pages on the Internet, there are countless details and clues in the Lake Missoula basin and in the flood path, called the channeled scablands. There are so many, in fact, that the notion that one can see them all and decipher their origins is as ludicrous as
suggesting that any one scholar can understand every word in the Talmud or that any one surfer can visit every page on the Web. Part of what defines these things is that it is impossible to know them completely. Their infiniteness, like the countless large and small flood features scattered between western Montana and the coast of Oregon and Washington, provide the sea of wisdom we can draw upon to better understand our existence in the world.

In Rosen's case, he uses the wisdom gained to "embrace contradictory forces: ancient tradition and contemporary chaos, doubt and faith, the living and the dead, tragedy and hope" as he reconciles the death of his two grandmothers, who came from very different backgrounds. I think that a similar study of glacial Lake Missoula can provide a comparable medium in which to study other contradictory forces: advancing technologies and natural heritage, increased standards of living and compromised ecosystems, spiritual growth and financial success, wildness and control, as we come to terms with the ways in which we want to continue to inhabit this planet.

Another scholar and writer, Umberto Eco, often reminds us that "men (are not) able to conceive of things occurring by chance, men have a holy terror of chance, and as a consequence make up stories which explain what has happened," which is really an explanation for human mythology. Ever since we learned to communicate, we've been using language and stories to explain the world around us. We now know this as Greek mythology, classical literature, Native American stories, science fiction, or even the newest Don DeLillo novel. In this regard, the story of glacial Lake Missoula is, in part, a mythology used to explain the chance happenings and the mysteries of our landscape.
Let me explain: Modern science knows little about Lake Missoula and the channeled scablands. As far as I can tell, the vast majority of geologists who have looked into it feel certain that Lake Missoula existed and that the channeled scablands were formed by floods, many of which likely originated from the Purcell Trench area of Idaho. That's it. The rest is up for grabs. Some geologists believe that Lake Missoula existed between 40 and 100 times. Many believe that the ice dams holding back Lake Missoula failed catastrophically at the end of each period of lake formation and that the following floods were responsible for carving the channeled scablands in eastern Washington. Some geologists believe that Lake Missoula existed once and went away slowly and that the channeled scablands were formed by other flood mechanisms larger than what Lake Missoula could have produced. The permutations of ideas surrounding these two giant phenomena and their relationship are endless, and none are widely accepted.

The mythology is the marvelous popularized version of the Lake Missoula story—the 40 lakes and humongous floods. The idea was first brought forth in the mid-1970s by the geologist Richard Waitt, who said that the 40 separate layers of flood deposits he found in back channels in the scablands were the direct result of 40 Lake Missoula floods. The idea was widely accepted, except by a few geologists who were quick to note the lack of substantial evidence, and all scientific inquiry seemed to halt thereafter. I cannot begin to speculate why the inquiry machine shut down after that, but I suspect politics and egos may have been part of it. The result was that this story, which in parts is accurate and in other parts is still speculation and unproven, was gobbled up by the media and natural history buffs. This became our story, our way of explaining the
heretofore unexplainable. A network of enthusiasts between Missoula, Montana, and Portland, Oregon, is now clamoring away, organizing, meeting, and planning to have a National Ice Age Geologic Trail approved by Congress and the National Park Service to tell that story. Somehow a few seeds of perceived facts grew into a grand story that now awaits Congressional approval. Meanwhile, the business of science is out of business.

Stories and myths are an important part of our culture; they define us and bind us to the natural world. So, if we already have the myth, what is it that we are trying to protect with “official park designation”? Is the popular story—the myth—not enough, at least until we have some scientific consensus? It may not be worth waiting until we know more to protect the lake and flood features, many of which are threatened by development, but we should proceed with caution before we begin to make this story “official.”

The vastness of the glacial Lake Missoula story spans beyond the number of physical features to be found and studied; it includes things more intangible, namely disciplines, which make a complete understanding of this story impossible. One of the most difficult parts of writing this thesis was trying to present the information in a linear fashion—one page following the next—when that is not how I learned it. Instead, I constantly revisited subjects, journal articles and places. Each time I returned, I would learn something new, and that new understanding would help me understand something in another area. For example, nowhere in J Harlen Bretz’s journal articles does he discuss the physical properties of basalt, only that the floods eroded basalt. I had to go elsewhere to learn about the basalt. And then upon rereading Bretz, I better understood how
giant currents could erode large channels in basalt. But I still didn’t understand the properties of water flowing at large volumes. So I talked to Vic Baker, who is an expert on such matters.

To understand how glacial Lake Missoula, its ice dam, and the floods in the channeled scablands operated, I found myself studying glaciation, hydrology, astronomy, paleoecology, plate tectonics, volcanism, and geomorphology, all at the same time. And also to understand how glacial Lake Missoula, its ice dam, and the floods operated, I found myself studying the Pleistocene Epoch, Lake Bonneville, the formation of the Belt rock supergroups, the Columbia Basalts, and North American anthropology. All these disciplines and stories about our planet are intertwined and held together by the long thread of time connecting the present to our origins. There are no boundaries when we begin asking questions about the natural world.

The path I’ve taken to this partial understanding is like that of a fox looking for its next meal. A fox doesn’t travel a straight line from one location to its food. It wanders and meanders, looking around, sniffing, and possibly retracing its steps if it hits a dead end, before it finds what it’s looking for. In this thesis, I’ve tried to clean up that path a bit and keep it straight where I can. But revisiting, rereading, and re-immersing oneself in the knowledge and lore of such a grand story is the only way to draw from it personal knowledge and real understanding. Besides, like the fox, I enjoy a good wander around the forest.
The Floods

(Author's note: numbers in parentheses refer to chapter endnotes, letters in parentheses refer to map locations.)

1. Geomorphology

Surface oceans and rivers of liquid water exist nowhere else in the known universe except here on earth where they cover two thirds of the planet. There are polar ice caps and dry river channels on Mars and on the moons of Jupiter and Saturn, but as far as we know, these celestial bodies contain no running water and no life.

The vast majority of water on earth is tied up in a complex system of deep swirling oceans that push giant currents around and around the planet. The currents regulate the climate and distribute warmth. A tiny fraction of water on earth exists on our continents in rivers and lakes. There it flows, driven by gravity, through our various landscapes from high points to low areas. As water drains off the continents into the oceans, it is replenished by precipitation in the form of rain, sleet, snow, or hail. This repeating system is called the hydrologic cycle.

When in lakes and rivers, water moves in relation to its surroundings. It is always in contact with the soil and bedrock, flowing in and out of the ground as well as along exposed channels. As it moves and interacts with its surroundings, it exhibits certain properties from which it never deviates.

The interaction between ground water and surface water is highly complex and integral to understanding how water relates to our landscape. The characteristics of surface water alone are dazzling, but much easier to
understand because we can see them. The study of moving surface water and its
effects on the landscape is part of the discipline called geomorphology and is the
dominant force behind the effects that glacial Lake Missoula had on our
landscape.

Water, as it moves through landscape, exists in a constant state of
deposition and erosion. Depending on the size and shape of the stream and what
earthen materials make up the river channel, water picks up some of these
materials, drops others, and leaves some alone. As water moves faster and with
more force, it erodes harder surfaces and carries heavier materials or larger
loads. When it slows, it drops what it can no longer hold. But it never sits still
and it never goes anywhere empty-handed.

With an understanding of deposition and erosion as well as current
dynamics, the movement and action of flowing water in an open channel
becomes quite predictable. For instance, on all rivers the current flows fastest
near the outside bank of a curve and that bank will always be eroded and deep
and undercut. (Water directly against the outer bank slows due to friction
between the water and the land.) The river carries what it picks up on these
outside curves until it finds slower water, such as directly downstream of an
island or on the inside of a curve, and then drops its load in piles. Straight
featureless channels are generally shallower and flow at consistent speeds. When
rivers or streams dry up and lose their water, as they often do in late summer,
they leave behind these erosional and depositional markings. The flood path of
glacial Lake Missoula is no different. Erosion and deposition shaped eastern
Washington into a complex system of giant waterless flood channels with
undercut banks, deep outside curves, and piles of sediments behind islands.
By mid August every year, the Clark Fork River in western Montana flows at roughly one-tenth of what it runs during spring runoff. Channels that were floatable a few weeks earlier have run dry. In the Alberton Gorge, a ten-mile stretch of rapids and deep pools set between towering walls of Belt rock, the late summer whitewater has mellowed like an old dog. Still, the fly fishing and the rafting remain popular because the river holds more water than any river for a hundred miles. This is because the large plexus of mountains and flat valleys in western Montana creates a giant inland basin with the Clark Fork as the only outlet.

During the end of the last ice age, the Cordilleran Ice Sheet crawled south from western Canada down to the United States border like an eyelid closing over a pupil. On the end of that ice sheet, four lobes extended from the ice’s terminus: The Puget Lobe, the Okanogan Lobe, the Flathead Lobe, and the Purcell Lobe. Each lobe had a unique effect on the landscape as it shifted drainages and created lakes and other features. The Purcell Lobe (A) moved down the Purcell Trench and split and slithered around the dense mountains of northern Idaho. One of its splits headed down the Clark Fork Valley into Montana and it plugged that valley, corking off the river. The basin, once effectively blocked, began to fill.

The lowest passes in that mountain basin are to the north. But the continental terminus of the Cordilleran Ice Sheet had climbed over them, creating a wall of ice comparable in many places to the heights of the surrounding mountains. In what is now Glacier National Park, only the tips of the highest peaks emerged.
In places near the ice margin, such as in northern Idaho, ice was exotic. It migrated south from Canada—where the frozen climate turned permanent snow into ice—to a place otherwise too warm to have created it. The climate near the margins only sustained alpine glaciers and low elevation or valley ice in the colder winter months. During the summer, large volumes of the snow and ice melted and filled the streams and rivers in this maze of valleys, and eventually all the water poured into the Clark Fork, which was still plugged by a 2,000-foot ice cork in Idaho. So the pool grew.

In winter it lay still as a mirror and froze. Fine sediments settled and dropped onto the lake floor. The lake swelled in summer, fed by torrents coming from all directions. Those flows carried rocks and dust from up in the mountains and from under the ice. When the flows slowed at the lake’s inlets, they dropped their heavier loads. Lighter loads flowed farther into the water before settling.

Two- to three-thousand foot ice walls stood along a third of the lakeshore and stretched from the lake through the Yukon and into the Arctic. Hellacious icy winds ripped across the ice and blew southeast across the lake smacking waves into the eastern shoreline. In the widest part of the lake—the Missoula Valley—the waves grew the largest and left behind a series of pronounced terraced shorelines. Mountainous terrain above 4,000 feet outlined much of the rest of the shoreline and probably supported little more than tundra plant species. No cedars or pines or firs grew in the region like they do today. No cottonwood or willow or alder did either. No blue bunch or any other grasses. And no fish in the lake—the water was too milky from pulverized rock dust to support any life other than tiny algae plants in the summer. Most likely, there were no humans.
The lake region filled in summer and froze in winter for four to eight decades. In its earliest incarnations, which were also its largest, the lake held up to twenty-five hundred cubic kilometers of water, more than Lake Erie and Michigan combined. It rose 2,000 feet at the dam in Idaho and 950 feet in the Missoula Valley, and was 4,150 feet above our current sea level.

Glacial Lake Missoula was larger than any human-constructed reservoir. Three thousand feet of ice over a 20 square-mile-area—exponentially larger than any human-built dam—pressed down into the landscape with immense force, creating an ultra strong seal. Even so, no seal is stronger than mountains attached to earth, and eventually, as is the way of things, something had to give: either the water would continue to rise as it looked for an outlet, or it would create one.

The ice dam sat near the end of the Purcell Trench, the tail of which is now called Rathdrum Prairie. The southeastern end of the dam flowed up against the northern Bitterroot Mountains. Lake Pend Oreille now lies at the heart of the dam. The lake is unusually deep and its origin still eludes geologists. Today the lake sits in a depression some 500 feet below the bottom of the surrounding landscape to the southwest. To the east and northeast, the lake butts up against the Coeur D’Alene Mountains. The Pend Oreille River, which some believe to be the rest of the Clark Fork, is the lake’s only major outlet. From the lake, this river flows west then north into Canada, banks an immediate turn back west and soon meets the Columbia, which flows south into Washington. The plateau above the lake, Rathdrum Prairie, slopes west and doesn’t drain into the lake. Instead, it spills into the Spokane River. The Spokane River heads directly west from Spokane and meets the Columbia at Fort Spokane, then the whole system loops south and west towards the Cascade Mountains.
The ice dam effectively cut off the Lake Missoula basin from the rest of the northwest and the water pressure behind the dam was monumental. Eventually the dam failed. God knows exactly how that happened; the rest of us are still trying to figure it out. Some geologists believe that once the ice dam was gone, it crawled back down and re-blocked the river, creating another Lake Missoula, which would again fail. Other geologists think this idea is hogwash.

2. Trying to Figure it Out

Last fall I adopted a friend’s washing machine. We hefted it down to the basement, I bought the appropriate fittings, plugged it in, and then I had laundry facilities, minus a dryer. This morning I washed a load of sheets and, pushing my luck a bit, I decided to hang them up outside. It snowed a couple inches last night, but the sky broke around dawn and the sun warmed the morning as it arched over Mount Sentinel. My clothesline runs roughly parallel to the tops of Sentinel and Jumbo, so when I hung the wet sheets on the line, I took a good, long look at the mountains. As is apt to happen when it snows just an inch or two, snow piled on the old terraced shorelines of glacial Lake Missoula and made them stark and obvious. I once tried to count the shorelines, but each time I went back to check my count, I came up with a different number.

Snow hits the old shorelines like this well enough to see the lines at least three or four times a winter. I figure that since the end of the last ice age about 12,000 years ago, those people who ever wintered in the Missoula Valley must have marveled at them. And I wondered what the early observers thought they were.
In an article published in 1910, United States Geological Survey geologist Joseph Thomas Pardee attributed the "strikingly horizontal parallel lines" on the western side of mounts Jumbo and Sentinel to terraces cut in the slope by wind-borne waves on a gradually decreasing glacial lake. (1) Features on the landscape led him to believe that there had once been a lake covering the Clark Fork drainage from the Flathead and Missoula valleys to the Montana/Idaho border. This article became the first substantial work done on glacial Lake Missoula. But it sat in relative obscurity for several years before geologists really began studying this and other glacial lakes.

About ten years after Pardee's study and several hundred miles to the west, a surly geomorphologist named J Harlen Bretz started looking at what the farmers in eastern and central Washington called the scablands, scab-like rock exposures spread across rolling green farmland. The prevailing explanation for the formations of the scablands was glacial recessional erosion: erosion caused when glaciers shrink and scour the earth underneath as they crawl back towards their origin. But Bretz had a keen eye and an open mind. Looking at recent topographic maps, Bretz recognized a dried up river channel—the Grand Coulee (B)—that doglegged off of the Columbia. That old river channel, he said, was part of an enormous dry riverbed that ran across the Columbia Basin, which encompassed most of the eastern half of the state. Dry Falls, located about half way down the coulee, he noticed, was a spillway for a large recessional waterfall. A series of plunge pools sat just below the falls, and beyond them, a deep cataract ran for about 17 miles. A skinny island as tall as the top of the falls ran perpendicular to the spillway.
When Bretz went into the field in the early 1920s, he found mounds of rubble at the mouth of Grand Coulee. This, he noted, was a depositional fan, which formed when fast moving water suddenly slowed and dropped its load in a fan-like pattern. Depositional fans can be found at the mouths of many dried up channels, provided they haven’t eroded away. Several miles downstream, near the Frenchman Hills, Bretz found similar but much smaller coulees that ran into the Columbia. Some geologists postulated that Grand Coulee and Dry Falls were once part of an ancient riverbed for an early Columbia River, but no formal study had ever been made. When Bretz started looking at the scabland tracts farther southeast, he saw how this might not be the case. “The pattern of channels on a tract … is much like that of a braided stream,” he wrote in 1923. “But the scablands are erosional in origin, while the braided stream pattern is depositional.”

Bretz realized that there wasn’t enough deposited material in the correct spots for these channels to be old riverbeds. And he noticed that they weren’t sitting correctly on the landscape; they crossed watersheds and many of the coulee heads were all at the same altitude, which led him to believe they all had the same single water source. It became obvious to Bretz that these channels, or coulees, came from a flood, larger than any flood anyone had ever seen. The source of that flood, he believed, was somewhere near Spokane, Washington and he thereafter called it the “Spokane Flood.”

Each summer Bretz dragged his family and a cadre of graduate students from the University of Chicago into the hot desert of eastern Washington to study the scablands. They walked and dug from early morning until well after dark. In fall and winter, he’d write and present his findings. Yet every time he’d
present, his theory of a giant flood would get shot down like a beer can at fifty yards.

Bretz's story was incredible. How could one flood, even one great one, erode a seventeen-mile long canyon? What was the source of his water—what flooded? Glacial lakes, including Lake Missoula, were known to have existed, but none was known to have flooded. At that point, no one connected the floods and the glacial lake.

So when asked about the source of his water, Bretz often offered these two explanations: One was that a subglacial eruption somewhere in British Columbia melted vast quantities of continental ice, which flooded from under the ice and came out somewhere near Spokane, Washington. The other theory said that an ice sheet that extended south beyond Spokane suddenly melted and inundated the area with tremendous floods. Both explanations were dismissed immediately as ludicrous. There were no volcanic areas in British Columbia that could have erupted, and there was no evidence suggesting ice had ever come down past Spokane. Bretz needed more water, for which he had no source, than any other geologist was willing to give him.

His other problem was the current geologic pedagogy. Geology, including glacial geology, was a new science, barely 100 years old. Before then, science explained the formation of our landscape as Noah's giant flood. Mountains and hills precipitated out of the waters. That the world was in fact much older and its creation much more dynamic than the Bible says had finally been accepted. The current canon said that mountains and rivers and valleys, buttes, bays and lakes all formed over large expanses of time by the same processes that were at work today. Volcanism was the only accepted anomaly.
Relative to what we now call geologic time—that expanse of time necessary to create geologic change—Bretz said the physical world changed instantly. Humans measure time in years, generations, and lifetimes. When geologic processes intermingle with time, the concept of human time becomes insignificant. It seems impossible to juxtapose geologic processes with the human passage of time. But Bretz's story did just that: it took large-scale geologic events and slammed them into the time it takes us to eat a dozen meals.

Despite his inability to answer his opponents, Bretz continued his meticulous fieldwork and his eloquent writings about the channeled scablands. He was simply impressed by the shape of the land. Unlike other geologists, he noticed that the scablands weren't "U" shaped like glacially-carved canyons, that much of the landscape showed no signs of glacial activity, and that the region wasn't formed from a karst solution (landforms such as sinkholes and caves created by dissolved areas of limestone or gypsum). Bretz dismissed these ideas. The only way he could explain the formation of the scablands was by a big flood.

He spent more time in the field in Grand Coulee and in the Cheney-Palouse scabland tract. His adversaries continued to crush his ideas with their own outlandish notions of what happened. Bretz seemed content to ignore these misgivings, as he was busy with field research. The Depression came in the '30s and many geologists shunned confrontation and simply focused on keeping their job. Bretz's evidence became more and more convincing, but no one would jeopardize his or her career to publicly support him.

