Geology of the Lower Owyhee River
Oregon's "Grand Canyon"

By Kenneth Giles and Kyle House

Intentionally Left Blank

Geology of the Lower Owyhee River
Oregon's "Grand Canyon"

By Kenneth Giles and Kyle House

Revised April 22, 2025

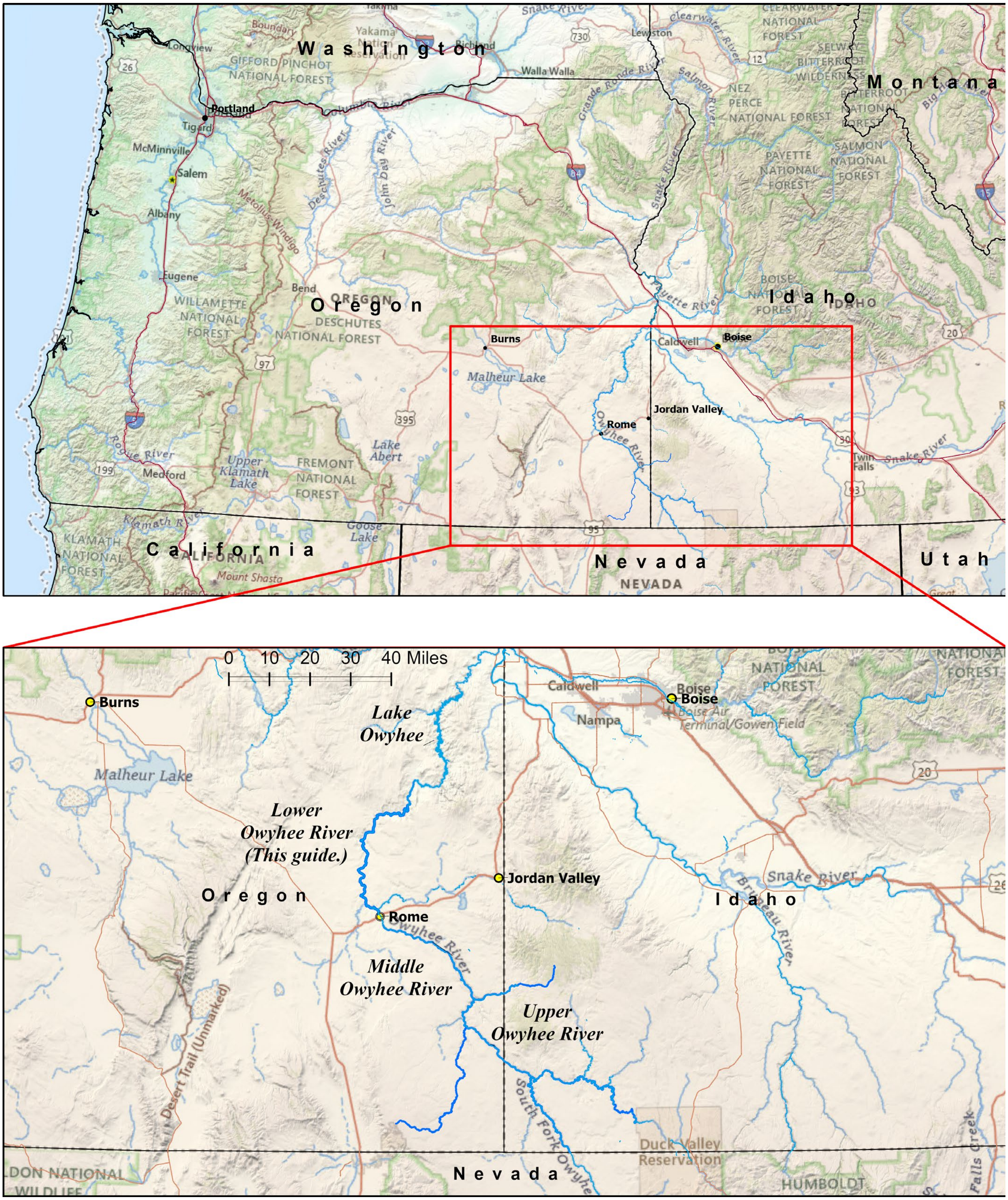
All photos and maps are by the authors, unless otherwise noted.

Kenneth Giles
giles1947@gmail.com
Woodland, WA

Kyle House
kyle.house@hey.com
Flagstaff, AZ

Cover photo: "Sleeping Dragon Gorge and Tanager Canyon" by Kyle House.