In the late '30s, J.T. Pardee went back to Lake Missoula for one final study before he retired. It is unclear whether or not he went looking for proof of what he may already have suspected or if he just wanted to know more about the lake.
Either way, at a beautiful spot in the Flathead Valley of Montana he discovered a critical piece of evidence that would vindicate Bretz and patch his most gaping hole: the giant ripple marks at Camas Prairie (C). With the help of aerial photography developed during World War II—remember Bretz had done all his research crawling around the scablands and looking at a few rudimentary maps; he’d seen nothing from above—Pardee found current ripples like you’d see on the sand at a beach or on the sandy bottom of a stream, except these were giant and in the middle of the Flathead Valley. The ripples—30 to 50 feet tall and 150 feet from crest to crest—were perfectly aligned with the way a current might rip through this landscape if it was once filled with water and then suddenly drained when the plug was pulled from somewhere down watershed in Idaho. Using aerial photography, other geologists found more current ripples in the basin, most notably near Tarkio and up by Eddy, both several miles west of Missoula on the Clark Fork River. If the ice dam really did break and the water really did scream out of here, as it appears to have, then Bretz had a source for his flood.

Bretz continued his research and wrote two more significant papers about the floods. In the first, published in 1956, Bretz introduced the idea that there may have been more than one flood. In the final paper, published 13 years later in 1969, Bretz offered more, but still limited, proof of multiple floods. Better proof was yet to come.

3. The New Guys

At the end of the 1960s, when the rest of the country was wrapped up in its first television war, a young geologist by the name of Richard Waitt spent
every chance he could walking in the lower Methow Valley (D) of northwestern Washington. He was working on a Ph.D. dissertation about glaciation in that valley when he stumbled upon some peculiar field evidence. About a mile from where the Methow River empties into the Columbia, Waitt found large chunks of angular (blocky, with unsmoothed edges, as if it had been broken off a larger block) basalt. Since the surrounding mountains were granite, Waitt didn’t expect to find basalt. It had to have come in from somewhere to the southeast. His first instinct said that glaciers receding back up the Methow Valley as the ice age waned carried in the basalt. But despite his searching, Waitt found no till (unconsolidated dirt and rock created and piled by the movement of glaciers) associated with these boulders.

Waitt's next hypothesis was that the basalt floated in on icebergs. When he examined the Columbia near the confluence with the Methow, he found evidence of a huge body of water that came down the Columbia and past the Methow. In doing this research, he read all of Bretz's papers, especially the final one published in 1969. Waitt quickly discerned that the basalt and the flood evidence he found must be part of Bretz’s story, even though Bretz had never studied the area. Waitt figured that the Lake Missoula flood came this far down the Columbia and ripped through this channel on the Columbia. Most likely icebergs carrying the basalt chunks got caught in the flood currents and washed up into the lower Methow Valley. As the water waned, the icebergs melted, leaving behind their basalt cargo.

"In a way, Bretz may have missed the biggest flood channel of them all," Waitt told me. Waitt and I met one Monday morning in September, 2001 in Vancouver, Washington, after I drove straight from Missoula the night before.
His office was on the third floor of the Cascade Volcano Observatory and it looked very much like the office of other geologists I'd met: cluttered with books and maps and papers and decorated with some of nature's most scenic examples of geology. Mount Saint Helens, the Washington Coast, and sunsets over the Rockies.

"That section of the Columbia is wider than, say, the Grand Coulee channel. And Grand Coulee was a channel made anew by the floods, whereas the Columbia is now this monstrous thing after tens of thousands of years. So that section of the Columbia has many, many times the capacity for water.

"It's hard to wrap your brain around it. After 20 years, I still get up on the high places of the Lower Columbia and look down at a valley two miles wide, a thousand feet deep, and imagine water flowing as fast as it can to get out of there. It's almost inconceivable to get so much water in one place at one time. To me it was exciting to imagine. I couldn't let the story go, especially once I realized right off the bat, you know, that Bretz, the old master himself, missed something important."

In 1975, Waitt published his first article on the flood. In it he presented evidence that the flood had come farther down the Columbia than just to the Grand Coulee area, which is what Bretz originally thought.

Around that same time, another enterprising young engineering geologist began his own work on the Missoula floods. Vic Baker revisited the classic scabland country in Grand Coulee and in the Cheney-Palouse area of far eastern Washington to determine whether or not what was known about the floods and the channeled scablands could be explained by what was known about how
large volumes of water behave in open channels. He measured the size of the channels from the high water marks left by the floods to determine the amount of water they held and how fast the water might have passed through them. He calculated that enough water flowed through the channels that, although multiple floods were possible, he only needed one monstrous one, like Bretz's original Spokane Flood, to explain the formation of the scablands. No good evidence for multiple floods existed yet, and Waitt, in his work on the Columbia near the Methow, reached the same conclusion.

In 1977, the two geologists along with a third, Don Easterbrook, led a Missoula Floods field trip to the channeled scablands for the Geological Society of America's annual meeting. For that trip they presented Bretz's original idea of one, possibly two floods.

A week following that trip, a fellow geologist and friend of Waitt's, Don Swanson, called Waitt and asked him to take a look at something peculiar he had found in the Walla Walla Valley (E) of southeastern Washington. Swanson was mapping the Columbia River basalts in the Blue Mountains. In the course of his study, he found deposits—several layers of sediments—that he reasoned could only have come in from the Columbia and they had to be flood related. When Waitt and Swanson took a closer look at those deposits, they found a layer of volcanic ash sandwiched in between two layers of flood deposits that Waitt recognized as having come from Mount St. Helens.

Waitt explained his reaction and what happened next to me like this: "If this was all one flood, which is the way we had been explaining this, and if all these layers were produced from one very catastrophic flood, how the hell can an ash layer from Mount St. Helens get in there?"
"In 1978, a year after finding the ash layer, I found other pieces of evidence in the flood beds, each one of which is independent. I found rodent burrows, thin layers of loess soils. At one of the soil horizons near Mabton [in the lower Yakima Valley (F)] I found a concentration of broken-up freshwater shells. I looked around at that horizon and found dozens of what looked like little dunes at the base of one particular bed. And I found them at two or three other horizons as well. The dunes had the same foreset bedding [position on a slope] as the rest of the horizon so it seemed to be part of the same inrush of water. Somehow this inrush of water just picked up some shells from somewhere—it couldn't have been very far because they were so concentrated. This site is right next to the Yakima River and I figured there must have been an oxbow lake. The floods must have come rushing in, scoured the lake and then dumped immediately on the bank of the valley. They couldn't have been transported any distance because otherwise they'd be so dilute you'd never see them. I dated them at 14 thousand years, which is perfect—that puts them right into the Missoula floods time frame. This was powerful evidence."

Waitt now believed that there were forty, not one or two, Missoula floods. His evidence was convincing and he immediately began to win over converts.

3. The Ice Dam

In just a few weeks, the season the color of bighorns will be on the ebb. Days will finally outweigh nights and vibrant, colorful life will reemerge. Light at the end of the long, cold tunnel. Not that I don't like winter—there is nothing more narcotic than a mountain landscape fresh after a storm.
But the problem with winter is that at a certain point in the day, it gets unbearably cold. And dark. And that’s only two hours after lunch. In northern hemisphere winters, bitter cold and long nights become my kill-joy to long stretches of life spent outside, even when I try and fool myself by engaging in such warm weather activities as camping. On one such overnight last season, we reached camp on day one by 4 pm and set up shelter in the dark. Forty-mile-an-hour winds sank the wind chill to well below zero and, in the pitch black, when I pulled my hand from my mitten to light the stove, which ended up cracking in the cold, my fingers solidified, leaving me with the dexterity of a mountain goat. In winter, sunshine and warmth from the flaming orb whipping around our planet dissipates to a dull trickle. (My sheets, by the way, never dried.)

My ache, I realize, pales in comparison to that of Elisha Kent Kane, a polar explorer with a similar fascination with ice and water but with bigger guts and a warmer coat than mine. In 1853 the American poet and naval doctor led a shipful of sailors and half-wild dogs up the eastern coast of Greenland towards the as-of-yet unvisited North Pole, looking for an open polar sea. The waters of Smith Bay between northern Greenland and Canada were solid ice chunks that softened enough during most summers to squeeze a boat through. After making their way to within 750 miles of the top of the world and hitting seas so solid they could go no farther, the men decided to make camp for the night. Only it was October, and night lasted the next six months.

Kane, his men, and his dogs remained there, literally frozen into the landscape like living fossils, for 17 months. The seas didn’t soften enough the following summer to leave and, after enduring another lightless winter, the few
surviving men had nowhere to go but to seek hope and light trekking over land and ice.

Winters at glacial Lake Missoula were, I imagine, very much like what Kane and his men saw: long, cold, dark. Glacial Lake Missoula froze. Bitter winds ripped across the ice from the north. It was brutal by human standards. Summer days during the ice age were longer and likely similar to today's Alaskan summers. Small plants bloomed and grew and glaciers released large volumes of melt water, but the ground escaped thaw most years. The climate remained ideal for sustaining ice, especially the chunk that blocked the Clark Fork River in Idaho. Something other than climate was responsible for its demise.

In an attempt to understand the mechanisms of how the ice dam failed, Richard Waitt studied other glacial lakes in Alaska and Iceland where the climate is similar to ice age Montana and where water has ponded behind glaciers. While many of these ice dams also fail and send torrents of water rushing from under the ice, none of them can compare even slightly in magnitude to the size of Lake Missoula and its ice dam. Still, Waitt believes these lakes give us a strong idea of what happened so many thousands of years ago.

Drawing an analogy to the Icelandic and Alaskan situations, Waitt envisioned that at the bottom of Lake Missoula, where water meets ice and they both meet earth, under the immense pressure of its own weight, water poked at the ice seal. Since water is denser than ice, it wants to be under it, not next to it. The water slowly wiggled its way in a thin ribbon under the ice dam, and as it
crawled, it melted and pushed the ice next to it. It flowed under the ice and soon found its way out at the lowest, flattest area, the Rathdrum Prairie.

As it traveled under the ice, the amount of flowing water increased and moved faster. The increased flow brought with it erosional power and melting warmth, which enlarged the tunnel to perhaps hundreds of feet wide. This system grew exponentially until the tunnel was wider than the ice was thick—the ice was over two thousand feet deep—and the whole roof collapsed. At that point, water tore through an open channel between ice walls.

Pardee and other geologists estimated that water ripped out of there at close to 30 million cubic meters per second. Grand Coulee Dam, Waitt says, has roughly 10 million cubic meters of concrete in it, which includes the face, the powerhouses, the huge apron, and all the footings under the lake.

"So," he told me, "after the ice dam blows out, we're talking about three Grand Coulee Dams worth of water going past in one second.

"You have to think about the ice dam failure and be familiar with the Icelandic literature to fully fathom this. Those that do have no trouble. But I find that a lot of casual readers, even some professional geologists, don't seem to get it. So now we've got this thing in popular literature that says the ice floats. It doesn't float. It becomes incipiently buoyant but it doesn't actually leave the bed. That ice dam is gigantic. The little tunnel of water is only a mile wide, maybe two, but it's not even that at first. There is no way that little ribbon of water is going to float this colossal dam. I don't have any special vision but I can't imagine it not becoming an open channel. It's too huge. So out goes the whole lake, all 2500 cubic kilometers of it."
Once all the water passed, two two-thousand-foot high straight walls stood facing each other separated by a perfect slot. Ice flows under three hundred feet of its own weight, so immediately following the drainage, the base of the ice started to flow in from both sides. Within a matter of months, maybe weeks, the channel plugged and glacial Lake Missoula started to fill again. Long before the lake hit capacity, Waitt believes, the tunnel healed itself.

Vic Baker isn't so sure about all of this. I managed to catch him on the phone for an hour while he was at his office at the University of Arizona. He had just returned from a trip to the Altai Mountains in Siberia looking at another giant glacial lake that catastrophically flooded (2) and was on his way to Japan. Baker believes that the mechanisms for the dam failure, as advocated by Waitt and others, were incapable of producing the floods needed to create the flood features seen downstream in the channeled scablands. "It's possible that Lake Missoula failed when it developed a tunnel underneath the ice dam, which is a way that some little modern glacial lakes fail, but that way did not produce the giant floods that affected eastern Washington," he said. Baker told me that more water—at least 10 times what was in Lake Missoula—was needed to flood the channeled scablands.

4. Cracking the Basalt

Every geologic process is preceded by another. And another before that. And before that ad infinitum. Until the world never was. And before that, something else happened. We don't call those processes geologic; more likely they were astronomic. But something happened nonetheless.
Even before the Missoula Floods, large, ostentatious, and not poorly understood planetary acts of nature shaped the landscape inside the Columbia Basin. Volcanoes erupted and created the Cascade Mountains, plate tectonics changed the coastlines and raised other mountain ranges, and erosion helped carve the Columbia River. By seventeen million years ago, the Earth had been around for four billion years and was fairly mature. The continents had traveled a good bit since the times of Pangea when all land was one mass, and they finally sat in their present configuration and shape. The Montana and Idaho border was no longer the western coastline of North America and the planet had recovered from its second major period of extinction, which killed upward of 65 percent of the world’s species, including the dinosaurs, about 48 million years previously (65 million years ago). Only the mildest geologic processes continued. But then the normal patterns of change shifted radically.

Southern Oregon, northern Nevada, and western Utah uplifted and pulled apart, which created a region of perfect north-south trending faults called the Basin and Range Mountains. Around the same time, the Cascade Mountains of Oregon and Washington stopped erupting and the climate in the Northwest became wetter and hotter.

Central to our story is that somewhere around that time liquid basalt flowed from the Oregon/Washington/Idaho corner and covered the inland Pacific Northwest like brownie mix spread along a pan.

The theories go that possibly an asteroid crashed into North America or, more likely, the plates underneath the surface of the Pacific Northwest split and left a giant lava hot spot somewhere near the border of the three states. Cracks from the crunching plates created a series of fissures in the earth’s crust north of
the lava hot spot. Lava oozed out of these fissures, many of which were miles long. Flows viscous enough to blanket the landscape in fairly flat 100-foot thick sheets spread for hundreds of miles across the plateau.

The first eruption spilled across a landscape of rolling hills, probably in a matter of hours, before slowly cooling into a hard, shiny black rock, like opal. The surface crusted over while the inside took up to several decades to solidify. Often, one flow would cover a previous flow before the landscape had a chance to become hospitable to either plants or animals. Other times, these flows remained for thousands of years before the next eruption covered them.

When the basalt cooled and solidified, it shrunk into vertical sections separated by cracks. And as the solid lava cooled further, it shrunk again, this time into well-organized tubular formations or columns. The basalt cooled from the top down and the bottom up, which created two distinct layers of these tubular columns per flow. Miners have said that basalt is much easier to blast than it is to drill; the rock is hard, but because of these fissures and cracks, it is structurally unsound, and therefore blows apart easily. This is the reason why the area eroded so dramatically under the tremendous force of the flood water and why the canyons left would make such lousy dams.

In between the flows, in the wet and hot climate, a combination of weathering, erosion, and deposition by moving water created ecosystems by depositing soil and seeds and cutting streams. Plants and trees grew, animals migrated, and new rivers flowed. The lava would return and cover the plants and trees and animals, freezing them into the landscape like a wooly mammoth in ice.
The flows grew to cover nearly 200 thousand square miles and may be up to 10 thousand feet thick. Although the Columbia River predates even the basalt floods, the flows managed to crawl under the river slowly enough so that the river could cut through the basalt. Basalt covers every part of the Columbia Plateau except for a small area of exposed granite at the far reaches of the flow near Coulee City. Since the flows, the basin continues to sink as the surrounding mountains continue to rise. Active faults have also twisted and folded many of the basalt layers. Layers once on top are now on the bottom and the elevation of the whole basin varies between below sea level in the Pasco basin to over one and a half miles above sea level in the Wallowa Mountains in northern Oregon. What lies below all that basalt remains a mystery since we can't see or get to it.

A thick layer of silty loess now blankets the basalts in expanses of rolling green farmland. In places, this soil is upwards of 200 feet thick. This rich and thick soil is comprised mostly of broken down and weathered pieces of granite, granodiorite, and in small percentages, basalt. Volcanic ash laid in thin layers from consistent Cascade eruptions makes this soil extremely fertile. When the floods came through several thousand years ago, they cleared large swaths of the soil and then cut long, waterless giant stream channels into the basalt.

Vic Baker began his work in the channeled scablands by looking for high water marks, or the upper limits of the floods on the landscape. These included divide crossings, placement of erratics—rocks or boulders that were moved by floods or floated on icebergs from their origin, like the basalt Waitt found in the Methow—and accumulations of flood-transported sediments up on hills. He used these as minimum high water marks in a process called "Step-Backwater
Modeling” to estimate flow volumes and speeds in various flood channels in the scablands. Baker measured the areas of several equidistant cross-sections of each channel and, moving upstream, plotted them against the change in gradient of that channel. The model calculated energy loss of the flowing water associated with the texture and change in size and shape of the channel. He did what many hydrologists do on modern rivers except that he did it for a humongous channel. Flows at that volume with that much energy, as he explained to me, behave differently than water in even the largest rivers today.

“At very high flows,” he started, “unusual phenomena happen as a function of the physics and the properties of the water. For example, if you could make a relatively thin layer of water flow fast enough, the pressure in the water is lowered so much that vapor bubbles form. This is called cavitation. It’s analogous to heating the water but in the case of the flowing water, the energy comes from the kinetic energy of the flow. Cavitation produces odd erosional effects in fast-flowing water.”

The kinetic energy, he explained, comes from the depth of the water and the gradient over which the water moves. When it flows, it becomes kinetic energy, which is the mass of water times the velocity squared \( e=mv^2 \). As the kinetic energy increases, the water flows faster and faster, creating turbulence. And that turbulence develops structure, like a tornado in wind. But this structure is defined as organized chaos, something even Baker admits to not fully understanding.

The effects of turbulence depend upon how the water interacts with its boundary, in our case basalt. The turbulence of large volumes of water violently
flooding across basalt creates very specific kinds of features like potholes, coulees, grooves, and other such characteristics of scabland erosion.

"Let’s say every square foot of a streambed or river, be it a mountain brook or the Amazon, has about the same pressure acting on it. Even when the channel floods, the rate of energy expenditure over any square foot of bed doesn’t increase by more than about a factor of two or three. This energy expenditure per unit area is called power. Water has a lot of power from its potential, so if you let water behind a dam flow down a steep slope into turbines, you get power that produces electricity. A river always expends power as it flows, but it does so slowly and uniformly over a long distance. A river like the Amazon has huge power, but it’s spent over a tremendous area. When the Mississippi goes into flood, the power level goes up a factor of a few times. The power level of a catastrophic flood like the Missoula flood goes up a hundred thousand times per unit area.

"The kinds of floods that people have seen, as terrifying as they are, don’t even come close to the energy expenditures of the Missoula floods. And that’s one of the reasons for the original controversy; Bretz said that flows from the glacial margins produced these features and the geologists generally thought: ‘Well, I’ve seen streams from glaciers and they’re not all that energetic. They move some cobbles but they don’t move boulders.’ They couldn’t conceive how Bretz could be right. The flows Bretz talked about were these extremely highly energetic kinds of flows."

5. Glacial Lake Columbia and Grand Coulee
There remains a divide between the Waitt school of deposition and the Baker school of erosion. Waitt gives us a plausible picture of the dam failure and the floods but assumes too much in his connection between the Lake Missoula Floods and the creation of the channeled scablands. Baker plays the devil’s advocate by questioning Waitt’s reasoning, but otherwise offers no real explanations. The idea that some gigantic floods did come down Rathdrum Prairie (G) and across the Spokane Valley still seems to satisfy everybody, though. For the sake of moving the story along, let’s assume Waitt’s dam failure mechanism as a way to get glacial Lake Missoula or other glacially related floodwaters into the Columbia Basin.

As the water burst through the ice dam, it scrambled up the Lake Pend Oreille depression onto Rathdrum Prairie. Thicker ice and mountains cut off all other routes for the water, including the former course of the Clark Fork to the east and north of the Selkirk Mountains. The floodwater, redirected by this temporary change in topography, cut through the boundaries of its own watershed and crashed into another. As the rush of water screamed across the prairie, it compressed the air in front of it and created a rolling wind. That wind picked up the upper layers of loess soils and spun them into a blinding fog the texture of sandpaper. The land rumbled and reverberated. You wouldn’t have seen it coming, but would have heard the warning. Finally, several hundred feet of water extending from one end of the horizon to the other crashed along at 60- to 70-miles an hour.

As the water spread out across Rathdrum Prairie, it lost some of its initial momentum, and following this sudden drop in kinetic energy, it deposited tons and tons of gravel. This bed of gravel rolled out across the prairie and into the
upper reaches of the Spokane Valley. Subsequent floods brought more gravel. These deposits blocked mountain streams that flowed from the Selkirk Range and created a series of lakes still there today: Spirit Lake, Twin Lakes, Hauser Lake and possibly Hayden Lake (H). These immense gravel deposits and flood currents may have also shifted the outlet of Lake Coeur D'Alene by blocking an old outlet and causing the lake to create a new one, now the Spokane River. The gravel that rolled all the way to Spokane eventually created the Spokane aquifer. The city itself sits on approximately 150 meters of Lake Missoula and other Pleistocene-age flood deposits.

The Rathdrum Prairie slopes south from Lake Pend Oreille between the Selkirk and northern Bitterroot Mountains until it runs into the Spokane Valley (I). The northern shore of Lake Coeur D'Alene and its outlet the Spokane River mark the southern border of the Rathdrum Prairie. Once the flood entered the Spokane valley near Spokane, its course spread out across the Columbia Plateau in patterns dependent on downstream topography.

The natural non-flood level course of water from here is down the Spokane River to the Columbia, through the Columbia and its gorge and eventually out to the Pacific Ocean. Today the Spokane River meanders through town in a shallow river bottom. Once it reaches the Camp Seven Mile area and Coulee and Deep Creeks northwest of town, the river drops into an ever-deepening gorge capable of holding several times more water than it carries now. A lowland prairie continues southwest of town past the airport and Air Force base.

Floodwater that poured out of Rathdrum Prairie flooded the Spokane River and spilled into the flatlands by the airports. The Spokane River took
several times what it holds today, which was still only a fraction of the floods. Water tore through the canyon and scoured the walls of loose rock, alluvial soils and every strand of riparian vegetation that grew there. Fish unfortunate enough to be in the river were washed out to sea like dust in a storm drain. The water that didn’t fit in the Spokane Gorge sloshed violently out of the river and mixed with the rest of the floods moving south and west. Here it left gravel bars fifty feet high behind eddy-like hills and it plugged mountain streams, creating more lakes like those in the Rathdrum Prairie.

Lake Missoula floods varied greatly depending on the behavior of the Cordilleran Ice Sheet and its many lobes. The advance and retreat of the Purcell Lobe did not necessarily coincide with the advance and retreat of the Okanogan Lobe farther west, although the paths of the floods created interplay between the two. The Okanogan was much larger and eventually extended much farther south than the Purcell Lobe. But it didn’t affect the watersheds on the Northwest until after the first several ice dams burst.

Waitt now believes that the first 15 to 20 floods, when the Purcell Lobe was thickest and the floods were the largest, came all the way down the Columbia past the Methow. That scenario changed during later floods. In north central Washington, the Okanogan Lobe (J) crawled across the North Cascades Mountains and rode into the Methow and Okanogan Valleys. This colossal ice thumb pinched off the Columbia, probably first near the towns of Brewster and Bridgeport, forcing the Columbia to find an alternate route. The water may have pooled behind this ice dam until it was high enough to cut a course along the ice wall and on the terrain above the river. Moses Coulee, one of the largest coulees
in the scabland system, is in the right spot for it to have been an initial temporary river channel and flood route for floodwater that rushed down the Columbia.

The Okanogan Lobe pushed farther on, eventually cutting off the Columbia near present-day Grand Coulee City, and covered the river between Grand Coulee City and the town of Chelan. The Okanogan Lobe sat in this position for several centuries, well beyond the life of glacial Lake Missoula, and created glacial Lake Columbia (K). The character of this glacial lake, also a giant compared to any modern reservoirs, differed completely from its cousin Lake Missoula.

At Grand Coulee City, the Columbia River flows through a wide channel between the Northern Cascade Mountains and valleys—which run perpendicular to the river—and the Columbia Plateau. When the Okanogan Lobe rolled south over the Columbia River and extended into the upper plateau, it effectively shut off the river's flow. The huge river basin filled with water, somewhat like it does today behind Grand Coulee Dam, but to a level 1,000 feet above the present day reservoir, Lake Roosevelt. The water backed up and filled the feeder valleys to the north that weren't under ice, and filled the gulches to the south. Water from glacial Lake Columbia lapped against ice moving down the Columbia Valley at Fort Spokane where the Columbia turns from flowing south to west and is met from the east by the Spokane River (L). In its prime, Lake Columbia pooled up the Spokane River nearly to the town itself.

Lake Columbia changed the character of the Missoula floods. The ice dam at Lake Pend Oreille still burst, flood water still shot up the west side of that lake, and the floods still rolled out across the Rathdrum Prairie. But once the floods
reached Spokane, they encountered a large sedentary body of water. When the Missoula floodwater hit glacial Lake Columbia, the effect was somewhat like trying to pour a swimming pool into a cow trough.

Water sloshed everywhere. It spilled over the top of Lake Columbia all the way along the lake. Because of its momentum, most of the water rolled right over the lake and continued southwest, shredding layers of loess before picking away at the basalt. As more and more floods came through, more soil moved and the cracks in the basalt grew deeper, longer and wider. Because the Columbia Basin lies in the rain shadow of the Cascades, before the floods it was likely arid with few streams that curved around the rolling hills. To the east and closer to the Idaho border, the landscape is a bit wetter and greener, but still rolling. When the floods came through, they disregarded these meandering drainages and cut as direct a route as they could through topsoil and basalt to the Snake and Columbia Rivers.

The water that didn't spill out near Spokane rolled down Lake Columbia towards the western end at the ice dam. By now, at the Lake Columbia dam, nature and water and landscape had worked out an agreement for equalizing this fluvial system. The present-day city of Grand Coulee, at the northern end of the eponymous coulee, is the approximate outer limit of the basalt ocean. Here, the Columbia flows through a granite canyon and is surrounded to the north by hundreds of granite peaks, called the Okanogan Highlands. On the southern side of the river, the granite rises about 700 feet above the river. A thin layer of basalt coats the top of the granite like chocolate icing. When the Okanogan Lobe settled here and created the lake, the impounded water needed an outlet. But because
granite is so much harder to erode than basalt, the water didn’t find one except at the icing.

Missoula floodwaters that filled Lake Columbia crunched a path in the basalt above the granite and created an overflow outlet. The level of the granite drops off just a few miles south of the river and the landscape is once again replaced with basalt. Escaped floodwaters eroded the basalt into a 700-foot deep and one-to-six mile wide canyon called the Grand Coulee. At the midpoint of the Grand Coulee, the coulee walls slip back into the ground and the whole area is flat for a half-mile or so. And then at Dry Falls, the coulee floor drops 400 feet into what’s called a recessional gorge.

This is classic and dramatic scabland topography. The spillway is about 3.5 miles wide with gouged-out lips and three deep plunge pools at the bottom. It is the terminus of a recessional waterfall that started some 17 miles south. Each flood released 300 feet of water that scoured the walls and floors and chopped away at the falls to create the lower coulee. The coulee ends at Soap Lake, which was the southern end of the coulee and probably the fall’s first plunge pool. Floodwater that ripped through the coulee slowed in this open area and dropped tons of material picked from the coulee. Still looking for a way back to the sea, the water continued south and made more of a topographical mess plucking out potholes and building sand bars in the Moses Lake area (M).

The floods carved one more monster coulee—Esquatzel Coulee—before entering the Columbia near the tri-cities area (Kennewick, Pasco, and Richland), which is also close to the confluences of both the Yakima and Snake Rivers (N). Between floods, glacial Lake Columbia likely used Grand Coulee as an overflow outlet and as a continuous but temporary alternate route for the Columbia River.
In the mid 1930s, while Bretz remained an ostracized loner geologist out to prove his theory to anyone who would listen, which was almost no one, a brilliant crew of Bureau of Reclamation engineers developed a unique and original plan to dam the Columbia at Grand Coulee (O). They wanted to build the world’s largest hydroelectric dam and then use power from that dam to pump water up into Grand Coulee to another reservoir that would operate to irrigate central Washington.

6. Slackwater deposits

My high school astronomy teacher impressed upon us the importance of observation in science. Get outside at night as often as you can, he instructed us, and look up. Take note of what you see. Be meticulous and write it down. Sometime around early spring of that year, Mars entered the sky. I’d crawl out of my window onto the roof late at night with a notebook, a pair of binoculars, and a pack of cigarettes, and I’d lie back on the tar shingles and smoke and stare. I drew rudimentary sky maps, noting as best I could the change in Mars’ location at the same time every couple of nights. The planet had a definite place in the moving sky, shifting among the stars with the slow passage of time. It remained a mere dot, though, even through my binoculars. To my conception, it didn’t yet have character. But as I read and studied more, got my eyes behind a couple of high-powered telescopes, and took a few college classes, the character of the red planet solidified. It is hard and cold and smaller than Earth, but with much bigger features. Lacking an atmosphere along with the absence of flowing water for close to four billion years has kept erosion, as we know it here on our planet, to a barely-detectable minimum.
In places, the complexion of our nearest neighbor looks similar to the channeled scablands of eastern Washington. Deep braided channels impress over vast expanses of arid barren landscape. Floods, we know, formed many of those channels. Faulting appears to have caused others, but even those show signs of water-related erosion: tear-dropped shaped islands and thick beds of layered sediments. Some planetary geologists believe that much of this water came from underground sources, such as giant aquifers. In channels caused by faulting, water likely seeped into the canyons and flowed at moderate rates.

In one such network of channels called the Valles Marineris, water that seeped out of the planet may have pooled in two of the chasma (coulees). Erosional features found downstream, like those carved into the basalt in Washington, suggest that the lakes in the Candor and Ophir chasmas catastrophically flooded when the divide separating the two chasmas failed. The relatively quick formation, lack of tributaries, and the shape of many of the landforms in these and other chasmas make this landscape look remarkably similar to the channeled scablands.

In another channeled area of Mars, where channels emerge from areas of surface chaos, groundwater seems to have erupted from cracks in the bedrock. Groundwater trapped under thick layers of permafrost could have become so pressurized that it blew a hole in the ground. The surface would have collapsed under the eruption and large amounts of water carrying the broken ground would rip through the terrain like it did in Washington and leave behind bare channels and downstream deposits.

It has been estimated that between 10 and 100 times the amount of water from the largest lake Missoula Flood might have inundated the landscape here.
But where did this water come from and, more importantly, where did it go? Scientists don’t have a good answer. This question brings up an interesting parallel with Bretz and the channeled scablands. Seventy years ago, geologists wouldn’t even consider Bretz’s flood evidence because he didn’t have a water source. Today, the scientific method and process has morphed to allow research and peer review even when not all the parts of a puzzle are known.

Most of what is known about the Martian scablands came from aerial pictures from the Mariner 9 and Voyager spacecrafts that circled the planet. In the mid-’70s, after the Mariner 9 spacecraft sent back the first clear and detailed images of Mars, Vic Baker switched his focus from eastern Washington to the mysterious channels on Mars. He worked with NASA scientists, wrote several papers and published a book, *the Channels of Mars*, which further developed the comparison between the channeled scablands and the Martian channels.

Through the ‘80s, Baker’s focus shifted again when geologists started to realize that catastrophic floods were not so unique as they once thought. Baker began looking at flood landforms in the Midwestern U.S. and in the Altai Mountains in Russia.

“Originally,” Baker told me, “Bretz said that the channeled scablands were unique and that we shouldn’t worry about the fact that they were different than normal river processes. I think that what we’ve found, though, is that the processes associated with the breakup of the large ice sheets at the end of the last ice age produced a lot of unusual water runoff features, including catastrophic flood-related features. And these are actually more common in areas that experienced the last glaciation than we once thought.”
Throughout his career, whether studying Russia, Mars, or the channeled scablands, Baker focused on erosion. Richard Waitt, on the other hand, studied deposition. The different approaches these two men took led them to very different interpretations. "The position that the 'scores of floods' hypothesis may complete Bretz's imaginative theory," Baker wrote in a 1992 paper referring to an idea Waitt had, "may prematurely divert attention from some of the outstanding problems that remain in interpreting the spectacular features of the Channeled Scablands."

Baker's biggest problem lies with other geologists' interpretations of slackwater deposits—layers, or varves, of material that settled out of pooled water. Waitt primarily studied these layers, such as the ones in the Yakima Valley that led him to believe there were at least 40 Missoula floods. But Baker says that those deposits don't need catastrophic floods to place them; they can be deposited by shallow, low energy flows. He doesn't see a proven and direct connection between the 40 or more floods that left the deposits that Waitt found in the Yakima, or the other similar flood deposits found elsewhere, and the floods that created the scablands. And he has found even less of a connection between those sediments and any floods that may have come out of glacial Lake Missoula. Somehow, though, Waitt's theories triumphed.

Missoula floodwaters took one of three routes across the Columbia Basin before joining again at a place called Wallula Gap (P) on the Columbia River. Wallula Gap is a topographical constriction just a few miles downstream of where the Yakima and the Snake Rivers join the Columbia. After the floodwaters made their way across the basin, they hit this narrow, short gorge and pooled.
The slack water stretched nearly half way back over the basin that it just crossed. Unable to pass through Wallula Gap all at once, the water formed what is called a hydraulic dam, which is one of nature’s most amazing hydrologic formations.

When too much moving water doesn’t have enough space to pass, even if it isn’t completely blocked, it gets frustrated. Wallula Gap is 1.5 km wide and 250 meters deep, not nearly large enough to handle the waters of glacial Lake Missoula. The initial wave of water to hit the gap was likely higher than the top and it spilled.

The hydraulic dam set up below the top, at the constriction. Because the rock here is hard and sturdy, not cracked like basalt, the gorge didn’t erode. As slow water eked its way through the gap, a current of faster water flowed on top of that slower water. On the other side of that constriction, the faster current fell from the hydraulic dam, like water at any spillway, and created a pocket of recirculating water. Whitewater boaters call these recirculating currents “holes.”

The pool of water behind the gap grew to encompass Pasco (Q) and Quincy (R) Basins and crawled several miles up the Yakima and Snake Valleys. These temporary lakes probably existed for two or three days before they drained. The pooled water dropped its loads, which was often several tens of feet of silt and rock. Much of what was dropped in Pasco and Quincy Basins didn’t stay. It washed away as the basins drained into the Columbia to the west—which left more spectacular coulees, like Frenchman Coulee—or it flushed down in subsequent floods, or between floods, the prevailing westerly winds blew the loess east. Many, but not all, of the sediment left in the Snake Valley washed away in the big Lake Bonneville Flood (3), which happened around the same time as the Lake Missoula floods. Backwater sedimentation in the Yakima Valley,
though, was protected; the surrounding mountains blocked the westerly winds and the narrow mouth of the Yakima Valley regulated the speed at which water could flow in and out of there. This valley now boasts some of the finest agricultural land in Washington because of the 100-foot thick layer of flood-deposited topsoil. It is also where Waitt found his evidence of forty floods.

In the late '70s, another geologist named Brian Atwater studied varves in tributary valleys of glacial Lake Columbia. Looking at the sedimentary layers in the Sandpoil Valley (S), Atwater counted 89 Missoula flood layers. He determined the origin of each of the hundreds of layers he found and could tell which layers contained sediments from floods and which layers were strictly lake-deposited sediments. Combining the earliest floods, which swept all the way down the Columbia before Lake Columbia formed, along with Waitt's estimates based on the sedimentary evidence in the Yakima, and Atwater's count in the Sandpoil Valley, Waitt now believes there were roughly 100 Missoula Floods.

6. Debunking slack water deposits as evidence.

"You can produce the rythmites (varves) of Burlingame Canyon on the Snake," Baker explained to me, "and the sedimentary structures in those rythmites in a flume 2 feet deep—that's the level of energy needed to emplace those deposits. The reason they're interpreted as being associated with big floods is the argument that ponded water from Walulla Gap impounded the water back up these valleys and created the flows that left those deposits. That's a theoretical argument; there are other ways to get deposits like those to go upstream in a valley. Rivers do it today in flood plains when they spill over levees."
"The argument is made that the water flooded all the way up to the highest watermark in Walulla Gap. Well, the deposits are much lower in elevation than the high water mark. So they could have been emplaced by much smaller flows. The high water marks only indicate the big discharges, and the sediment deposits at the high water marks don't have multiple flood signatures on them. The only indication of 80 or 100 floods is in these low energy deposits down at low elevations."

Baker links what he calls confusion about what constitutes a big flood with our lack of proof about how the ice dam failed. Sedimentary records are notoriously incomplete. These slack water deposits may tell us something about some of the floods and ice dam failures, he told me, but not necessarily about the big floods, the ones responsible for carving the channeled scablands. "I don't think," he said "that all of these deposits necessarily tell us about the same floods that did the eroding. I haven't seen a time correlation between the deposits and the erosion."

Baker points out that many deposits now sit in places eroded by catastrophic floods, which shows that no catastrophic floods occurred during the time in which those deposits were emplaced. Catastrophic floods eroded Steamboat Rock in the upper Grand Coulee, yet today you find slack water deposits immediately downstream of that giant feature. Another example, Baker explained to me, is the entrance to Wallula Gap. Catastrophic floods scoured this area but there is a sequence of 20 or so slack water deposits in a railroad cut just upstream.
Once the floodwaters passed through Wallula Gap, they had just the length of the Columbia River Gorge (T) left to go. Water cruised the upper gorge and its tributary gorges until the next constriction near the confluence of the Deschutes River. Water backed up into both the Deschutes and John Day Valleys. It continued on again until the Portland Basin where it spread and slowed and again dropped its load. Another constriction northwest of Portland caused the water to pile up to 300 feet above the basin floor and back up into the Willamette Valley as far as Eugene, Oregon. Like the Yakima, extremely fertile lake sediments now blanket this valley.

The floodwaters, still full of rocks and ice and silt and whatever else they managed to hold onto through their thousand-mile course from Montana, hit the ocean a couple hundred miles beyond the current-day coastline. Since so much of the planet’s water was tied up in northern hemisphere ice, the sea level dropped by over 300 feet and the coastline now sat much farther out to sea. Still full of kinetic energy, the floodwaters shot from the Columbia and tore along the ocean floor with such force—these gigantic ocean currents are called turbidity currents—that they cut one last canyon; this one followed a previously cut channel that extended for almost four hundred miles to off the coast of Central California. But that’s part of an entirely different story....