Location of the Lower Owyhee River



Segments of the Lower Owyhee River

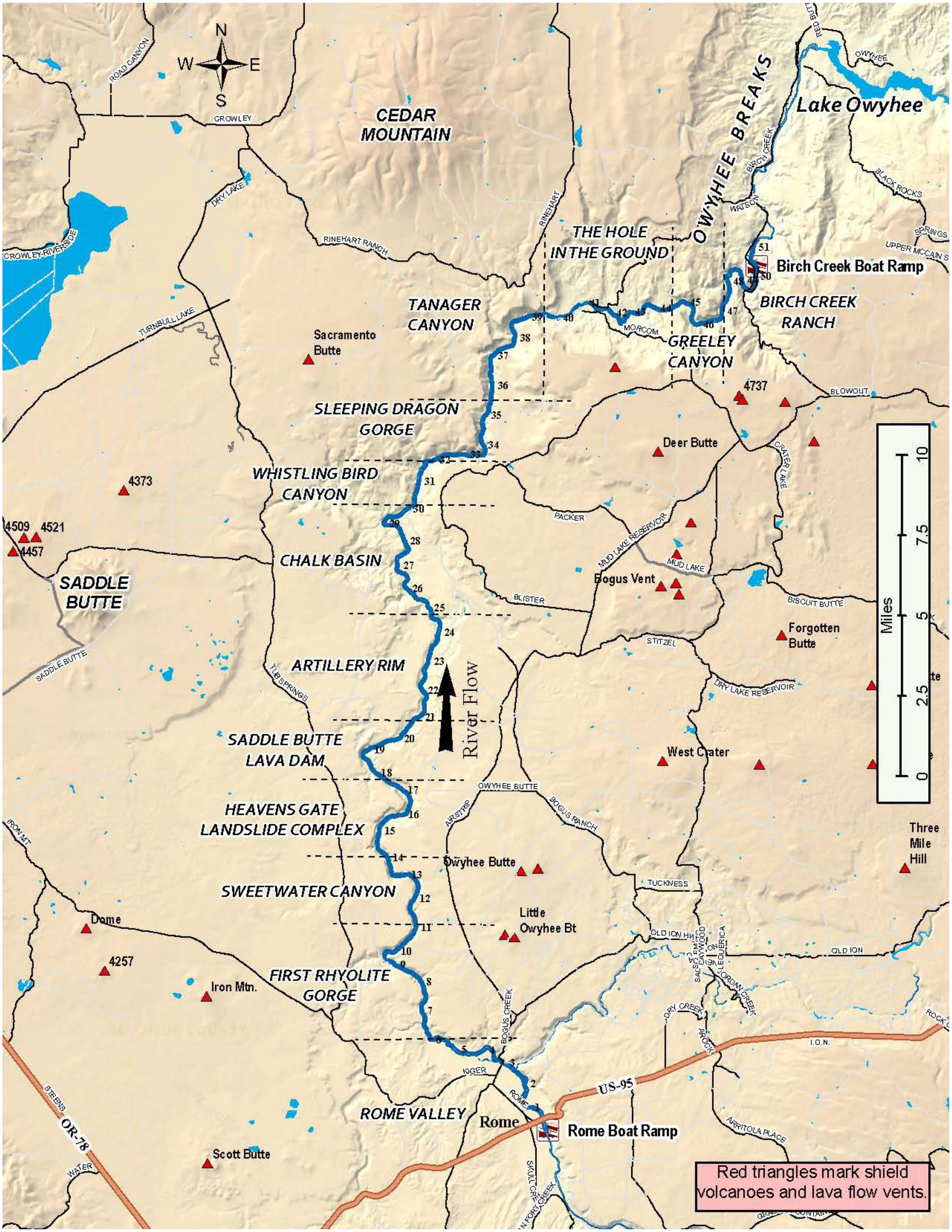


Table of Contents

Introduction

Welcome to the Owyhee River, a unique geological playground where visitors will thrill to deep canyons, mysterious hoodoos, and rugged badlands. Often called "Oregon's Grand Canyon," the Owyhee is among the most remote places in the continental United States, almost inaccessible other than by boat during a brief spring rafting season.

Wild and untouched, 120 miles of the Owyhee was designated a National Wild and Scenic River by the U.S. Congress. This geological guide interprets the river's most popular and spectacular 50-mile-stretch from the rafting put-in at Rome, Ore. to the Birch Creek takeout.

A lot is going on in this dry and windy landscape. Towering lava cliffs, narrow gorges, riverside hot springs, and colorful candy-striped mountains will catch your eye. Part of this exciting geography was created as recently as a few thousand years ago while sections are almost 16 million years old. There's evidence of ancient landslides and lava dams that trapped the Owyhee for thousands of years before its waters would break free, carving new channels, scouring out dogleg bends. Canyon walls display volcanic rock in almost every form: Vertical, pinkish rhyolite cliffs in Sleeping Dragon Gorge to multi-colored lakebed sediments and ancient lava flows in the badlands of Chalk Basin.