Chapter Footnotes

1. Pardee originally attributed the multitude of shorelines to a gradually decreasing lake. Today some geologists believe that each of the lines represents a separate lake. As the ice age waned, the Purcell lobe shrank, creating lower dams
and lower lakes. The highest lines represent the oldest shorelines. But this isn’t necessarily correct. If there was just one filling of Lake Missoula, then the lines are as Pardee hypothesized: the result of one gradually decreasing lake.

2. Near the end of the last glaciation, a glacier advanced out of a valley perpendicular to the Chuija Valley in Siberia and blocked its drainage, which at the time was huge. The ice dam broke and the meltwater floods raged out of the mountains like they did in Montana. That lake was 3000 feet deep, but held only 200 cubic miles of water. Even so, the resulting flood may have been even more powerful than the GLM floods. Water probably poured out of there in a 1500-foot wall at close to 90 miles an hour.

3. Lake Bonneville is the giant ancestor to the Great Salt Lake in Utah. The wet climate during the last ice age filled the southern desert basins, including the Salt Lake City Basin. The lake spilled into Idaho and Nevada, eroding its outlets. One such outlet spilled over Red Rock Pass in southern Idaho and into the Snake River in southern Idaho. At one point, approximately 300 feet of soft rock holding back all that water in Idaho broke, and Lake Bonneville flooded. The flood probably released more water than any from Lake Missoula, but it did so over a few weeks, thus drastically reducing the discharge and power behind the flood.
The Lake

Before I made my way to Montana, I lived in the Teton Mountains of Wyoming. I spent summers at a marina on Jackson Lake sending tourists to my second and third favorite spots, and I worked winters at the local newspaper doing everything from reporting to layout to delivery. Each summer I would make my way up Avalanche Canyon. An unmarked, unmaintained trail disappears and reappears at different spots along the drainage until it rises above tree line. From there I'd have to navigate my way by reading the landscape. As I climbed up to the first lake, Lake Taminah, I'd have to scramble on all fours up boulders and eventually onto a ledge. When I first pulled my head over the edge of the ledge, I was eye level with a cirque lake in a scree-filled bowl. I'd climb up along the north side of the lake and find a good spot for lunch. After lunch, I'd continue along, careful not to twist an ankle in the scree.

At the far end of the lake, I headed straight up and over the little lip at the top of the cirque. And then I would see it: a perfectly turquoise lake—Snowdrift Lake—still ice-covered well into July, and behind that, a 2000-foot wall that runs all along the back of the canyon like the backdrop on a stage. The wall, the base of which is at ten thousand feet above the current-day Pacific Ocean, is an ancient sea wall; it contains thousands of marine fossils, mostly snail and clam
shells. It was once much closer to the valley floor, but when the Tetons rose about 12 million years ago, up, too, went the wall.

Hard as it is to fathom, most areas in the middle part of our continent, like this sea wall that now hangs in the sky, were, at some point in the long trail of time, under water; most of the Midwest was under an ocean as was much of the Rocky Mountains before the Rockies were even mountains. Large bodies of water are not ubiquitous to our landscapes, but in recent geologic time, a body of water the size of Lake Missoula is. Only Lake Bonneville, which is the giant ancestor of the Great Salt Lake in Utah, can compare in magnitude.

Lake Missoula left details of its past in sedimentary records, ripple marks and other flood scars. Debris from the mountain glaciers and the Cordilleran Ice Sheet were carried into the lake by flowing water and deposited on the lake floor in layers. Because of its proximity to the Cordilleran Ice Sheet, sediments are thickest and hold the most clues in the Flathead Valley. In contrast, deposits in the Bitterroot Valley are thin or non-existent; that valley had no direct contact with continental ice. Rapid draining of the lake left ripple marks, like those in Camas Prairie, and flood scars, such as large boulders that were ripped off of canyon walls under the tremendous draining lake currents.

The sedimentary records, like the fossils in the sedimentary rock at the top of Avalanche Canyon, provide the best details—better than flood scars and ripple marks—about how Lake Missoula functioned, and those details tell a much different story than what was found and interpreted in the channeled scablands. Even so, geologists can only decode those sedimentary records, not read them as truth.
Our understanding of the paleoecology of the lake region—the interaction between living organisms and the physical environments—comes from other sources. Lake sediments do provide some clues, but anthropological and biological records and fossils in the surrounding hills offer the best clues as to what else was happening while Lake Missoula was doing its thing.

Paleoecology: life at the lake

Geologist J.T. Pardee first calculated that, at its highest level, Lake Missoula's surface covered 2,900 square miles at about 4,200 feet above sea level. The lake contained 500 cubic miles of water, was 2 thousand feet deep at the dam, and 950 feet deep in the Flathead Valley. It reached south beyond Darby, east past Garrison and Ovando, north to Polson or maybe Ronan (depending on how far south the ice came) and north up the Thompson River drainage, maybe as far as Pleasant Valley.

When the lake drained, it flowed along a strait, narrow and deep section of the Clark Fork Valley from Thompson Falls (U) to the ice dam in Idaho. Pardee was the first to calculate the lake's discharge as 9.46 cubic miles per hour, ten times what the rest of all of the rivers in the world combined discharge. The speed and size of this discharge created a tremendous vacuum-like pull on the rest of the water in the lake. Not only did water shoot horizontally out of the lake basin, tearing out soil and sediments, but it fell vertically over every lip and ridge and hole in the lake basin, pounding like a giant jackhammer into the newly exposed bedrock.

The climate was ten degrees Celsius colder than it is now and those few degrees caused the ground around the lake to freeze in winter. None of the
vegetation that grows here now would have survived beyond one season.

Mountain glaciers were significantly larger than what we see in Montana today and extended farther down the slopes. Frozen winds ripped off the ice and the lake. Ice didn’t melt in the higher elevations, and even summers above freezing wouldn’t have been warm enough long enough to melt all the valley ice.

Glaciers grinding along the granite and Belt rock canyon and valley walls pulverized the rock into a dust the consistency of graphite powder. Mountain and ice drainages washed this rock flour into the lake, creating a chalky, gray, cloudy, ice and rock soup, which allowed nothing but diatoms, a diverse group of algae, to survive there. The dust blocked sunlight and remained in suspension for long periods of time, but it brought with it dissolved mineral nutrients, which made for fertile growing seasons and large algae blooms in the shallower parts of the lake in summer.

Algae can live in nearly every condition on earth, including this cloudy lake that froze for half the year and possibly disappeared every century or so. Diatoms are the best-preserved algae fossil specimen from the last ice age because they have cell walls made of silica, which resist decomposition. But their growth is based more on water quality than on climate conditions, so it’s unknown how well they survived on glacial Lake Missoula. These and other algae died, sank and mixed with clay that also sank in winter to produce the dark bands in the lake varves we see today.

The ecosystem around Lake Missoula was most likely similar to a Beringian Steppe-Tundra. This cold prairie ecosystem, a mixture of arctic tundra and Asian steppe (vast, arid grassy plain) vegetation, wrapped around the northern half of the globe in areas adjacent to ice. This type of vegetation
supports more animals than would be found on simple arctic tundra, including smaller species like prairie dogs, gophers, and sage voles, which only inhabit grasslands. But no fossils, bones, pollen, wood chards, or clues of any type have been found from that time period to tell us what, if anything, lived there. This type of ecosystem might have sustained life, but because of its proximity to ice and its uninhabitable water, it’s likely that nothing survived for long.

Missoula, hub of valleys

The Missoula Valley (V) was the largest section of the lake. The valley is like the palm of a hand with the other valleys extending off it like fingers. It tends east to west and sits between the Flathead (W) and Bitterroot (X) Valleys with the Ninemile Valley (Y) at its extreme western end. Mount Sentinel and Mount Jumbo (Z) make up the eastern walls and, because of the shorelines that Lake Missoula left behind, these mountains have become rich cultural resources.

The only glaciers in the area of the Missoula palm were in the Jocko Mountains (AA), also called the Rattlesnake Mountains, just north of town. The Ninemile Mountains also produced a few glaciers, but these were small and short lived.

Some of the only remaining valley-floor sediments are found by the airport. Most of the lake deposits were swept away when the lake(s) drained, but because the valley west of town is wide and low, some of the sediments remain. There is a set of Lake Missoula sediments at the mouth of the Ninemile Valley just above the Clark Fork River and 200 yards from the Ninemile Steak House. The sediments, exposed in a road cut, are stacked in perfectly horizontal layers some as thin as a sheet of paper and others as thick as a beauty magazine. These

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sediments are pink and soft like baby skin. They were likely carried by the river
and deposited where the river now slows into a large horseshoe-shaped bend.

North of town, water impounded up Grant Creek (BB) soaked into the
hillsides and turned the soil into muck, releasing large amounts of gravel into the
lake. When Lake Missoula drained, water shot out of this canyon into the main
lake body where it immediately slowed and dropped the gravel. Lake currents
fanned the gravel along the valley floor. This and other similarly deposited
gravels, which were eventually covered with lake and flood deposits, created a
sealed aquifer from which we in Missoula now get our drinking water.

The pastoral Bitterroot Valley

The Bitterroot Valley, surrounded to the west by the Bitterroot Mountains
and to the east by the Sapphire Mountains, opens up into the Missoula Valley
south of town. Of the two ranges, only the Bitterroots were high enough to catch
and keep weather long enough to form and maintain glaciers, which is why these
mountains are so much more jagged—they glaciated. When the lake was high
and the glaciers were big, the Bitterroots calved icebergs into this arm of the lake.
Today, many of the boulders that were caught in the icebergs have been
deposited along the valley floor.

In the southern end of the valley—Hamilton and above—the valley floor
was high enough that when the lake levels were low, the glaciers left terminal
moraines at the mouths of some of the canyons. (Moraines are piles of
unconsolidated earth that is pushed and moved by glaciers. Terminal moraines
are moraines left at the end of a glacier while lateral moraines are moraines
created by glaciers pushing material off to the side.) In the canyons farther north,
the terminal moraines are much farther away from the valley floor. When the lake(s) drained, the water in this valley emptied into the Missoula Valley. But because the valley is so wide, especially at its mouth, the drainage flows were relatively tame and did not noticeably alter the landscape.

Flathead Valley: land of confusion

The Flathead Valley, the lowest basin in Lake Missoula, is not as simple a drainage. We know that the Cordilleran Ice Sheet came as far south as Polson because of the giant terminal moraine there. And because it has shorelines on it, like on Sentinel and Jumbo, we think the ice came before the last of Lake Missoula.

The Salish Range (BB), an island spur of low mountains also in the southern half of the valley, splits the drainage in that watershed, creating another small drainage called the Little Bitterroot Valley. The Flathead River drains the main body of the Flathead Valley east of the Salish Mountains and the Little Bitterroot River drains the Little Bitterroot Valley to the west. The Little Bitterroot flows into the Flathead northwest of the National Bison Range and the Flathead flows into the Clark Fork at Paradise (CC).

Camas Prairie (C) looks like an extension of the Little Bitterroot Valley, but it is cut off by a low divide called Markle Pass. The pass is another bedrock high point, but on a topographical map, it looks like Camas Prairie is the southern end of the Little Bitterroot Valley. Could it be that they were once connected, when the valley and the prairie were filled in with sediments from a previous geologic time, and other Pleistocene floods scooped out these sediments exposing the divide? Maybe they were never linked. Either way, this small patch
of yellow grassland, tucked away inside a crown of low forested hills, holds the key piece of evidence linking Lake Missoula to the channeled scabland floods, over 100 miles away.

The Flathead Valley was under 950 feet of water, which was several hundred feet above Markle Pass. As the water drained, it poured over this divide to the north and south and created sandbar-like ripples on both sides of the divide. Neither erosion or development have erased the ripples from landscape, but their size—some are 50 feet tall and 150 feet from crest to crest—make them nearly impossible to see unless you know they are there. Pardee discovered them using aerial photography, and from above, they are clearly discernable. The ripple marks are perpendicular to draining currents emptying out of Camas Prairie into the Flathead River at Perma. Pardee took them to be proof that Lake Missoula drained quickly enough to create such a phenomena. The shape and position of the ripples make them convincingly part of the cataclysmic flood story, but they otherwise offer no proof of multiple drainings.

Just a few miles to the east of Camas Prairie, lake sediment outcrops along the Flathead River (DD) hold the best evidence that lake Missoula didn’t exist beyond one filling. In 1993, after spending three years looking at dam safety on the Flathead River for the Bureau of Reclamation, geologist Daniel Levish began another three years of doctoral work on the glacial history of the Flathead Lobe and Lake Missoula. As part of his research he reinterpreted glacial features throughout that valley that had previously been used to show multiple fillings of Lake Missoula.

Levish measured a handful of sediment outcrops along the beautiful Flathead River. In one such outcrop, named the landslide outcrop, Levish
counted varves in 75 feet of lake sediments than had been exposed by the river. Mapping this and other outcrops, Levish found that similar layers were found at similar altitudes throughout the valley. This, he reasoned, could not be the case if the lake had catastrophically drained multiple times; if that had happened, the stratigraphy—the map of the sediment layers—would have been dramatically warped and not uniform throughout the valley. Levish also mapped the ancient riverbeds and drainage channels in the southern half of the valley. He found that there weren’t enough old channels to support the draining of a giant lake multiple times. And his interpretation of the formation of the Flathead River is that it cut quickly down into the soft lake sediments after the lake drained. If the lake drained more than once, the river channel would be larger and more eroded. Areas like the landslide outcrop wouldn’t boast outcrops of sedimentary layers as clean as they are now.

From Ferma, the Flathead River drains the Flathead Region for a few more miles until it meets the confluence with the Clark Fork in Paradise. There is a commercial nursery at that confluence and, in downtown Paradise, a casino, a closed-down second hand store, a bar, and CJ’s defunct shack. Not much. The Clark Fork gets big here and flows through a deep valley. The walls are high and sheer and completely scrubbed clean of soil and vegetation. The trucks on the road are huge and even the trees seem large compared with those just over the ridge. Where the Flathead River drainage crashed into the Clark Fork drainage and submerged the valley under several hundred feet of turbulent ice and rock water, the skidding together of two highly powerful currents made for some funny water. There were most likely large underwater spirals, or tornadoes, that moved along eddy lines and current lines. These swirls, called kolks, which also
appeared in other places during the lake draining, plucked boulders off of the Belt rock cliffs and dropped them haphazardly just downstream of the convergence.

Levish doesn't believe that the lake drained catastrophically, but just as he doesn't believe there was more than one filling of the lake, he feels it didn't flood because there is no evidence of it in the stratigraphic record. Camas Prairie and other rippled landforms throughout the basin and rocks ripped off canyon walls offer fairly convincing evidence that this lake did drain quickly and powerfully.

The Blackfoot; Dea's (and Norman's) storied river

The Blackfoot Valley (FF) is the other main intermountain basin covered by the lake. This valley is a bit different than the others in that it shifts between a wide valley and narrow canyons from its headwaters east of Lincoln—where Ted Kaczynski built his mail bombs—to the confluence with the Clark Fork in Bonner.

Near Ovando (GG), the river hides one of its many secrets: an old delta system from glacial Lake Missoula. This is where the river ended and at least one of the lakes began. Through postglacial floods, soil creep, riverbeds shifting channels, and development, many of these old delta systems into the lake have been lost, or at least remain undiscovered. This one remains fairly intact and it helps tell the story of this corner of the lake.

About 22 years ago, geologist Peter Dea found the delta and deciphered its parts. What Dea found was a series of lithofacies. Lithofacies are like a book that contains multiple chapters. The chapters are distinguishable from one another, but together, add up to tell a larger story. Lithofacies are sequences of
layers, each distinguishable from one another, but together they show geologic change. For example, in eastern Montana, in the Cretaceous period (65 million years ago), there was a shallow sea that inundated the land. At a certain location, shoreline sediments were deposited, which later became sandstone. Then, as the sea rose, the water at that spot became deeper and smaller particles settled out because of their distance from shore. These deposits eventually became shale. When the sea became even deeper and the shoreline moved farther away, calcium carbonate precipitated on top of the shale because, at that depth and distance from shore, there were no more particulate sediments, only what precipitated out chemically. So limestone sat on top of shale, on top of sandstone. These rocks are genetically related because they were all created by a rising sea level. This is called a transgression. When the seaway in Montana disappeared, sandstone formed on top of shale on top of limestone, and this is called a regression.

The lithofacies Dea describes in his three study areas near Ovando and Monture Hill are only partially exposed. Before the lake was there, or between lakes, the Blackfoot River deposited small alluvial pebbles and other river sediments. Once the lake backed up far enough, a large delta complex formed and sand, silt, and clay piled in layers. During this time and afterwards, ice from the Swan Valley pushed till (glacial deposits) into the area, which mixed into the delta.

The top lithoface that Dea found is glacial till from the glacial advances after Lake Missoula had gone. Till consists of rounded and partially rounded (as a result of varying amounts of weathering) sandstone-quartzite or argillite (both Belt rocks) pebbles and cobble. Ice crushed the softer rocks—mudstones—into
sand and gravel, which made up the rest of the glacial till. This stuff sucks for farming.

Lacustrine lithofacies lie under the glacial lithofacies. These sets of layers give us an idea of minimum water depth and minimum distance from shore. The lacustrine lithofacies consist of small rocks and pebbles from when the water was shallow and the shore was nearby, and silts and clays when that spot became deeper. Intermixed in the lithofacies are dropstones, stones that were carried into the lake on icebergs and deposited when the ice melted.

Below the lake sediments are deltaic lithofacies and below them, fluvial, or river, lithofacies. Fluvial lithofacies are deposits made from moving water; they are river deposits. When the river brought in enough water to back the lake up far enough, it became a delta and the sediments were deposited differently. These deltaic lithofacies, which consist of silty sand and muddy clay, are some of the thickest in the group of lithofacies because water went from moving swiftly to barely moving at all; that change in inertia caused the water to drop most of what it carried.

Here at the delta—the transition zone between moving and static water—where the sediment load was largest, the sediments were able to separate themselves fairly quickly, or at least quickly enough that they lie in distinct layers before the above layer was placed. The sediments sorted themselves by size, the sand dropping to the bottom followed by the silt and then clay, which is the smallest of the particles that make up dirt. But these layers didn’t lay themselves flat, like stacks of multicolored paper. Because they were laid by moving water, the water added ripples to the layers. And looking at the size and shape of the layers—the height of the crests and the distance between them—Dea
was able to determine flow direction and which layers were deposited by faster-moving water.

This pattern of rippled sand-silt-clay would repeat itself with each new major influx of sediments. After all those years of the river flowing into the lake, these lithofacies grew to be between 10 and 20 meters thick.

Below the deltaic lithofacies—somewhere between 25 and 35 meters below the surface—Dea found glacial till from an older ice advance, before glacial Lake Missoula was functioning. Below that, he found thin layers of loesses (windblown soils) covering what are called paleosols, old, inactive soils.

Dea makes no mention in his article of multiple lakes and his lithofacies only describe one delta into Lake Missoula. I wonder if anyone has looked at both Levish’s and at Dea’s sedimentary records and what, if any, correlation can be drawn between the two.

The Blackfoot River is pinched again at Russell Gates up until the Clearwater Bridge, where the Clearwater River flows into the Blackfoot. The Clearwater River was likely a source of some of the heaviest concentrations of melt water with rock flower as it drained the southern end of the Swan Valley, which was submerged under ice during even the milder glaciations. At Ninemile Prairie on the Blackfoot, the river drops below a terrace into a magnificent canyon 16 miles long. Below the canyon, the valley stays narrow and winds its last 12 miles to the confluence with the Clark Fork in Bonner. Mining polluted the upper Clark Fork to the point that today 6.6 million cubic feet of toxic mine tailings sit behind an old and failing hydroelectric dam just downstream from the confluence.
Not much is known about the northwest corner of the lake. Up here, along the Kootenay River drainage, the landscape underwent many phases. Sometimes it was covered with ice, other times it was under water, and still other times, it was dry and bare. But it was surely the most heavily glaciated corner of the state.