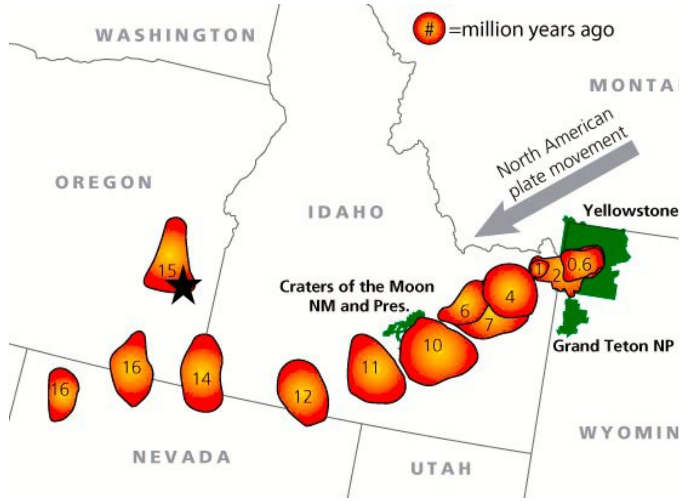
The goal with our Geology of the Lower Owyhee River is to explain what you see as you travel downriver, knowing there is a "WOW moment" around every bend. Try out a few hikes away from camp. Enjoy a hot springs riverside soak as did the first people who came into this region. Marvel at their ancient petroglyph-covered boulders. Try to imagine life on the Owyhee near Birch Creek when a group of hunter-gathers lived in pit houses there 7,600 years ago. Wonder at the geology, enjoy the wildlife, and let the serenity of the Owyhee seep into your bones. This is a magical place with much to tell us.

Kenneth Giles
Kyle House
2025

Four Key Events

The Yellowstone Hotspot

The wonderful Owyhee geology was made possible by the Yellowstone hotspot that created a huge pool of magma just below the surface here about 15 to 16 million years ago and left a trail of now buried explosive volcanic calderas in its wake. Today, the hotspot plume has rotated eastward under the North American plate and is now under Yellowstone National Park. Millions of years ago, hot springs, geysers, oozing lava flows, and caldera lakes like we see today at Yellowstone likely existed in this corner of southeast Oregon. So much time has passed that hotspot evidence has long since been eroded and buried by later geologic events. Although the hot spot moved on, volcanic activity continued. Later lava flows created the rolling high lava plains that now cover the Owyhee landscape. More than once, they dammed up the Owyhee River channel, altering its course. Almost everything we now see in the Owyhee Canyon is volcanic in origin and a consequence of the hot spot.



Trail of Yellowstone Hotspot volcanic calderas across North America began near here about 15 to 16 million years ago. Lower Owyhee River location marked with star. (Source: NPS.)

Birth of Owyhee Canyon

The bulk of the modern narrow and deep Owyhee Canyon was carved in only the past few million years. Before that, sometime between 2 and 5 million years ago, the ancestral Owyhee River occupied a much wider and shallower canyon. Geologists think the birth of the ancestral river was probably caused by fluctuations in the level of ancient Lake Idaho. For more than 6 million years, Lake Idaho filled the Snake River valley with a huge lake about the size of Lake Erie. Water levels fluctuated but generally stood 1,000 to 1,600 feet above today's valley floor. The water was so high that there was little elevation difference between the lake surface and the surrounding Owyhee landscape, so streams emptying into the lake did not incise deep canyons. Then sometime between 2 and 3.4 million years ago, the lake gradually overflowed to the west down what is now the Snake River, in the process carving Hells Canyon and leaving behind an empty lake basin—today's fertile Snake River Valley. The lake emptying took several million years, causing the ancestral Owyhee River's base level elevation to drop by over 1,000 feet. The drop in base level triggered accelerated erosion and downward cutting of the river channel, producing today's deep and narrow canyon.

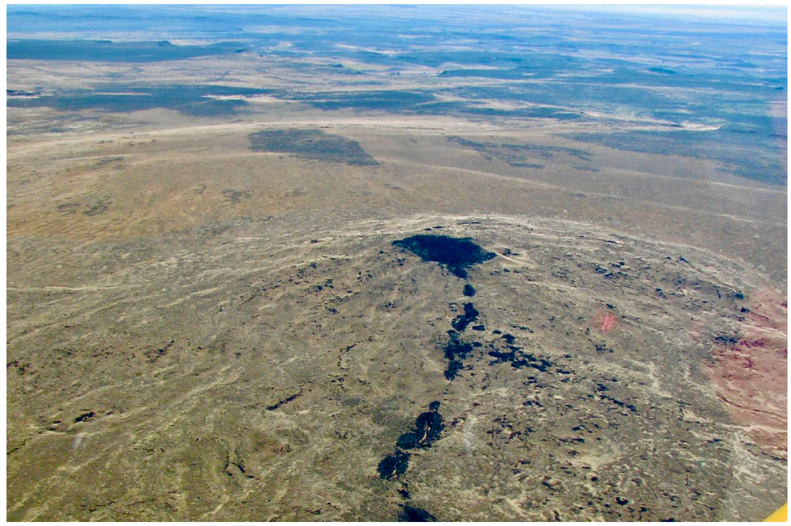
Ancient Lake Idaho. (From Geology Underfoot in Southern Idaho by Shawn Willsey 2017)

Plateau forming lava flows

After the hotspot moved east into Idaho, volcanic activity persisted in southeast Oregon. The magma composition shifted from viscous rhyolite and andesite to highly liquid basalt. About 10 million years ago, volcanic fields consisting of shield volcanoes and fissures began erupting runny basalt lava flows that traveled miles from the vent.

Hundreds of lava flows probably occurred, each usually covering a small area. On high plateaus, newer lava covered older flows, forming an erosion-resistant “roof” over the ancient basin sediments. Thick canyon rimrocks developed when rivers cut through the plateau. In basins, successive lava flows were interbedded with sediment layers, creating banded canyon walls.

The volcanic fields in southeast Oregon and Idaho represent some of the youngest and most extensive basalt volcanism in the western U.S. They include features like Jordan Craters in Oregon (~3,200 to 4,500 years ago) and Craters of the Moon in Idaho (~15,000 to 2,000 years ago).



Saddle Butte lava flow vent on the lava plateau near the Owyhee River canyon. Eruption occurred 145,000 years ago.

River changing lava dams

The Owyhee River is well known for its many lava dams. Lava flows repeatedly entered and dammed the river canyon, forming lakes that stretched many miles upstream, often redirecting the river. During the last 2 million years, at least six different lava dams are known to have formed across the river, some hundreds of feet high. Earlier dams likely existed, but evidence has been erased by erosion.

Although the lava dams no longer exist, abundant evidence of their existence can be seen in today’s canyon walls. When a dam-building lava flow enters a large body of water, the lava rapidly cools and usually fragments into pieces that accumulate in slanting layers in front of the flow. The formation is called a “lava delta”, like a river delta, but formed by flowing lava instead of water. The distinctive, orange-colored dipping layers in the lava delta are called “foreset beds”. The horizontal contact line between the dipping foreset beds and overlying lava flow marks the elevation of the water’s surface. “Pillow lavas” are often found intermingled with the fragmented rocks in the foreset beds. These are lavas with bulbous, spherical, or tubular-shaped structures formed when lava is extruded underwater at slow effusion rates.

Geologists look for lava deltas to figure out the geological history of the Owyhee Canyon.

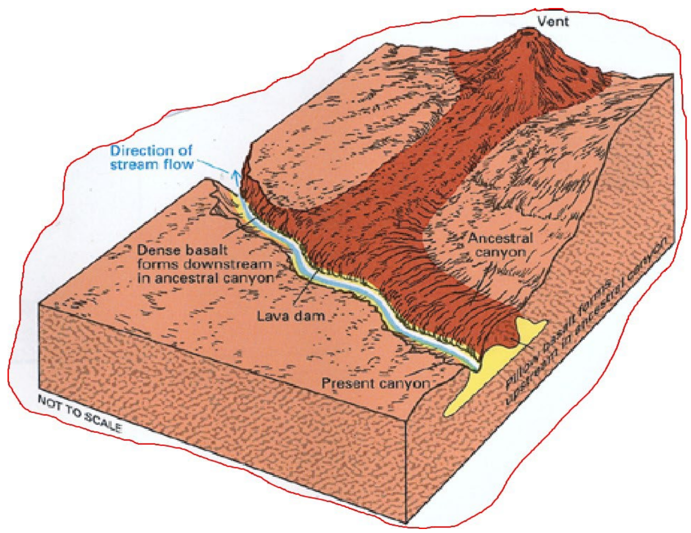
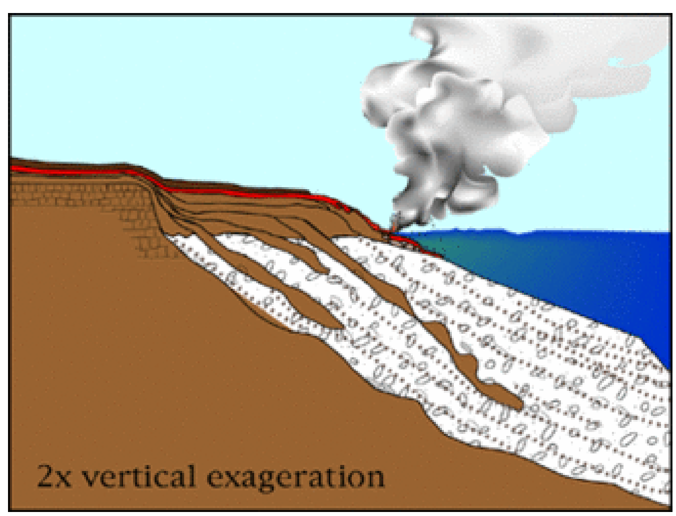