Paleoecology, revisited

At the end of the Wisconsin glaciation—the last stage of the Pleistocene Ice Age and in Montana called the Pinedale—there was a major reshuffling of species and ecosystems in North America. Once the ice began retreating significantly, the northern half of our country was open for business, possibly for the first time to many new species—particularly megafauna, including humans—that migrated over the Bering land bridge and across the Bering Strait.

Apart from the Lake Missoula floods, when the ice began to permanently melt and the glaciers retreated back to the poles, the land underneath was inundated with torrents of water rushing from the highlands and from under the ice. Floods of unknown size ripped through the modern drainages, once again destroying the terrain in their path, redistributing silt and soil and rock. Melting like this likely occurred at the end of every glacial period, of which there were at least 10 in North America. Could it be that one or more of these floods were responsible, in part, for carving the channeled scablands?

The Gulf Stream shifted back north and North America experienced its first warm and wet spell in quite some time. When the ice retreated about 14 thousand years ago, the average Montana temperature gradually rose to where it is today. With that increase in temperature came a change in the vegetation. Around 11 thousand years ago, the climate dried and sage and dry land grasses
began growing. Within a couple hundred years, the treeline began climbing and pines, most likely white bark pine, moved into the landscape. Pines, Douglas fir and larch dominated the forested hills. Sagebrush grew where the land was otherwise too dry to support anything else. Around 9 thousand years ago, lodgepole pine and engelman spruce lined the hillsides until about 3 thousand years later when the ponderosa and whitebark pines moved into the lower elevations. By then the Nez Perce, Anasazi, and other North American Tribes, and grizzly bear, wooly mammoths, saber-toothed tigers and other large mammals had made themselves at home in this climate and region.

By 6,000 years ago, the glaciers had retreated as far back to the poles as they are now, the oceans had risen over 300 feet, and the average planetary climate remained wetter than it is today. Twenty-five hundred years ago, the landscape looked very similar to how it appears today—low elevation ponderosa pines and sagebrush; mid-elevation doug firs; above that cedar-hemlock forests; and above that, to treeline, spruce and fir forests—except where we've destructively cut or mined. And then it just looks like hell.

I climb up a ridge in the Rattlesnake Valley (HH) and look out over Missoula and I imagine the water filling the basin all the way up to the "M" and I see it sway in big sheets lapping up onto the sides of Mount Sentinel and Jumbo. I erase the buildings and roads and recreate that deep, dark, cold place at the bottom. I follow the lake out of the low spots in the valley to the Bitterroot and the Blackfoot and the Flathead, watching it expand in my mind as if the water were filling from one spot inside the earth instead of dripping out of the
surrounding mountains until I can't keep the picture all together anymore. And then I start imagining it again as I look at the bottom of the basin in front of me.

There was once a wildness in glacial Lake Missoula that is now almost all gone. All that is left inside its shores are patches of geomorphic scars: the terraced shorelines, exposed lake sediments, gravel deposits, and giant ripple marks. Forests and grasslands blanket the lake basin like moss on a rock left unturned. The rivers and creeks, as they extend to every corner of the lake, are like the skeletal remains. The ice and the water and the biting arctic winds are all gone. This change cannot be helped. Roads, towns, farms, cultures have been imprinted into the landscape, too. Trees have been cut. Mines dug, rivers dammed. This, too, cannot be helped, only managed wisely. Our landscape will continue to change, regardless of what we do or don't do to it.
As Ice

“A man who keeps company with glaciers comes to feel totally insignificant by and by.”

—Mark Twain

From up in an airplane, everything on earth appears tiny and meaningless. Rivers drape lazily. Mountain ranges flake like the broken end of a wafer candy bar. Towns and cities look like corduroy. At 39 thousand feet, even the thought of a 2 thousand-foot thick ice sheet seems like a wedding veil over the earth. The earth itself is the only feature that looks big: the curve, the haze wrapping around the arc of the horizon.

When I flew back from Europe once, our plane literally flew around the earth. Prague is significantly farther east than London and it is closer to fly north over Denmark and Greenland and Canada to get back to JFK airport in New York, than it is to fly west over the Pond. When we passed over Greenland, which is set in a diorama that resembles the end of the last ice age 15,000 years ago, the earth’s features didn’t look insignificant; the mountains and ice together took on a wholly larger shape than did, say, the Rockies or the Alps when you fly over them at 39,000 feet. I don’t know if this was because we lost altitude or if there was something about all that ice that made me feel closer to the planet. The
massive ice sheet that extends north beyond the earth’s curve seemed to pull the entire island, including the poking peaks and seacoast, south into the ocean like the ancient ice sheet in Canada that once moved towards the U.S.

When the last great ice formed 2 million years ago and covered the earth south of the 49th parallel, much of the topography we see today had formed. Weather patterns were similar, too. Pacific storms brought snow across Washington and Idaho and Alberta, like they do today. But the average temperature was colder and the snow didn’t melt in summer. Instead it piled up, year after year, in stages of up to 100 thousand years.

Continental ice like the Cordilleran Ice Sheet and the present-day Greenland Ice Sheet starts off as glaciers, those pretty white snowfields hanging off mountains all year long. Glaciers grow and eventually run together into great seas of ice, complete with current and their own weather. But the process takes a long time.

Ice began sculpting the landscape 2 billion years ago when all the continents were one large mass called Pangaea. During the last billion years, there have been six different periods of ice that may have lasted up to 50 million years each, occurring every 150 million years or so. But these numbers are vague and convey little other than the fact that ice has been an integral part of our interstellar ride and will continue to be so. As we approach the present, we have a much better idea of how and when ice acted.

Between 250 million and 55 million years ago—while the continents broke apart, first as Gondwana in the southern hemisphere and Laurasia in the northern hemisphere, and then further separated into their present planetary configurations—there were no major periods of glaciation. About 55 million
years ago, small glaciers formed in Antarctica and they grew and shrank and grew until about twenty million years ago when ice covered the entire continent, like it does now. Twelve million years ago, Alaska became glaciated, three million years ago Greenland was covered, and by two and a half million years ago, ice sheets in North America and Europe began advancing and retreating into the middle latitudes into places like Switzerland and Montana. During the last 2 million years, these advances and the variations within them happened anywhere between four and ten times. In North America, we count four and call them, for the corresponding states that they most affected and from oldest to most recent, Nebraskan, Kansan, Illinoisan and Wisconsin. It was during the Wisconsin that, here in Montana, we had two distinct stages, the Bull Lake and the Pinedale.

The Wisconsin stage began some 115,000 years ago. The height of the Bull Lake stage was about 75,000 years ago and the height of the Pinedale stage was between 15,000 and 18,000 years ago. What this meant for glacial Lake Missoula is that, during these times when glaciation was at its thickest, the dam was also at its thickest. A thick dam meant a deep lake and a large flood. But when the ice was thickest, it also advanced farther south, so more of the Flathead may have been covered and the dam surely crept farther down the Clark Fork Valley, maybe even as far south as the Bull River in Montana.

I would like to have seen the lake, especially the dam, from up in a plane. I imagine that the ice sheet wrapped around the planet resembled the blunt end of an egg. The rest of the landscape south of the ice might have been brown and rugged, like it is today. The dark turquoise water of Lake Missoula would have sat between the brown mountains and the white ice. The dam, which extended
off of the main body of ice, sat cradled between the water and the mountains. At some spot along the ice dam, there were no mountains and nothing to hold it back from the tremendous pressure of the impounded water. When the dam broke, assuming that's what happened, the lake flooded into the Columbia Plateau from this spot. The earth underneath the ice must have looked ravaged and scarred. The schism in the ice would have been dramatic. But, borrowing an anthropomorphic phrase, the ice would have healed itself; the two slabs of ice—the main stem of the ice sheet and the smaller piece left to the south—would have melded back together like skin that's been cut.

What happens to snow, or, Snow Grows Together

As we know it, snow falls, accumulates or not for a winter, and then melts back into the ground, re-entering the water table. From there, it is absorbed by vegetation and eventually released back into the air as waste vapor, or it reappears as surface water in lakes or rivers, or it becomes trapped underground indefinitely. But during periods of glaciation, snow acts more like sediment; the formation of glaciers resembles the formation of sedimentary rock, but on a much more brief time scale. Glaciers can form in as little as a couple thousand years while rock takes eons to form.

In the case of glaciers, snow is a parent material, the basic substance from which glaciers are formed. Rock has parent material. So does soil. Snow falls as individual light, fluffy crystals with beautiful and unique structures. It is delicate and has a very low density compared to ice or water. Crystals fall and accumulate. Colder, drier snow (Powder!) piles quickly, retaining its low density, usually less than 0.1 grams per centimeter cubed (g/cm³) and champagne-bubble...
texture. Snow accumulates in successive layers after each snowfall and each layer retains distinction from the previous.

Stratification remains throughout the process of transforming snow into glacial ice and during the life of the glacier. As snow falls and accumulates into layers, it takes with it bits of the outside environment. Air bubbles often get trapped between layers, preserving clues to the atmospheric makeup. And the snow itself holds dissolved elements. Snow also grabs volcanic ash, pollen, rock dust, and smoke particles and locks these into its layers like animal and plant fossils trapped in sedimentary rock.

Over the course of a few hours to a few weeks, the snow crystals collapse and the density increases, creating coarse, granule aggregates or pebbles of snow. (Spring corn!) At this point, the density increases to about 0.3 g/cm³ and is referred to as old snow. The snow continues to compact in warmer temperatures or under the weight of successive layers. When the density reaches approximately 0.55 g/cm³, the snow becomes something called firm and its function and behavior begins to change.

The densification of snow while it is still light and fluffy is a result of the individual snow crystals collapsing and shifting among themselves so that they fit together snugly. Snow beyond 0.55 g/cm³ begins to compact differently. At this density, snow may tend to melt and refreeze in a tighter crystalline structure. Snow crystals also collapse further, so that they cease to look like snow. Permeability between crystals and between individual pieces of firm decreases even more until the snow is no longer porous, about 0.82 g/cm³ to 0.84 g/cm³. The ice may continue to compact to 0.9 g/cm³, 0.917 g/cm³ being the density of pure ice. This rarely happens except in tiny pockets.
This glacial ice still retains individual layers, although distinctions may become difficult. At this stage, the ice takes on many characteristics of sedimentary rock in the way that it folds, cracks, or is acted upon by water that percolates through these fissures and refreezes, causing further cracking, or creating pipes or waterways that grow and weave through the ice.

Once formed, glaciers become more than just ice cubes sitting in the ice cube tray we call our landscape. They take on functions unique to earth. Individual glaciers have two main parts: the accumulation area and the wastage, or ablation area area. In the accumulation area, total snowfall exceeds meltage, and conversely, in the wastage area, melting exceeds snowfall. The annual snowline separates the two areas.

The snowline is the lowest area on a glacier where snow falls and accumulates, like the snowline on a mountain. Snow may fall below the snowline, but it melts as part of the wastage area. Snowlines change from year to year, based on accumulation and weather, and they can be tracked from year to year, even once they become buried; they retain a distinguishable record in the sedimentation of the glacial ice.

The interaction between the accumulation and the wastage gives a glacier its so-called life. And this life is directly tied to the glacier’s snow budget, which is the amount of snow it accumulates compared to what it loses. Budget years don’t start and end on the same day but are marked by events. As seasons progress and winter is replaced by summer, accumulation declines and wastage increases. When wastage once again exceeds accumulation, a new budget year begins. The time that this happens changes from year to year, based on climate
and snowfall. When accumulation once again surpasses wastage in the fall, the
seasons change and the glacier is now in the accumulation phase of the year.

Inherent in glaciers is that they like equilibrium; they want accumulation
to roughly equal wastage. When accumulation exceeds wastage, they grow, and
conversely, when wastage exceeds accumulation, they shrink. Today,
fluctuations in glaciers are measured by comparing their accumulation to their
wastage. Moving terminus points in a glacier—the “end” of the glacier—is often
a result of past events or previous yearly deficits and not a result of that year’s
snowfall or climate and is not used to measure the change in size of a glacier. To
measure accumulation, we calculate the volume of snow remaining on a glacier
above the snowline at the end of the melting season. This can be a bit tricky as
the shape of the residual snow is a wedge: thin at the snowline and thick at the
top end of the glacier. But using snow pits and drilling core holes and employing
a bit of messy high school geometry, it is not impossible to draw a close
estimation. The same can be done to measure wastage. Stakes can be placed
below the snowline and marked throughout the year, and a rough volume of
wastage can be determined and calculated. This is more difficult than measuring
accumulation since you’re measuring something that has disappeared.

Because melting ice, which is compacted and old, is a different density
than accumulated snow, the amounts of the two volumes are converted into
equivalent volumes of water so that they can be compared.

Within one year, accumulation rarely equals wastage, but measured over
several years, they reach a closer balance, relative to their climate. Excess
accumulation must be transferred to the wastage area and deficit accumulations
eat into the accumulation area, both of which shift the snowline. This internal
shifting of resources is the source of glacial movement.

When localized climates remain below freezing for more than half of the
year, over time, glaciers will tend to grow. If that changes and temperatures rise
above freezing for more than half of the year, the glaciers will shrink.

Glaciers are manifestations of climate; they depend on climate for their
substance and subsistence. Precipitation, radiation, cloud cover, temperature,
exposure, albedo, wind, and altitude all affect the interactions between
accumulation and wastage and keep glaciers functioning and moving. Like the
great whales that live in the oceans, glaciers are giants in their landscape,
delicately linked and extremely responsive to all the elements in their
environment.

Nearly all of a glacier's accumulation—its nourishment—comes from
snow. But wastage—the spending of resources—is a finely tuned and not well
understood combination of several factors relating to climate and geographic
location. Some glaciers are more efficient than others, like those in Greenland
and Antarctica today: they receive very little new snow, but because of climactic
conditions, melting (wastage) is kept to a minimum. Since we don't know much
about the climate in Montana during the Bull Lake and Pinedale glaciations and
since the Cordilleran Ice Sheet was so big, it's nearly impossible to know how
efficient it or its lobes were. Clearly, though, there were enough resources
shifting within the ice to close the dam once it had broken.

Melting is the primary manner in which glaciers burn ice. It is caused by
radiation—both on and below the glacier's surface—conduction, and
condensation. Radiation from the sun is constantly working to melt the glacier
but cloud cover, humidity, wind, albedo, glacial makeup, season, and location all create complex variations in glacial loss from the sun. Wind may be the most counter intuitive factor that contributes to glaciers melting. Air around a glacier cools and acts as an insulating layer. But when a wind picks up, that insulating layer is lost and the warmth of the sun is much more effective at melting the ice.

Humidity is another major melting factor. If the surrounding air is packed with enough moisture, then when that air rests against the glacier, condensation occurs. The act of water condensing out of air takes a great deal of energy. When that energy is expended to precipitate water, it also burns snow, assuming the glacier is close to the melting point.

Which brings me to the difference between warm and cold glaciers. Climate, that omniscient, omnipotent force behind the existence of glaciers, also controls their temperatures. Many glaciers are large enough and cover a large enough range of altitudes and topographies that their net temperatures can vary based on location. Glaciers that have a southern exposure or that lie at low elevations may be just below the freezing point, while others may be 20, 40, 60 degrees below freezing. Their temperatures come from the surrounding climate. The temperature at which snow turned to glacial ice remains with the glacier for the life of the glacier if the climate stays relatively stable. Ice cores can be dug on glaciers to determine temperatures from previous times. Otherwise glaciers stay the same temperature as their climates unless the climate is warming and the ice hasn’t had a chance to warm up with it.

Each glacier is different and must be studied individually. But for our glaciers, the ones that flowed together to block the Clark Fork River so many
thousands of years ago, these details are lost, only available through extrapolation, conjecture, and a bit of educated guessing.

Creeping Rivers

Even though ice is solid, glaciers flow. And like the way they speed up geologic time in their formation compared to that of rock, glaciers slow down river time in the way they move like water. Speed and direction of flow all vary within glaciers based on, like streams, gradient, depth, and channel width. Some of the earliest glaciologists in the Swiss Alps observed that straight lines on the front of glaciers would eventually become parabolic curves; the central parts of glaciers, like rivers, tend to move faster than the edges. They called these parabolic flows. Other glaciers, they observed, moved at consistent rates except for the edges, which didn’t move at all: plug flows. Still others moved in funny variations of these, some symmetrically, some randomly.

The shapes of these flows are directly related to the glacier’s thickness, the width of the ice flow, and the gradient over which the glacier is moving. For instance, widening or narrowing of the space of the flow, on either or both sides, will cause the glacier to slow down or speed up, respectively, just like water in a river.

Variation in the speed and direction glaciers flow is also directly related to the thickness of a glacier. Glaciers tend to move fastest at their surfaces and slow down as they approach the bottom. Surface rates are also fastest at the thicker parts of a glacier. The movement at the bottom of the glacier is called basal slip and the difference between movement on the surface and the basal slip is called internal flow. The line between internal flow and basal slip is not a perfect curve
through the thickness of the glacier, but internal flow is always a positive number.

Ice, unlike water and rock, is semi-plastic: sort-of solid, sort-of viscous. It bends, curves, stretches and it has a stress point. Ice doesn’t strain (change its dimension after being acted upon by outside forces) until it hits a certain stress point (force per unit area), after which it yields and strains. But unlike other plastic substances, when ice finally does yield, it happens at a changing rate, dependent on the amount of stress.

Ice moves like sticky water, rolling along a fall line, reflecting its gradient and terrain but slowing itself against the forces of gravity. And that allows ice to make some pretty fancy maneuvers.

Ice moves fast enough that you can see it, if you’re there to bear witness. It has been estimated that many valley glaciers, like the Purcell Lobe, can move at an average of two feet per day. Steeper glaciers can move 10 to 20 feet per day, and the occasional anomaly or ice fall—glacial versions of waterfalls—can move as much as 125 feet per day. But these are short-lived. Ice above the snowline on glaciers tends to speed up in winter, when accumulation increases enough to give the glacier an extra push. And in summer, when ablation increases, the glacier below its snowline may noticeably move faster.

Ice piles. When faster moving ice hits slower moving ice, the faster ice piles up behind and on top of the slower moving ice. Eventually, the slower ice gets pushed downward and the faster ice moves across the surface of the glacier.

Ice falls. Sometimes it flows over extremely steep gradients and creates an icefall. At the top of these falls, the ice thins and cracks. At the bottom—the plunge pool—the ice piles and compresses down on earlier fallen ice that may
have cracked. Layering that may have occurred farther up the glacier is usually now lost on the glacier's new path.

Glaciers ripple. Occasionally, ice will bulge and pick up speed as it moves down a glacier. This bulge, cruising three to eight times as fast as the surface, can pass through other areas of slower-moving ice like water rippling downstream in a river or like shock waves pulsing from an epicenter. Most likely, these bulges are caused by a quick and forceful accumulation of snow and ice at the head of a glacier, possibly from an earthquake or avalanche.

We don't know exactly how ice flows, but most likely it moves in slabs, similar to the way snow will move in slabs. Unlike water molecules, ice crystals probably don't roll over each other.

The Cordilleran Ice Sheet was a compound valley glacier fed by many tributary ice sheets, which means that it was comprised of a series of distinct and separate tributary ice flows. Ice moved from mountain canyons in the Canadian Rockies and the Canadian Coastal range into the lowlands between the two ranges like feeder creeks drain into a valley river. But unlike tributaries that feed rivers, ice streams like these don't mix. They remain separate and individual, retaining their integrity. Ice flows lack the turbulence that eventually mixes water. Larger ice flows will eventually sink and push their way down to the valley floor while smaller flows will often piggyback down a valley on top of the valley glacier.

At their lowland edges, ice sheets grow out, pushing in every direction possible but focusing on the paths of least resistance. At the edge of the Cordilleran Ice Sheet, fingers, or lobes, stuck out in every direction and even these lobes split as they moved around the landscape. Ice in the southern part of
the Flathead Lobe may have helped gouge present-day Flathead Lake by expanding like spilled milk at its terminus. Over in Idaho, one piece of the Purcell Lobe found its way down the Clark Fork Valley. That lobe moved down the Clark Fork Valley and became the ice dam that held back glacial Lake Missoula.

All that shifting of water, from the liquid oceans to continental ice, changed the shape of the big orb we call home. The ocean surfaces sank upwards of 400 feet. But that didn't put the ancient coastlines at a depth of 400 feet. Ten million cubic miles of ice covered one third of all the landmass on earth. The plates under the ice sank while the plates not under ice bulged, similar to what happens when one steps on a slightly deflated soccer ball. This extreme pressure on the earth's mantle pushed it aside and shifted the molten rock underneath. And it pushed up the bottoms of the oceans, shifting once again the location of the shorelines.

Greenland is only green in one tiny strip of land on the island's southern coast. It was so named by European explorers before they had the skills or technology to venture farther north and before they knew anything about continental sheets of ice. Today, Greenland is much the same as these early explorers saw it. The maximum thickness of that ice sheet is 3,200 meters, or almost 10,000 feet. It is smaller than the ice sheet that covered the island at the height of glaciation 18,000 years ago. It may even have been connected to the Laurentide Ice Sheet, which covered the eastern half of northern North America. Because of the extreme weight of the ice, even today, the actual landmass of Greenland is below sea level. If all the ice were to suddenly melt and the land
didn't isostatically pop back up, Greenland would be a ring of an island with an opening on its western shore. Imagine that view from up in an airplane.
Soil

The five soil forming factors

1. time
2. climate
3. parent material
4. topography
5. biological activity

Sounds like something out of a metaphysical witchcraft manual, doesn’t it? Add a pinch of latitude, brew for 7 moons.

It seems like we’re always dozing soil out of our way to build, or digging it so that we can fill the hole with something we deem necessary. It’s dirt: we wash it from our clothes and off our bodies. Pick up a fistful and roil it around in your hand. It’s brown and coarse and has little sparkly bits. When it’s wet, it’s mushy. But add a seed and some water, and then, it’s something else entirely.

Today, my tomatoes grow big and sweet in the hot July sun. Soon they will ripen. I have six basil and two tomato plants. Most of my plants are growing in a mixture of backyard and store-bought soil. They are lush and full. I have a few plants in just a thin layer of regular backyard soil, but they are weaker and limp. That soil is lighter in color and always drier to the touch. It doesn’t support much
more than brown grass. I water my plants every day and constantly pluck unwanted little green visitors from the nearby soil.

Not a day goes by that I don’t marvel at these plants, which so miraculously happen to match my palate. They grow bigger and heavier just by drinking water, lapping sunshine, and sucking nutrition out of dirt. They expend no energy running around, or talking to people who probably aren’t even listening. I don’t even think they think. They just grow, converting sun into sugar, changing dirt into soil.

Soil represents transition. It literally lies between the rock attached to the core of our planet and the living organisms that float on the planet’s surface. Soil connects basil to bedrock. And soil links the physical processes that shape our landscape to the ecological systems that rely on our landscape to survive. It binds the world together.

So it’s no wonder that when I began thinking about glacial Lake Missoula, and I began wondering how this phenomenon from so long ago could matter to us today, I kept coming up with soil.

The streams and rivers that fed Lake Missoula brought in millions of cubic feet of glacial melt, which was full of pulverized rock dust. In summer, the lake filled with this dust. Eventually, it would settle to the bottom and create a light-colored layer of sediments. The summer sun also brought microbial algae and microscopic animals, which was the only life the lakes could support, both on and below the surface. In winter, freezing temperatures killed the cellular life and the dead matter settled and created a dark layer of sediments that sat on top of the lighter layer.
Each series of light and dark layers, called a varve, represents one cycle through the seasons. Sets of varves can be grouped into individual lake fillings; the bottommost set shows the earliest lake in that set of varves. In 1971, geomorphologist and professor David Alt and his then-graduate student R.L. Chambers studied a road cut just off of I-90, west of the Ninemile exit and very close to the Clark Fork River, looking for varves to count to see if they could figure out a minimum number of glacial Lakes Missoula. Alt and Chambers expected to find a sequence of varves. Instead, they found very thin sequences of these varves with river silt stuck in between. Apparently, there had been enough time between fillings for the river to deposit distinguishable sedimentary layers and, apparently, the river had either shifted its channel or was large enough to flow over the area where the road cut sits, which is a good one hundred feet higher and at least 300 feet from the current river.

Alt and Chambers counted 36 varves separated by the silt layers, and they interpreted that to denote 36 fillings of the lake. They found a total of 1,000 varves and estimated that the lake existed for a minimum of 3,000 years. It is impossible to know whether these layers and varves represent a total number of lakes or just a minimum count, and if they happened in a continuous chunk of time or if they are a collection of surviving layers over several thousands of years. But this gave them a fairly reliable minimum number.

Alt could also see by counting the varves in each sequence that the oldest lake existed for 58 years and that all the other lakes existed for fewer years, the last one existing for only nine years. But once again, this only tells us about these lakes and leaves no clues as to other lakes and how big or for how long they existed.
Soil, unlike most everything else in the universe, does not follow a pattern of entropy—that is, it doesn’t progress from a state of organization to a state of chaos, like what happens immediately after I clean the kitchen. Soil tends in the opposite direction. It starts out as a disorganized pile of minerals and rocks, including clays, sands, and silts. Given tens of thousands of years, soil usually organizes itself into a neat, predictable pattern called the soil horizon, which happens to put the most fertile soils on top. But that takes more time than since the last glacial Lake Missoula episode. Thus, the lacustrine (lake) and flood sediments from the last episodes are still disorganized, or unconsolidated. There are spots in the glacial Lake Missoula system that have consolidated: the finer-grained soil elements have floated to the surface and the larger components have fallen below, creating a system of healthy top soil and below that, a well draining soil base. These places give us a glimpse at the possibility of older glacial Lakes Missoula, probably from much earlier in the Pleistocene Epoch.

When the lakes drained, they took with them most of the lacustrine layers that had been so neatly laid. All the varves were now gone. It was only in certain areas that some of the sediments remained, usually behind an obstruction where the massive current couldn’t get at them. These drastic drainings had two major effects on the sediment layers. One was that the floods washed most of the layers away. The road cut that Alt studied in the early ’70s was a lucky survivor. A quarter mile away, there are no layers that thick.

The other result was that most of the good floodplain soil was now washed downstream. What happened after the floods carried the soil away puts an interesting twist on life in the lake region today. Jim Sheldon, a geologist with
the Forest Service, explained this to me one afternoon during a field trip on glacial Lake Missoula. We were standing on the north side of Rollercoaster Road, way out in western Missoula, admiring the rolling and historically unproductive farmland.

"When Lake Missoula flooded, it either went into Lake Columbia and drained throughout the Columbia River Basin or, if Lake Columbia wasn't in, it drained right along the Cheney-Palouse track in far eastern Washington, carrying with it most of the sediments at the bottom of the lake. Either way, eventually, the floods had to get through Wallula Gap. And it's too little. So it always backed up into a lake, in what is now called Moses Lake country. The water would gradually drain off, leaving a mud flat out there.

"Back then, the continental ice probably acted like the Antarctic ice cap does today, which also shares a border with dry land and dirt. Hellacious winds blew straight down from the North Pole and then curved east to where, at the margins of the ice, they're always blowing from west to east. So the mud flat dried out, and this constant, powerful wind would pick up the mud and blow it off across this country, now spectacularly deposited in the Palouse country, which is just immediately down wind. There is a gradation from the Palouse country back into the Moses Lake country with the largest soil grain size being left in the middle of the temporary lake. It's exactly what you'd expect.

"The part that I don't think is well recognized, and the part we haven't thought about enough over here, is that all the soil didn't stop over in the Palouse country. Most of our recent soils, all of our fine, silty, brown forest soils, are loess, also, and they've blown over as part of that same mechanism.
“Since loess is, by definition, soil carried by wind, it’s got some restraints on its physical nature and its grain size. Loesses have some unusual properties, which makes them the most fertile farm soils around the world. So for our benefit, the formation of these big loess belts back in the ice age was an important operation.

“There is good evidence that Lake Missoula functioned through all four stages of the Pleistocene ice age, even though we only tend to see remnants of the lakes in the Wisconsin, the last stage. That gives you enough time to dump enough mud in the mud flats to make wind deposits the thickness of what’s in the Palouse region and all of the loessal soils here in Montana.”

Sheldon went on to tell me about the soil that washed out of Lake Missoula. Glaciers dumped large amounts of mud and rock flour into Lake Missoula. And all the tributaries carried their normal sediment load. As you go around the perimeter of Lake Missoula, he said, you can find a couple of the old deltas. But you have to look pretty hard for them. “To me, this is a hint that something ecologically unusual happened. It was cold and dry, certainly. That implies a lack of ground cover. And lack of ground cover usually implies a high sedimentation rate. What is preserved of Lake Missoula indicates that only some drainages had a high sediment rate, which we can see in a few deltas.

“Once the flood water got moving, it was extremely powerful. It stripped all the soil off of the flood plains and the walls of the canyons. Soils are usually younger at the top of the ridge. They get thicker and more mature as you go down into the flood plains where the soil is typically extremely fertile. Well, Lake Missoula got rid of the lower slope fertile soils and cleaned out the alluvial soil. That gave us a fertility inversion; the soils up the hill are older, thicker and more
mature than the soils on the bottoms of the slope, thus the vegetation up there is more diverse. That’s just the reverse of what you’d normally expect.

“Those soils up top have a head start because they didn’t get removed by Lake Missoula. All the lower elevation soils have had to get started and do all their development since Lake Missoula. In addition to that, once the winds started blowing and carrying the soils back from the mud flats, they tended to get caught up high on the mountaintops. Most of the silty loams in western Montana that aren’t in crick bottoms are loesses because talus slopes are good loess catchers. And if you dig into the talus, you will find that they are loess in the middle, not just dry, clean rock piles.”

During the cycles of ice and floods that occurred on the Earth’s surface some 12,000 to 2 million years ago, fire brewed deep beneath. The volcanic peaks of the Cascade Range, which are the westernmost border of the Missoula Flood region, held back magmatic pressure. When that pressure grew high enough, the volcanoes blew their tops. Activity in the Cascade Volcanoes began some 36 million years ago, continued right on through the ice ages, and is still a factor in our landscape today. In 1980, we got to see what happens when that fire builds up enough pressure to blow. On May 18th of the same year in which Ronald Reagan took office and I entered kindergarten, Mount St. Helens in Washington erupted, projectiling scorching ash 15 miles into the atmosphere and laying flat 200 square miles of forested landscape. The town of Yakima alone reported four to five inches of ash, which weighed an estimated 600,000 tons. As the ash spread farther from the volcano, the deposited layers became thinner and in western Montana trace amounts to a half-inch settled.
Three years before St. Helens erupted, geologist Richard Waitt studied Missoula Flood varves in the Walla Walla Valley of Eastern Washington and thought that he had found one thick layer from a single gigantic flood. Among the varves, though, he found two layers of undecomposed ash, which, by his estimate, didn’t belong, and which coincidently he believed were from St. Helens. The ash that Waitt, and later other geologists, found at this and other sites exposed two things to the world: Volcanoes were active during the last ice age and the floods happened on numerous occasions. That they were active is what’s important here.

The uniqueness of Mount St. Helens in our time was not its size or its intensity, or that it happened, it was that we saw it. Important to our discussion is what it left behind: volcanic ash. Ash degrades rather quickly into clay. And clay is essential to good, healthy, fertile soil.

Soil is made up of four elements: sand, silt, clay and organic matter. The first two, sand and silt, are broken down rocks that give soil its body. They take up the majority of the soil’s volume and are basically inert. Clay (which can also come from broken down rock) and organic matter, on the other hand, exist in smaller amounts but do disproportionately more work.

Soils have characteristics based on the distributions of these four building blocks. And this distribution is almost entirely responsible for what lives on top. Soil full of sand and silt with very little clay and organic matter will quickly drain water. Soil that holds little water tends to support limited vegetation and without much vegetation, soil has a tough time commandeering organic matter, which is the nutritional base for soil. Western Montana is full of soil like this. If a
soil has a good base of organic matter and clay, such as the loess found in the Palouse region or in the Yakima Valley, it will retain water and nutrients.

One clay particle is less than one ten-thousandth of an inch in diameter. It's impossible to see it, even with a microscope. And one gram of clay particles has as much surface area as the walls of a dining room. The small-size-to-large-surface-area ratio is what makes clay so special. This, and the fact that clay colloids are negatively charged, allow it to collect and distribute nutrients to plants. Clay absorbs plant waste like hydrogen, which is positively charged, while clay releases other negatively charged substances such as potassium, magnesium and calcium into the soil.

"The loess appear to be mixes of silts—and the silts were to come from Lake Missoula—and volcanic dust or volcanic ash, similar to Mount St. Helens," Sheldon continued. "The loesses have a high component of granular materials that are not a whole lot bigger than the clay particles. Some mechanism other than glacial grinding may have generated this stuff. These clays and silts carry and hold onto other ions well; they make a great fertilizer storage device. And since clays have such a fine grain size, they store water well, too."

When the events were timed right, as was apt to happen at least every once in a while over a 2 million year time span, volcanic ash landed on dried up mud flats, decomposed into clay, mixed with the fine flood silts, was picked up by the westerly winds and blew east. Most of that good loess landed just down wind, which is why the topsoil in the Palouse valley is 200 feet thick, but some of it continued on into Idaho and Montana, landing high up in the mountains. As soil does, it's been slowly creeping back down to the valley floor. But not fast
enough, which is why I had to buy the store-bought topsoil to get my basil and tomatoes to grow.
Designation

Before Interstate 90 was built, old Highway 10 ran between Seattle and Spokane, Washington. It crossed the Columbia River just north of the Wanapum Dam and then hugged the river for a few miles before shooting northeast. The old road climbed out of the river basin at Frenchman Coulee, which dropped from the Pasco Basin into the Columbia. The landscape here is stark and arid and open. Not much beyond sage and a few grasses grow in the basin or in this coulee. Towns tend to center around a few lakes in the Columbia Basin, most of which were created by the floods or by the retreat of the Okanogan Lobe.

Pasted on the southern wall of Frenchman Coulee, the floods left behind a fencerow of big, bulky basalt columns, nearly 80 feet tall and several hundred feet wide. When Dale Middleton was just a kid, his family often drove that road between Seattle and Spokane and he and his brother stared in amazement each time they rolled by the striking basalt formation. At that time, the Spokane Floods were little more than a rumor circulating between a few geologists and curious natural history buffs. To the young Middleton kids, the basalt columns were merely spectacular! Like something out of a comic book. The family also drove up Grand Coulee to see Dry Falls. There were no signs, no visitor centers, nothing to explain to them what this megalith canyon was doing in the middle of the Columbia Basin.
In the 1960s the federal government changed the route of the highway and Interstate 90 now climbs out of the river basin at the gas station town of Vantage. You can still see the formations on a scrap of the old road by getting off of I-90 where it first crosses the Columbia at the Gorge Amphitheatre exit. “But because it’s now off of the main road,” Middleton told me, “that very dramatic formation has otherwise disappeared from people’s consciousness.”

“When we stopped at Dry Falls, my dad, brother and I were overwhelmed. What happened here? With it all, we wondered why this wasn’t better known, why wasn’t it presented to the public. Even today, you gotta really search to find a sign or anything that tells the story, or even a part of the story.”

Both professional and hobby geologists have been kicking around ideas for years of ways to tell this story. But even now, roadside signs are few and far between, are often filled with inaccurate or outdated information, and rarely say more than a few words about the entire story. This story, as large and influential as it is on our landscape, remains ignored, hidden in mystery like so much of our natural world is without some sort of public effort to open our otherwise closed eyes to it.

Dale Middleton is one of a handful of people on a regional crusade to spread the word of the floods. The National Park Service and people like Middleton, who is president of the Ice Age Floods Institute (IAFl), see fit to change that. The Park Service released a report in the fall of 2001 that outlined a plan for a National Ice Age Geologic Flood Trail, which would run from Missoula, Montana, follow the floods route, and end up in Portland, Oregon. The auto trail would include visitor centers, information kiosks, side trails and hiking and
biking loops. The proposal is now stuck in Washington, D.C., awaiting approval in Congress.

In late August 1987, the Park Service sent an internal memo requesting the agency take a leadership role in pulling together the many agencies responsible for land containing flood features. The idea was for a group of land management agency representatives to collectively evaluate the public value of flood features and determine whether or not a collaborative approach to telling the flood story was necessary.

The Park Service contacted everyone from geologists to regional NPS, BuRec, BLM, state, tribal and local leaders, educators and chambers of commerce about the project. After six years of newspaper articles, memos, and field trips, the Ice Age Floods Task Force met for the first time. Its initial task was to promote the story. Local and regional leaders needed to understand and get excited about the lakes and floods so that the task force would have a network of knowledgeable people throughout the region with whom to work.

From early on, three themes regarding the project emerged: The federal government should acquire no new land; the best and most effective way to educate the public on the floods was a region-wide interpretive program; and this interpretive program should be used to boost local and regional tourism in an economy once dominated by logging, fishing, mining, and farming but which is now in shambles due, in part, to environmental degradation. Although the Park Service is admittedly not in the business of boosting local economies, the agency realized that local economies were an integral component to a regional
network and it should thus not challenge efforts to marry parts of the project with localized economic development.

By 1996, the Task Force fell apart due to lack of funding and internal squabbling. But two years previously, it birthed the Ice Age Floods Institute, which was designed to support a coordinated interpretive program from a citizens' perspective.

"One of the good things," Middleton told me, "to come out of the task force was a cover sheet listing all the agencies and potential participants in the interpretive effort. [Then Interior Secretary Bruce] Babbit got his hands on the sheet and waved it back and forth at a meeting saying 'This is what I mean!' He was talking collaboration and partnerships and all that business. Well, he never followed up on that or any other letters I tried to shove under his nose. So the task force had to put things in the closet and wait for a better day. It was about then that the institute got started."

As it grew, the institute reflected citizen curiosities and needs, raised private funds for education programs, and engaged local communities in the flood pathways project, all while continuing to work with the Park Service. The IAFI worked early on to ensure that information about the floods, which was disseminated to the public—whether the institute sponsored the project or not—was accurate, generally accepted by the scientific community, and consistent. The institute played an active role in producing a video, The Great Floods, in 1994 and a year later, it partnered with NASA, the Jet Propulsion Laboratory, and Arizona State University on the Mars Pathfinder project. Floods scholar and paleohydrologist Vic Baker spent years comparing the channeled
scablands to the Martian channels and NASA sent a mission to explore this area of the red planet.