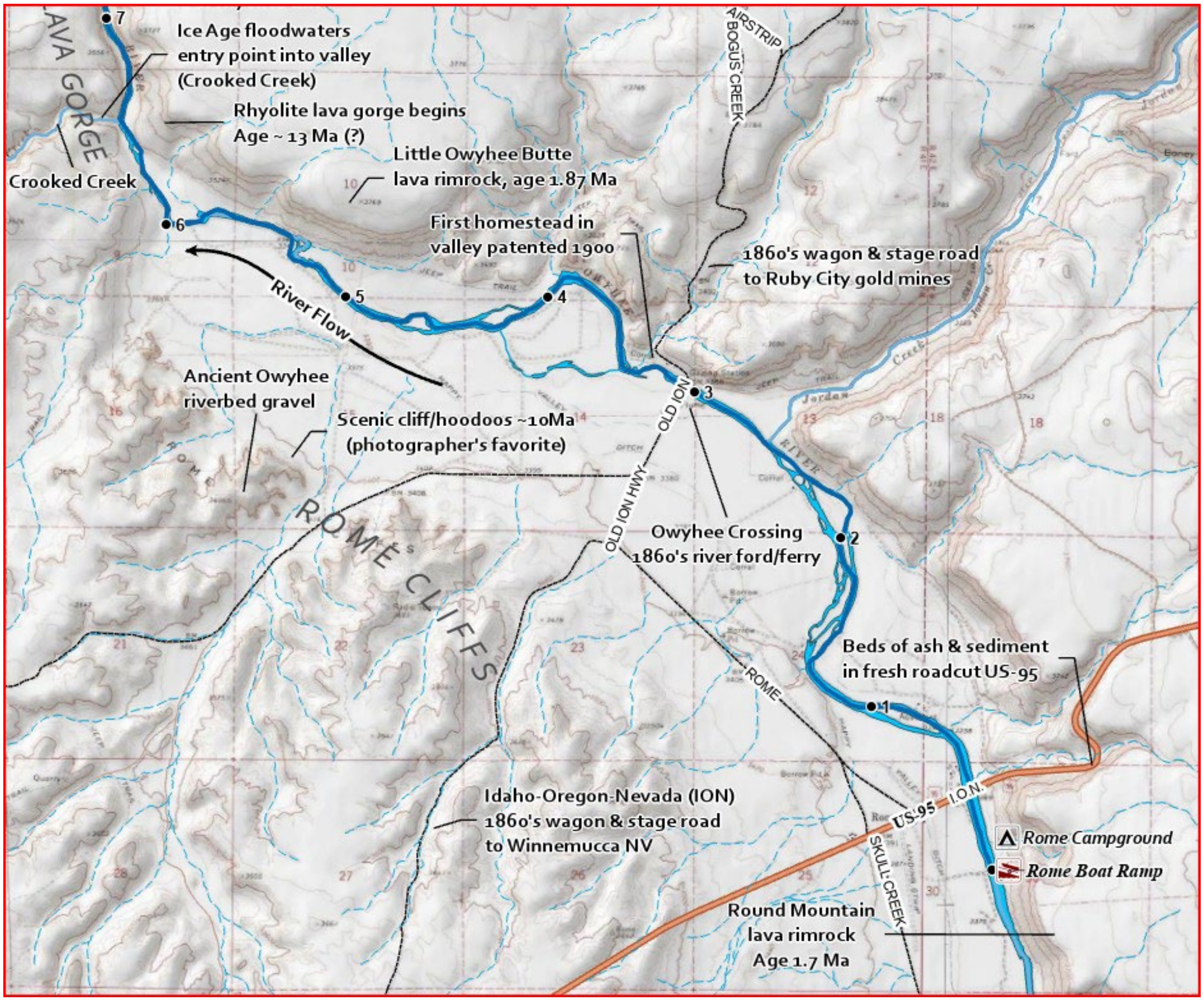
Illustration of a lava flow damming a river. (Source: USGS)



Cartoon of lava delta showing lava flow entering water and creating slanted foreset beds and pillow lavas. Source: USGS.

Sources: (Wood & Clemens, 2002), (Camp & Wells, 2021), (Willsey, 2017), (Staisch, et al., 2022),

Rome Valley *(mile 1)*



Rome Valley map

Rome badlands and cliffs *(Kiger Road)*

The ancestral Owyhee River and its tributary, Crooked Creek, began carving out the Rome valley several million years ago. Weathering and erosion created the scenic badland formations that pioneers called the "Pillars of Rome." The best way to see the badlands and striking rock cliffs is to take a drive along Kiger Road, north of Rome Station on US-95. If time allows, take a short hike through the sagebrush to any cliff and try to guess which, if any, layers of sediment were deposited in lake water (lacustrine) and which were deposited by a stream or flood (fluvial).

Before the Owyhee River existed, a series of poorly connected shallow lake basins (including this one) probably occupied today's river corridor from Rome to the Oregon-Idaho border. Downstream (north), the river corridor is lined with sedimentary strata like we see here in the Rome valley. The sediments change somewhat when the riv`er crosses into a new basin, each of which has its own history of local volcanic eruptions and sources of sediment, and

Mile 1: US-95 bridge crosses the Owyhee River. In the distance, 340-foot-tall Rome cliffs line the east bank of the Owyhee River. Green fields outline rich floodplain soils deposited by the modern river. (View north from rimrock.)

Rome cliffs: Ancient floodplain, shoreline and lakebed sediments over 9.3 million years old. Looking west from near Kiger Road (Photo: Marli Miller.)

possibly a different history of faulting and uplift. But in general, the Rome Valley story applies to the sediments throughout the Owyhee River corridor all the way to Lake Owyhee.

These sediments were deposited in a large basin that formed here after the Yellowstone Hotspot passed nearby and basin and range faulting began; it's just one of the several basins that define the river corridor. Sediments started accumulating more than 9.3 million years ago based on the age of overlying volcanic ash deposits near Arock, a few miles east of Rome Station.

At least three research papers have been published on the Rome beds. Studies show that before the first sediments, probably sometime between roughly 12 and 15 million years ago, two thick layers of lava flooded the basin floor. First a basalt lava flow and then a rhyolite flow, both of which are exposed at the north end of the valley where the strata have been uplifted slightly with respect to the central valley. Researchers think these lavas underlie the entire Rome valley—it's bedrock.

Pillars of Rome rock formation near Kiger Road in the Rome valley. (Photo: Marli Miller.)

Streams and. intermittent floods carried material from surrounding volcanic highlands and deposited it onto gently sloping mudflats and floodplains in the basin, creating layer upon layer of coarse-grained sediments. At times a shallow lake formed that saw many changes in water level (including drying up) which caused the shoreline to frequently advance and retreat. Intermittent eruptions from nearby volcanic fields sometimes covered the basin floor with lava flows and volcanic tuff (ash and rock fragments), some of which were deposited in standing water. Over time, it all cemented into the multicolored rock layers that we now see in the valley walls and extend an unknown distance east beneath the lava plateau. Eventually sediments filled up the basin, and it was probably roofed over by one or more lava flows—like the gently sloping lava plateaus we drive through on the way to the valley today. All this happened long before the Owyhee River existed.

In the final basin-filling phase, a long-lasting perennial (year-round) freshwater lake formed near today's Crooked Creek State Park. It's unclear whether it covered the entire basin or just a small area. The lake left behind an approximately 100-foot-thick layer of very fine-grained lakebed sediments containing abundant fish skeletons and vertebrate bones, including beaver. These fine-grained sediments are exposed below the Crooked Creek canyon rimrock, near US-95. Fish skeletons and vertebrate bones have been dated as Hemphillian (4.8 to 9.0 million years ago), which means the lake formed at least 4.8 million years ago.

US-95 roadcut in valley rimrock showing upper layers of sediments. Light-colored layer near the base is volcanic ash. (About one-half mile from Owyhee River.)

Closeup of volcanic ash layer likely more than 1.5 million years old in US-95 roadcut.

US-95 Roadcut

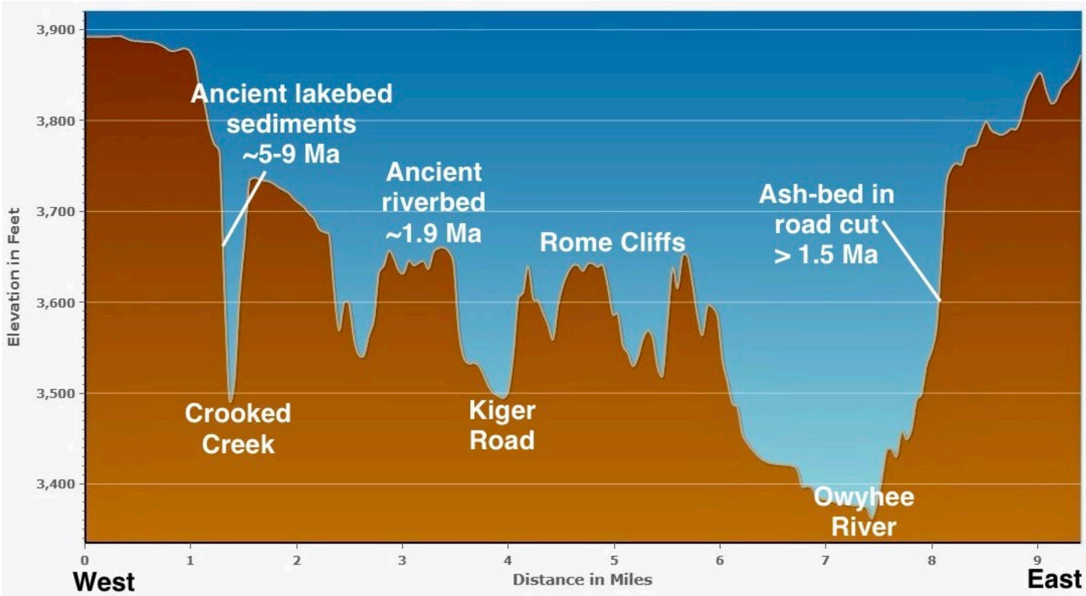
A good place to see freshly exposed layers of Rome valley sediments is in the roadcut along US-95 where the highway descends into the valley. Here the sediments have been preserved beneath a protective lava rimrock. Elsewhere in the valley, the topmost sediments are often buried under lava flows or eroded away. The thick, light-colored layer in the roadcut is a bed of volcanic ash likely older than 1.5 million years based on overlying lava flows.