Still, the institute was faltering. It had no permanent home, it was growing only slightly, and some of the original members had disappeared from the scene. The institute tried to hold annual field trips but in 1997 lack of both funds and interest killed that. Nevertheless, the light didn't completely extinguish; progress and interest intensified elsewhere. Smithsonian magazine featured the floods in a 1995 article. In 1997, *Fire, Faults and Floods: A Road and Travel Guide Exploring the Origins of the Columbia River Basin* was published. In 1998, KSPS television from Spokane, Washington started work on a one-hour documentary entitled *Sculpted by Floods*, and the Discovery Channel did a bit piece on the floods in a special called *Amazing Earth*.

Perhaps the most important outreach publication was the release of a full-color, 36 x 45 inch map, *Glacial Lake Missoula and the Channeled Scablands*. This beautiful map, developed for the Forest Service, showed a snapshot interpretation of the Northwest—lakes, flood, and ice—when Glacial Lakes Missoula and Columbia were in and near capacity. It included other area glacial lakes, including Glacial Lake Great Falls, and the entire southern margin of the Cordilleran Ice Sheet, and it extended from Helena, Montana to the ice age coast, and from Bellingham, British Columbia to Bend, Oregon Its scope reached beyond just that of the floods and told the story of the glaciation in Idaho, the Puget Lobe of the Cordilleran, which covered all of Puget Sound and the Seattle area, and the ice age sea level, which was 300 feet lower than modern sea level.

With each new project or mention in a project, interest and knowledge of the
lakes and floods spread. A seed had taken root. But like the giant sequoias, it grew ever so slowly.

In 1999, Congress finally approved funding for a Study of Alternatives and the institute stood ready to assist the Park Service. As interest in the institute and the Park Service's study fed off of each other, institute membership grew.

A Collaborative Effort

For over a decade, "a sense of place" was the literary phrase de jour in the West. Today, it seems "collaboration" has taken its place. Despite their triteness, both ideas fit nicely into this story. Finding "a sense of place" in the middle of Grand Coulee can be a powerful experience; the thought of a 300-foot wall of muddy, icy water crashing and banging around between those walls, spilling violently at Dry Falls—if you can even think it, let alone sense it—rattles my brain. "Collaboration," an obvious next step in protecting the integrity of your "sense of place," is also integral to this story, but with a different connotation to how it is otherwise used today.

Whether it was intended or not, "collaboration" brings to mind contentious solutions to difficult regional environmental problems: grazing on federal land, protection of roadless areas, water rights that satisfy irrigators and habitat needs, and timber sales. I can see the flags burning, the yelling, the walking out, and the eventual grudging acceptance. To collaborate doesn't always need this, though. In the case of coordinating a region-wide interpretive effort, it means that a multitude of federal, state and local agencies, tribal councils, and private land and business owners need to work together to hammer out the logistics of organizing the nation's, perhaps the world's, largest
natural history interpretive effort. Because the most contentious elements of "collaboration" are absent—no land is changing ownership or management except where voluntary, and no natural resources are being extracted, or not extracted—the process should run smoothly. And it has thus far. But money spent by the Park Service and potentially made by local communities and the enormous size of this project still add challenge.

The Park Service, in conjunction with the institute, began creating a network of interested and accountable parties. To do that, the Park Service split the lakes and floods region into four study zones. Each zone set out inventorying and cataloguing its flood features, hosting study zone meetings to both seek public input and provide information on the floods and the project, and drumming up local interest by contacting media and other influential groups like chambers of commerce.

In addition to forging partnerships that are unique and specific to this project, the Park Service study explored the agency's criteria for designation within the NPS system. The *Criteria for Parkland* document says new areas must possess "nationally significant natural, cultural, or recreational resources; be a suitable and feasible addition to the NPS System; and require direct NPS management instead of protection by some other government agency or by the private sector."

As the study continued, each zone sent catalogued flood features, lists of interested people, and comments and recommendations from local communities back to the NPS and the consulting firm in charge of administering the study. Based on the information sent and evaluations by USGS and university geologists, and based on the *Criteria for Parklands* document, the Park Service
recommended that the region and some sort of geologic trail be considered for inclusion in the National Park System. The agency added, though, that the floods region wouldn't work as a more traditional national park or monument.

When I went to see Keith Dunbar, Team Leader in Planning and Partnerships in the NPS Columbia Cascades Office in Seattle, I was looking for insight into the Park Service's interest in this project and how it planned to coordinate a region-wide interpretive effort. Dunbar has been the point man in the Park Service for this project since its inception in 1993. He's a man of business. His office is neat, his shirt pressed, and his belly hung perfectly round.

"The National Park System has 387 units around the country," he started "and there are actually more historic sites related to our culture and the history of our nation than anything else. We have Civil War battlefields, Rosie the Riveter, and Pearl Harbor. We also have a wealth of natural sites in this system, some of which directly relate to geology. Devils Tower in Wyoming, Fossil Beds in Colorado, Pinnacles in California, Volcanoes in Hawaii. This project, like these places, tells us something about the formation of our planet.

"The Floods Region isn't one place; it's pathways of floods that occurred over a couple thousand years with varying intensity. And while this is not conducive to a park in the traditional sense with a boundary and a Smoky the Bear superintendent, it's very conducive to a trail."

The NPS is for it. Keith Dunbar says let's go. The project, the lakes and flood story, and the region meet all three criteria for some sort of NPS designation. The region covers just about every physiographic and ecological zone found in North America: mountains, rivers, lakes; deserts, prairies, wetlands; tundra, forests, marine environs. And it includes three of the biggest
geologic themes in North America: the Belt Rock supergroup in Montana, the Idaho Batholith, and the basalt flows of eastern Washington. It features visible and stunning remnants from possibly the largest freshwater flood to ever sweep the planet. It's unique. And its features are in fairly good shape.

Once deciding that the story was worth telling, the Park Service set three goals in designing alternatives for what the study project should do or how it should tell the story. Based on the historic role of the NPS and the available natural and cultural resources, it wanted to: identify for the public ice age floods resources; develop physical and visual access to these flood features; and develop a framework for cultural education and in-the-field interpretation for the natural and cultural history of the floods region. The Park Service drew up four alternatives, one of which eventually became its Preferred Alternative.

Interpretation and Education

In its study, the Park Service differentiated between the idea of education and interpretation. Interpretation, it says, is revelation based on information. It's the WOW! factor, the amazement in people's faces when they look at the Palouse Falls cataract and, in their mind's eye, see it gushing with so much moving water that they understand how the floods cut a new route for the Palouse River. Interpretation is interactive. Education, on the other hand, "refers to educating the public about the Ice Age Floods in an effort to engender a sense of protection and 'possessory' interest," says the Study of Alternatives. That's bureaucratic speak for, as Wendell Berry has said in so many others' essays, "We know enough of our own history by now to be aware that people exploit what they
have merely concluded to be of value, but they \textit{defend} what they love. To defend what we love [what we have interpreted], we need a particular language [education], for we love what we particularly know.” The Park Service slipped some ethics and values into its \textit{Study of Alternatives}. But the study stays true to its government agency roots and precisely breaks down its plans for interpretation and education.

To frame interpretation, the Park Service outlined an Ice Age Floods Region, which included the area of the lakes and floods and also an Ice Age Floods Geologic Trail that roughly follows the route of the flood waters from Missoula, Montana, to the Pacific Ocean. Within the pathway and region, the NPS wants to identify flood features and then interpret them in a uniformly similar style. For example, in the Moses Coulee, you might find a sign or series of signs that identifies the coulee as a flood feature, explains the floods story, including how this coulee was believed to be an old diversion channel when the Columbia was blocked by the Okanogan Lobe of the Cordilleran Ice Sheet, and postulates what the region might have been like geologically before the floods.

A flood trail would connect sites like Moses Coulee and its signs to one another. Although the Park Service initially envisioned the trail to be strictly a motor path, the idea has expanded to include bike and water trails and overhead air routes for small plains and hot air balloons. This was an important expansion in thought because of the similarities between a windshield and a television set, and because of an automobile’s inherent inability to float or to fly.

The flood trail is divided into four parts: the single connecting pathway, loop trails, spur trails, and gateway communities. The connecting pathway runs from Missoula through the panhandle of Idaho around Lake Pend Oreille, down
across the Spokane Valley and then follows the Columbia to Portland, Oregon. The loops and spurs spin off the connecting pathway through coulees, gravel bars and other flood features like a spider weaves her web from a single silk strand. Adjacent towns—the gateway communities—plug the perimeter of the floods region.

The NPS identified 13 gateway communities, each of which would have its own set of visitor centers and signs. The Park Service has also sketched 8 spur trails and 30 loop trails. Since these places would be in every and all types of designated land, managing the trail would not only require keeping close to 100 wayside signs, information kiosks, side trails and visitors centers unified, but keeping them unified among several different jurisdictions.

Alternatives

In its Study of Alternatives, the Park Service outlined four options on how best to structure and manage a coordinated, inter-state, inter-agency, private and public coordinated interpretive effort. Alternative 1 is the standard, do nothing, alternative. Alternative 2 establishes a committee run by the state legislatures and governors’ offices that would manage a floods pathway trail with no NPS involvement. The third and fourth alternatives involve the Park Service and differ only in their layers of management and jurisdiction. Both alternatives establish a separate group whose sole responsibility it would be to establish and maintain a floods pathway trail, here called the Ice Age Floods Geologic Trail complete with wayside informational kiosks and visitor centers, educational outreach efforts and media productions. And both would heavily involve the
IAFI to help coordinate and to raise private funds. But Alternative 4 goes one step further to include management of an Ice Age Floods Region.

If you imagine a four-state map of the lakes and floods and include on that all the trails and interpretive efforts that already exist, you have Alternative 1. Now add to that map a layer—by layer I mean a transparent cover, like a plastic sheet—which includes colored lines and shapes depicting a coordinated effort by the four states to develop an interpretive trail that follows the lakes and floods, and you have Alternative 2. On that layer you can see highlighted trail routes and road signs superimposed onto roads spanning the entire region. Add another layer that adds more loop and spur trails to the one major flood pathway. And add a dozen or so dots marking visitor centers and another dozen squares at the gateway communities. Each visitor center and trail section might be a different color based on the agency in charge of that resource or area. Now you have Alternative 3. You can see how each layer adds richness to the map and complexity to management. For Alternative 4, add another transparent layer with a shaded region that covers the entire area of the lakes and floods, much like the colored and shaded area on Jeff Silkwood's map, and put a thin border around that shaded area. That is the Ice Age Floods Region and Alternative 4.

"Of course," Dunbar reminded me, "this study was created for Congress and it's up to them whether or not this National Geologic Trail is created. But I'm pretty optimistic that it will be created. Granted the events of September 11, 2001 have changed some things in terms of our national priorities, but after we've made sure we're doing what we need to do in terms of the military and defense, I think Congress will return to these domestic tasks at hand."
Regardless of the alternative the NPS preferred—which was Alternative 3—and whether or not Congress approves it for designation—I hope that they do—the Park Service acted more like a wildlife agency managing elk or bear habitat, except in this case it is managing cultural habitat, than it does managing islands of wilderness, like traditional Western national parks. And although it has done this before, it hasn’t done it to this extent.

Layers comprised of interlocking watersheds and jurisdictional Venn diagrams may still not be the best way to view our world, but it is much better than seeing it as a two-dimensional pan of neatly cut lemon squares. For ease of management, the NPS chose to remove the floods region layer. But by eliminating the region from its 186-page *Study of Alternatives*, the agency has not eliminated it from our minds.

A Final Note

It’s a curious thing, both Dunbar and Middleton told me, and I agree, that so many people, especially those living in the region, don’t know about the floods. Dale seemed to feel it is because no one has ever bothered to tell them about it, and thus, there is the need for some sort of designation and interpretive program. Dunbar agrees, but feels the problem runs deeper.

“I know there is a lot of open country near Missoula,” he began. “But most people live in city centers of some kind. As people go about their daily lives, they aren’t as in tune with the natural world as past generations were, when we were more agricultural and we lived closer to the land. I would suspect that if you went out into some of the farming communities, the people would know the soils and the precipitation; they would know when the winds come, when the storms
come; they would know the cycles of the earth in terms of the seasons and changes in climate and topography. And they would know what part of the slope not to plant on and what part of the slope gets moisture more than others. All those things are more related to agriculture or timber production. But because all of us go to Wal-Mart and travel down asphalt roads and go in our homes and have cable TV and all the appliances, we don’t interact with our natural world as much. It’s machines and it’s what Man Has Built and it is not dealing day to day with, not just geology, but botany and biology and the flora and fauna of the earth.

“I think people don’t know much about the floods because they have generally lost touch with the land. And even those who do have contact with it might not know the geologic story of how the deposits in places like the Wallamath and Yakima Valleys affected our settlement patterns during the time of the Oregon Trail pioneers. There is a hundred feet of fertile topsoil there that wasn’t there 17 thousand years ago. But it’s not just the floods geology; there are probably a lot of other things about our natural world that people aren’t aware of.”

The flood region is not one site, but several smaller ones scattered around our cluttered landscape and our busy culturescape. The Park Service recognizes that and is, in effect, threading this story back into our lives.
Field Trip

I left Seattle Monday morning, a little after 9:30 so as to avoid rush hour traffic. After a week in town, I had met Richard Waitt, geologist Brian Atwater, Dale Middleton and Keith Dunbar. And I had a hoot of a visit with Brian Priest and Matt O'Brien, the same two friends I once lived with and with whom I sat and watched Mount Sentinel burn almost two and a half years ago. The Freemont neighborhood, where they now live, was cool and clear, but as I made my way over Lake Washington, the fog increased until I was covered by pea soup. Lake Washington is a freshwater lake set in a puzzle-work archipelago of islands, inlets, sloughs, bays and straits known as the Puget Sound. The lake owes its freshwater status to the Puget Sound lobe of the Cordilleran Ice Sheet, similarly responsible for Lake Missoulas and the floods. As it moved southward, this particular lobe gouged out the islands, inlets, sloughs, bay and straits, but it didn't quite dig as deep where the lake now sits. Because the top of the lake is above sea level and the bottom is above the level of the sea floor, when the ice receded, that basin never filled with sea water. Instead it filled with freshwater tumbling out of the Cascades. And so, Interstate 90 is built on floating bridges as it crosses from Seattle into Bellevue.

The weather cleared on the eastern side of the Cascades and I drove straight on through to my first stop on the Columbia. Because I started in Seattle,
I took a salmon’s-eye view of the floods; I started downstream and made my way upstream to the source of the floods in Idaho.

I got off I-90 where it first crosses the Columbia River at the same exit one gets off to see concerts at the Gorge Amphitheatre. Instead of heading to the music venue, I dipped back towards the Columbia River on the old highway. Waitt and Middleton both suggested I stop here. Frenchman Coulee was one of those unusual spots they saw as they drove between Seattle and Montana before the interstate was built in the late 1960s.

Babcock Basin sits to the north of the Frenchman Hills, which run perpendicular into the Columbia River. The coulee, a mile wide and 3-4 miles long, is a sharp gouge cut out of the basin over the river at the base of these hills. It looked as if someone had taken a giant woodcarving tool and chiseled a hunk of earth out of the basin. About a mile away from the river, several hundred feet above the water, a dozen or so large black basalt columns stick straight out of a cliff. They stand tightly next to each other like a mouthful of crooked teeth. At the bottom are several access roads and flat parking areas. Two pickups and a Subaru wagon sat parked on the near side so I drove around to the far side to park my truck. Broken glass, a few scattered beer cans and plenty of cig butts covered the ground. I walked over to check out a bulletin board. Frenchman Coulee. Maintained and managed by the Washington Department of Fish and Wildlife. The information sheet read: “The striking topography is a timeless testament to the raw power that shaped the landscape.”

REI and the Access Fund, a climbers’ nonprofit, had jointly worked to promote access and protect the area. Their info sheet said a bit more about the topography: “Frenchman Coulee is one of many canyons in Central and Eastern
Washington that was carved by a series of colossal floods. Waters originated in northwestern Montana where a huge glacial lake broke from behind an ice dam and released water south and westward across the Columbia Plateau.” There was a website and some info on protecting this delicate desert landscape, along with contact information for the Frenchman Coulee Climbers Coalition.

I turned from the board and walked towards the basalt formations. Patches of exposed basalt worn down to a soft gray color poked through the dirt road. Some spots were sharp and I became a bit nervous driving around out here with only one spare. I walked a path up the cliff to the formations. The talus below the cliff was all chipped basalt and sounded like clanking bits of china beneath my feet. Most of the rock was smoky dark brown where it wasn’t covered with graffiti. It turned my hands rusty. The column formations stood a good thirty feet above my head. Many had bolts drilled into them. I walked through a gap between two of the columns to say hello to a couple of climbers. They were computer jockeys from Seattle, they told me, but were otherwise too preoccupied with ropes and belays to chat.

From up here, I had an amazing view into the coulee. The floor sloped gently towards the river until it dropped off into the water. I could see buried gravel bars in the sage—gray and teardrop-shaped, the pointy side facing upstream to the flood currents, the rounded side towards the river; ghosts from the ancient floods. Across the coulee, the basalt cliffs on the other side waved like an ocean on its side. Each individual wave was made of small tubes of basalt, much smaller than the tubes of the formations.

I climbed down and ate lunch with the black flies. They seemed to enjoy my Tang.
After lunch, I walked to the mouth and lip of Frenchman Coulee, out across the sage and the other plant types, including a flowering steppe grass, a bunch grass, and some other scraggly brown itchy thing that kept scratching my leg. The land rippled and rolled towards the edge, but was mostly flat. The soil was gray and powdery. Some spots had what looked like petrified cow patties—round mounds of dry brown dust. Some areas seemed to have a cryptobiotic-like soil crust. It didn't look like much more than silt, but it had fine green and brown strands running through it, which I could see when I picked up a handful. I tried to stay off of these areas and I instead walked on the scabs—the basalt bumps on the land where the soil had been washed away and not filled back over by flood deposits.

A light breeze blew up the coulee around 4, pushing out a layer of clouds that snuck in after 1. The coulee rolled along until it came to the edge. Here it dropped off a couple hundred feet into Wanapum Lake, one of the many such lakes hiding the Columbia River. There was nothing across the river but more rock and sage for at least 15 miles in the Colockum and Quilomene Wildlife Refuges, and eventually Highway 97 and beyond that, the Wenatchee Range of the Cascades.

I walked back to the truck and drove down to the boat ramp. Then I came across a guy in his boxers perched on a rock. He had one of those annoying little yapp dogs with him. I waved but walked around him to the water. The man put on a pair of jeans and a button-down and came to say hello. Turns out that this road going down to the boat ramp was the old highway. You could see it continuing on into the water, parallel to the shore, just a few feet below the surface. The road came out of the water like a jumping fish, went up the mouth
of the coulee, right next to the basalt formations Waitt and Middleton spoke so affectionately of, and continued east. This guy also drove the road as a kid, like Middleton, between Darby, Montana, where he was born, and Seattle, where his family lived. And he was also fascinated by the formations he saw. So fascinated, in fact, that he bought a house in Soap Lake, at the southern end of Grand Coulee, the next stop on my trip. He told me about the nude beach just down the pathway and about another nude beach on Soap Lake. He preferred these beaches, he said, because they tend to be less crowded, nicer, and a bit more out of the way.