Ancient riverbed (in the badlands)

We don't know exactly when the Owyhee started carving out the Rome valley, but researchers have recently found traces of an ancient riverbed running through the center of the valley about 1 to 2 miles west of the present river channel that the Owyhee may have occupied more than 1.9 million years ago. If confirmed, this means that by about 1.9 million years ago, about 140 feet of today's 340-foot-deep valley was already exposed. That's over one-third of the valley's present depth. The river then shifted its route to the east, widening the valley, for reasons yet unknown. Evidence for the ancient riverbed consists of an unusual layer of river-rounded rocks and gravel about 200 to 230 feet above today's river level. These rocks lie beneath a layer of distinctive white lakebed sediments thought to have been deposited 0.6 to 1.9 million years ago when several lava dams blocked the river downstream.

Once the Owyhee River came into existence, lava flows from intermittent basalt-rick volcanic eruptions on the surrounding plateau entered the river canyon and blocked it with lava dams, sometimes creating long-lasting upstream lakes that stretched past Rome (very likely to well past Burns Junction) and filled the valley with lake water. Published and ongoing research suggests that from about 1.9 million years ago to 600 thousand years ago, the Rome valley cycled between a lake and a through-flowing river because of multiple large lava blockages that occurred downstream. These distinctive lakebed sediments are found throughout the Rome badlands at around 3,600 feet elevation.

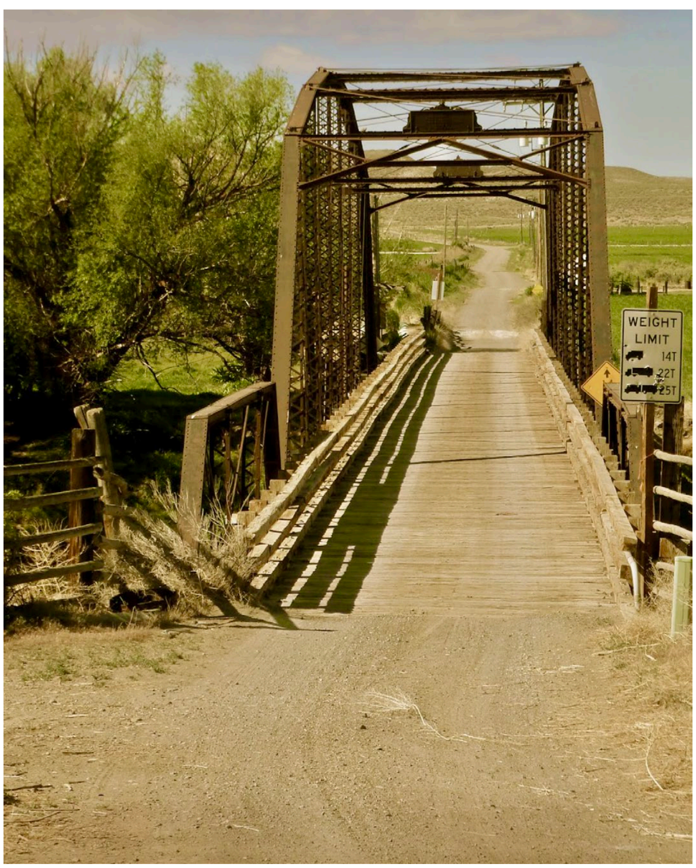
The distinctive tan dome is a "new" bed of fine-grained lakebed sediments deposited when a lava dam blocked the river downstream and created a long-lasting lake in the Rome valley. View north from near Kiger Road.



Elevation profile of Rome Valley. Running east to west, from the Rome boat launch site to Crooked Creek State Park. Source: Oregon DOGAMI online maps.

The Owyhee Crossing *(mile 3)*

Gold miners and pioneers gave the name "Owyhee Crossings" to the well-used river ford at the mouth of Jordan Creek. Before the iron bridge was built in 1903, all travelers either forded the Owyhee River (at low water) or paid a toll to use a hand operated ferry. Archeologists believe prehistoric people may have been crossing the river here for thousands of years.



Mile 3: The Owyhee Crossing. 1903 iron bridge on Old I.O.N. Highway. Photo from "Church of the Open Road Press" blog post May 28, 2013.

When the bridge was built in 1903, traffic likely consisted of local team-drawn wagons. Few, if any, automobiles existed in this remote corner of Oregon because of the rugged terrain and lack of improved roads. The first gasoline station in Jordan Valley was established in 1928.

For about 20 years starting in 1863, this was an important and heavily used road that carried freight from California to the newly discovered gold mines in the Owyhee Mountains southeast of Jordan Valley. Initially it was a system of trails traveled on horseback with packtrains. By 1866 a toll road (the "Skinner Road") had been built from the Owyhee Crossing through the Jordan Valley and up to the mines, finally allowing wagons and stagecoaches to travel the route. Stagecoaches took days, freight wagons took weeks to reach Ruby City and Silver City (now ghost towns) from the nearest railroad at Winnemucca, Nevada. The road remained a heavily used wagon supply route until railroads finally reached Idaho in 1883. The old wagon road can still be traced on Google Earth through the sagebrush from Owyhee Crossing west and then south towards the Oregon-Nevada border.