Driving up from the water and into the mouth of the coulee, I stopped at a road cut. Sure enough, the entire hillside, all the way from the water to the lip of the coulee, was unsorted rock and sand: flood deposits. As the water came tearing through the canyon, it carried with it large sediment loads. When the flood currents dropped into the Columbia, they released the rock and dirt they had been carrying. Frenchman Coulee is one of the smaller of the dozens of coulees on the Columbia Basin, but it is dramatic. And it's just one small piece of the very large puzzle I was in the process of piecing together.

From Frenchman Coulee, I drove northeast through Quincy Basin to Soap Lake at the southern end of Grand Coulee, up past the first few lakes, including Soap Lake, and deep into the chasm to an area called Sun Lakes State Park in the lower Grand Coulee. I put the truck in four-wheel mode and cruised down a two-track to Perch Lake. I spent the night with the lake to myself. I had a sage fire big enough for one on a basalt outcrop next to the water, and I watched the moon rise over the cliff wall behind me and illuminate first the opposite coulee wall and then the coulee floor, including the lake, which turned silver. I woke the
next morning to watch the sun follow the moon's path and illuminate the wall across from me. I ate my corned beef hash, swilled some coffee and continued on down the dirt road to the east side of Dry Falls. I could clearly see the worn out spillways, where the rushing floodwater plummeted from the upper coulee. The area reminded me of red rock country, without the red, so I could accept this erosion on such a grand scale. But this was strange in that the water flowed down from all the way up there. The pourovers were so distinct, though, that with a little suspension of disbelief the scenario became clear: water fell off the top of the falls and scoured out the plunge pool at the bottom, now referred to as Dry Falls Lake. A bunch of old fishermen had schlepped their aluminum canoes and rowboats all the way out here just to fish the alkaline water for a few rainbow trout, which clearly didn't belong, especially since the lake had no outlet.

I stare at water all the time, both fishing and river guiding and often I can see it just by closing my eyes: pourovers, riffles, runs, eddy lines, dark water, clear water, fast water usually. There is a spot on the Alberton Gorge section of the Clark Fork where the river is 80 feet deep. The current constricts and pours over a rock ledge. Normally when water pours over a ledge like that, the water will create a "hole," a pocket of recirculating water that sucks you up and down like a washing machine before spitting you downstream. But at this particular spot, Tumbleweed, where the river channel is so deep on the dropoff, the current tends down, not forward, as it recirculates. And it stops and holds you before letting you go, if it decides to let you go. I tend to avoid that hole. I can only try and imagine the hole at the bottom of this falls when the floods came through. Not only is the drop 417 feet, but the water was estimated to be as high at 300 feet at the top of the drop.
I hiked up from the plunge pool at Dry Falls onto another plateau. It seems the rock wall I'd slept below wasn't the coulee wall, as I thought it was, but was instead a long skinny island, like the dorsal fin of a fish, in the middle of this giant canyon. On the other side of the fin a roily plateau with another dry falls and plunge pool sat a bit farther back.

I walked clear to the downstream end of the fin to another outcrop of basalt formations like the ones I saw at Frenchman Coulee. On the way back, I found a trail up to a notch and took it. From up there, I could see a scabland eddy-like feature on that far east plateau, the one hidden behind the fin. And I could trace the current over the spillover into the plunge pool and across the plateau. This feature was a chunk of basalt sticking up out of the ground. The upstream side had been rounded smooth by the flows. The downstream end came to a point surrounded by a long gravel tail, like on a comet. Just my side of the feature was another peapod-shaped gravel bar, pointed on both ends and pregnant in the middle. The current had come around the basalt chunk and deposited gravel at both the end of the basalt as well as in a bar on the other side of the main current channel. I couldn't see any of this as I walked right over it.

It's amazing, I thought, that for two to three thousand years, this was the main stem of the Columbia, and it was full of water. It's big in here, wide and deep. It would hold a hell of a current. Did the Lake Missoula floods fill this whole hole? I couldn't compute magnitudes any more. How much water was here? Did it really all come from Lake Missoula and roll this far away in a day or two? For a moment, the whole thing—lake, floods, landscape—became uncomfortably unfathomable. And even after I regained my sense of three dimensions, a slight feeling of vertigo remained.
Dry Falls, Bretz was the first to postulate, started some 17 miles south of its present location and moved northward with the erosive power of the floods. The lakes left along its path in the lower coulee—Lenore, Alkali, Blue, Deep, Perch—are remnants in a way of the old plunge pools. Not a drop of water falls off these falls today. It's so hot and dry out here that I can hardly imagine the rock even being wet.

As the floods tore through and receded the falls, they carved out this canyon and deposited several cubic miles of rock and dirt debris both carried through here and plucked from here onto a depositional fan in the Quincy basin. Most likely, during the biggest floods, the current coming from the bottom of Grand Coulee would have cut through deposits from older floods, leaving a river channel. But there is none, which adds to the evidence that geologists like Waitt and Brian Atwater see as proof that the floods waned in size. Atwater found other evidence in the Sandpoil River Valley, where I’m headed tomorrow, that glacial Lake Columbia existed about a century longer than glacial Lake Missoula. So the depositional fan we find here today must have been from glacial Lake Columbia overflow, not flooding, because that would have left a river channel.

During the big floods, the waters backed up here, into Quincy Basin, also the Pasco Basin above Wallula Gap, and up the Yakima and Snake River valleys. As backwater drained out Wallula Gap, it also spilled into the Columbia through tiny Frenchman Coulee.

I drove farther into the coulee to the upper section, above Dry Falls. For about half a mile above the spillway, the coulee seems to disappear; it's flat in all directions and there are no walls. Soon, the walls begin to creep out of the
ground again at the far southern end of Banks Lake. Perpendicular to Dry Falls is a long but shallow dam—Dry Falls Dam, and behind it is Banks Lake. The dam’s spillway is tiny; it’s maybe sixty feet wide and with a similar drop. Below the spillway is a small cement-lined irrigation ditch that runs along the top of the eastern wall of the lower coulee all the way into Soap Lake. This dam is part of the Central Washington Irrigation Project. Today it’s filled at the other end by pumping water out of the Columbia/Lake Roosevelt, when the Grand Coulee dam is turned down at night, and up 500 feet into Banks Lake. It’s a way of getting water into central Washington fairly easily. What I find remarkable about this process is how similar it is to the way glacial Lake Columbia operated with the Grand Coulee so many thousands of years ago.

Banks Lake is a shallow lake that covers very little of the Upper Grand Coulee. Except at the head, this upper coulee is a basic straight shot between basalt walls. The talus on the walls today is post-flood talus; during the floods, the coulee floors would have been swept clean and the walls would have come to a perfectly square corner with the floor. This is a low reservoir partially because fractured basalt walls, which erode so easily, won’t hold a dam.

For the most part, the Missoula floods stuck to preexisting drainages where those drainages could handle the load. More often than not, though, the floods proved to be too much and they carved new drainages, often making shortcuts between watersheds. Coulees today are dry drainages that all point to the Columbia but often cut across watersheds. They were the paleofall lines of the basin, extra drainages cut by the floods in order to drain the Columbia Basin. Grand Coulee is the largest and most dynamic and complex of these coulees.
Some geologists postulate that Grand Coulee was a streambed of some sorts before it eroded into a giant coulee. But which way did it flow? Was the topography of the basin such that it could have been flowing northerly into the Columbia?

As I drove up the northern end of the coulee, I could see a change in the geologic formations. Most of the black and dark brown basalt was scraped away or left in thin layers. Monstrous chunks of tan or milky colored granite came up from underneath. This exposed granite is the only place where the floods cut all the way through the basalt. Although it erodes easily in the path of rushing water, the basalt is thousands of feet thick across the landscape. The basalt formations began as flowing lava about 17 million years ago, when they possibly moved in waves from the southeastern Oregon, northeastern California, western Idaho region. I say possibly because the exact nature of these flows is not well understood.

By now, it was mid-afternoon, I was thinking about dinner and a campsite and ready to move north. I headed up to the Grand Coulee Dam and the Columbia through Electric City and Grand Coulee, both of which seemed to be a mix of local motorboat heads and government workers. By the time I got to the dam, the visitor center had closed, but I didn’t need to go in. The dam is built between two granite mountains on either side of the Columbia. Forty-four million tons or 11.9 million cubic yards of concrete make up the 550-foot tall structure, the largest such concrete structure in the United States. The base is 500 feet thick and the top and narrows to 50 feet thick. The dam has three powerhouse complexes, miles of high-tension wire shooting every which way, and a lot of pretty flowers planted on green strips all over the viewing area.
There is a laser show here once a month. At the bottom of the spillway a sign points to the water trickling out of the biggest concrete structure in North America. It says “Columbia River.”

I suppose that I should marvel at the engineering accomplishment that is this dam and hydroelectric project. And I suppose that I am also expected to feel sympathy for the loss of native riverine life due to that dam. But I feel neither. I can only think that this dam and what it can and has done in terms of producing energy, storing water, changing landscapes, and altering ecosystems pales in comparison to the ice dam that once stood here. This pathetic little thing feels like a minor bruise in the geologic life history of the Columbia River.

The way the dam is built into the lower half of the canyon, it looks like, if someday deemed necessary, stacking more concrete on top of it could enlarge the dam. Driving along Lake Roosevelt, it is obvious that just the basin in which the river sits could hold quite a bit more water, as glacial Lake Columbia once did. To the north is a wall of granite some 400 to 700 feet above the lake. And to the south the landscape gradually uplifts to a flat, broad shelf. That shelf is full of curious-looking rippled farmland.

I wonder what the BuRec guys knew about the operation of glacial age Columbia River in 1940 when they were putting the finishing touches on the dam. That was the same year that J. T. Pardee revealed to the geologic world his previously secret source of Bretz’s floods: glacial Lake Missoula. When glacial Lake Missoula was finally linked to the floods, the story of the river finally began to take shape.
I camped that night on a sliver of BuRec land on a beach that I imagine normally wasn't there, judging from the high water marks on the rock next to my tent. I opted against the state campground just down the road even though only a few of the 100 sites were taken. I wanted something less lonely. So I found a place next to Lake Roosevelt where I once again saw no one, again feeling like I had the lake, or at least a tiny thumb of it, to myself. The moon, still almost full, came out to keep me company.

In the morning after beans and toast and coffee, I headed up lake to Keller's Ferry, probably only one of a few gratis ferries left. This motorized barge holds a maximum of six cars and goes back and forth across the lake from 6:30 am to 11:30 pm all day, every day. Once across the lake, I headed up the Sandpoil Valley, a tributary of the Columbia and now part of Lake Roosevelt, to look for glacial Lake Columbia deposits. A few feet from the north shore of the modern lake, I entered the Colville Indian Reservation. The Sandpoil Valley looks much like the rest of this part of the Columbia: gray and brown granite covered with yellow and brown earth, a few shrubs on the north aspect hills, and some ponderosa pines.

I first went up the Manila Creek drainage, a tributary to a tributary, in search of some of the sedimentary layers (varves) that Atwater talked to me about a few days earlier and researched back in the late "70s. The Manila Creek road turns immediately to dirt and goes by two shanty ranches before it is fenced off, well below where my map says the road is supposed to end. I parked where I could and headed down to the river, here still a lake, and found nothing. So I went back to the mouth of the creek and found a small road cut. I picked up a handful of dirt by my feet. It was coarse but not rocky and made up of all the
same material. I went up by my knees. This stuff was silky, like baby powder. Up by my chest, the dirt was again like it was by my feet.

I pulled out my new field shovel and began cutting away at the cliff. Layers: a thick layer of brown gray followed by a thinner section of many different colored varves. Above that, another thick layer of gray followed by another section of many different colored varves. Above that, though, was a thick layer of clayey material. This, I knew, was lake deposits. I didn’t know about the other layers below. As I continued cleaning off my layers as best I could with what was proving to be a lousy new shovel, I found a surprise: tucked inside the top, multicolored section of varves, I found a thin layer of almost pure clay. I pulled a bit out of the cliff, spit into it and rubbed it around in my hand. It absorbed the water, swelled, and looked and felt like the gray clay I once used in pottery classes. This, I figured, was either a layer from a very short-lived lake or an ash layer from some Pleistocene Cascade explosion.

I crossed the road to take a leak and found a huge cliff loaded with layers from my feet to well above my head. The motherlode! Sort-of.

The cliffs sat about 15 feet above the lake. I had to climb another six feet up soft talus to get to exposed layers in the cliff. The layers went from there up another 12 or so feet. And to think that these were once the bottom of the lake. I climbed up the talus and dug footholds. My first swing into the deposits roused a hornet’s nest. Three came tear-assing out of there but seemed surprised that someone would be chopping at their home. As one hornet flew by my left shoulder near my ear, I yelped as if my tail had been stepped on, and I jumped down the hill, sliding the last three feet. I moved left about 20 feet and tried again.
The talus was too thick and my shovel too small and crappy to dig into it so I started near my knees and found two similar multicolored sections of varves like what I had seen across the road. The multicolored layers had strips of reds, yellows, greens and lavender. I imagined them to be either flood layers of some sort, either Lake Missoula floods or some other giant paleorunoff. In between these sections I found a similarly-colored gray section, but in this one I could see layers, wavy layers that rolled across the cliffside. Above the second multicolored layer were thicker layers of a gray clayey material. These layers were about 3/4 of an inch thick and very crumbly. I tried unsuccessfully to pull an intact block off of the cliff. Above these layers were layers of a similar substance, but these layers were much thinner, less than 1/2 of a centimeter. I figured my findings were consistent with what Atwater says: he found that as the layers got higher, indicating more recent lakes, they got thinner, corresponding to smaller glacial Lakes Columbia and smaller or no glacial Lake Missoula floods.

Another 10 feet to the left, a bit farther from the hornets' nest, a bit more of the lower part of the cliff was exposed from under talus. A thick section of a sandstone-like material sat right where the bottom section of multicolored layers was and extending down. It broke in large angular blocks like sandstone, but was much softer. Still, I had to really whack at it to get it to break. Below that anomalous section was another section of very thin clayey varves. These crumbled with just a touch; the layers seemed to have no cohesion between them at all.

By now I was dusty so I took off all my clothes and took a quick bath in glacial Lake Columbia.
I air-dried and cruised up the valley to find the end of the lake, where the Sandpoil was again a river. Up valley in this sparsely populated Indian reservation the hills grew greener, steeper and closer together. Abandoned cars on blocks sat like mushrooms after a rainstorm clustered under the bigger trees. The river itself was barely a trickle above the lake.

The ferry once again carried me across Lake Roosevelt and I climbed back up the Columbia basin to the wavy farmland. I headed east towards Spokane and, looking far to the north, I could see clear across the golden landscape to the drop-off into the Columbia. The Kettle Ridge Range stood dark gray, almost blue under the smoky sky. At some point, the Columbia River/Lake Roosevelt turned north, laying a drainage between the Kettle Ridge Range and the Selkirk Mountains, at which point the Spokane River took on the task of continuing east with me. That river also flows through a similarly deep cut in the earth. During the ice age, glacial Lake Columbia continued on up the Spokane River sometimes as far as Coeur D'Alene. Since the north was covered by the Cordilleran Ice Sheet and cut off the Columbia, the Spokane River became the far end of the drainage.

Looking downstream from the Lake Missoula ice dam, now only a few miles northeast, as the floodwater poured into Spokane, they had one or a combination of three major routes: down the Spokane River to the Columbia, which is the route I followed, down the Telford-Crab creek scabland through the center of the state, or down the Cheney-Palouse scabland, the farthest-east reaching of the floods pathway.

Coming from the southern arm of Lake Pend Oreille, where the ice dam once stood, the floods would flow down the Rathdrum Prairie, the southern end of the Purcell Trench. The Rathdrum Prairie is a wide sloping, semi-forested
plain between the Selkirks and the northern Bitterroots and was the path that the
floods most likely took when they first burst from the dam at Lake Pend Oreille
so many thousands of years ago.

A wall of water between 200 and 2 thousand feet high that spread across
the Rathdrum Prairie rumbled southwest, looking for a way back down, into the
Columbia, where it was destined to go. In Spokane it sometimes found options,
depending on where it found the path of least resistance and whether or not that
path could handle the entire volume of water. Often it found the tail end of
glacial Lake Columbia.

Oddly, today Rathdrum Prairie has no clear drainage—no river of its own.
As I got closer to the southern end of Lake Pend Oreille, the forests grew thicker,
the air cooler, and the sky bluer. I'm back in the North Country.

Lake Pend Oreille, like Lake Roosevelt, doesn't fill its basin. In this case,
the lake empties into the Pend Oreille River, which is really the Clark Fork
returned. That river heads west and then immediately north into Canada where
it immediately turns back west and hooks up in just a few miles with the
Columbia, which flows due south into Washington. That outlet, along with the
lake, the basin, and the continuation of the river, was under thousands of feet of
ice. When the dam broke, Rathdrum Prairie was the only way it could go. Today,
the lake sits in a depressed basin. The forest is thick on the shelf above the lake
and you can't see any water. Sometimes you can see the mountains on the
opposite side of the lake sticking between the trees.

I drove around and around the southern end of the lake looking for my
one-site and no facilities or services campground. I had a road picked out.
Closed. No explanation. The sun now cast a beautiful alpenglow on the Coeur
D’Alene Mountains. I was tired and hungry. The next closest option was around the bay at some state campground or a forest service road near Bayview.

Lake Pend Oreille is smothered with places like Bayview. You drive four miles through pristine forest on immaculately paved roads only to descend upon Disneyland towns. RV parks that are more like parking lots in the center of town, tent camping on the grass next to the garage—watch out for the sprinklers in the morning—shady marinas, and rows upon rows of summer homes and trailer parks. The Forest Service roads are just the roads you take to the big, rich-people houses. This is not the first town like this I’ve found on Lake Pend Oreille while looking for a nice quiet place to camp and that’s too bad. The lake deserves some undeveloped shoreline. Like Lake Roosevelt, which has boat launches and campgrounds every few miles, roads encircle the lake.

Eventually I found a nice field next to big trees on state park land to set up camp and eat dinner. It was flat and it wasn’t the campground. A family of whitetail had the spot next to me.
A Plea

This is what once happened to water and ice left to their own demise, when nothing or no one could stop them. It is the story of a great cleave of ice that blocked a mighty river and formed one of the largest freshwater lakes the planet has even seen. The lake may have burst under the tremendous influence of that water and released unprecedented floods, which drastically altered the landscape downstream. It may have returned. The glacial Lake Missoula phenomena disappeared with the last ice age, and I suspect that as long as we remain the dominant species, even if we do make it to the next ice age, we will never see anything like it again. Society would Hayduke the ice dam; as amazing as we pretend to think the lakes and floods were, the whole thing would put a damper on our lifestyle.

Those of us living in the ice margins would have new forces with which to reckon, forces we couldn't stop but could soften a little with the help of bombs and dams. I have no doubt we'd try; we're clever people. Yet just by trying, plus whatever effect we would have on the ice and floods, even if only slight, those wild forces would lose some of their integrity. Clever people don't always do wise things. This is why it is so important that we protect the memory of when water and ice, like grizzly bears and salmon, were wild, and free to do as they pleased.
Following is a partial list of sources I used in writing this thesis. I also spent a good deal of time reading other popular works, walking and visiting the various places mentioned here, and chatting casually with scientists over coffee or outside of libraries.

Prologue
This piece first appeared in a similar form in *Camas*, Fall 2001

Introduction

The Floods


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Soil

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