In 1933, the Oregon highway commission designated the route a Secondary Highway, the I.O.N. Highway (Idaho-Oregon-Nevada), named for the three states it passed through. Parts of it later became US-95.

Sources: (Sheppard & Gude, 1987), (Campion, 1979), (Ellison, 1968), (Wolf & Ellison, 1971), (Fretwell-Johnson, 1990), (Skinner, 2025)

Mile 6.5: Brush-filled mouth of Crooked Creek. The entry point of ice-age floodwaters from Alvord Lake. Looking West.

Now dry lakebed of Alvord Lake, covered with clumps of brush. The notch in the distant rimrock was carved by ice-age floodwaters exiting the lake to the Owyhee River.

Ice Age Outburst Flood *(mile 6.5)*

It's hard to imagine that the largest floodwaters ever documented in the Owyhee River canyon came down Crooked Creek. Today it's a small brush-filled tributary stream—not given a second glance.

The flood(s) occurred 13,000 to 18,000 years ago, at the end of the last glacial advance. The floodwaters came from Alvord Lake, one of the many large lakes that existed at the end of the ice-age in the high-desert region of the west. At its peak size, it was about 70 miles long and about 270 feet deep. Today it has no water and parts of it are known as the Alvord Desert.

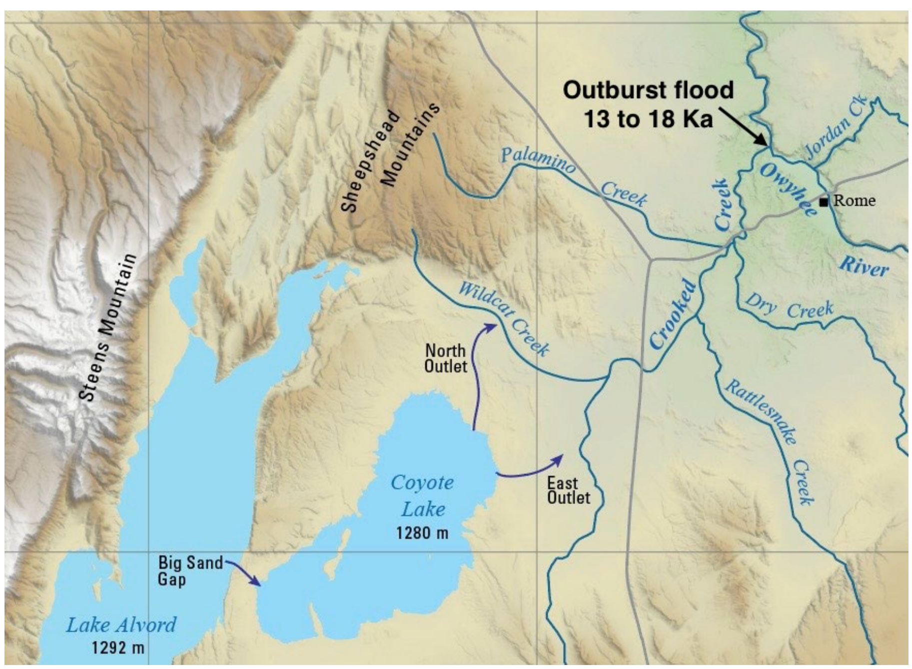
While the lake existed, its overflow was down the Crooked Creek drainage and into the Owyhee River. Abundant flood evidence exists. Along Crooked Creek geologists have found eroded canyons, scoured bedrock surfaces, scabland topography, numerous boulder bars and 15-foot boulders left stranded over 100 feet above the present channel.

Based on the size of the lake and the topography and constrictions of Crooked Creek, geologists determined the peak downstream flood was about 350,000 cfs (cubic feet per second); 6X larger than the highest water flow (55,000 cfs) recorded on the Owyhee River since records began in 1950. The flood lasted at least 13 days, probably much longer.

As the floodwaters entered the Rome basin, they fanned out and flooded the Rome Valley upstream to the US-95 highway bridge. A shallow lake in the Rome Valley lasted several weeks.

Though the evidence is much less complete, it's plausible that another older and much larger outburst flood occurred. Geologists identified an older (and higher) Alvord Lake shoreline that indicates older periods of overflow into Crooked Creek and the Owyhee River. They also found flood deposits and drainage topography along Crooked Creek that could only have been created by a large flood with a peak discharge of 1.4 million cfs. The postulated older flood is four-times larger than the flood that occurred 13 to18 thousand years ago, and 25-times larger than the highest modern water flow recorded on the Owyhee River since records have been kept.

Sources: (Carter, et al., 2005), (Personius, et al., 2007)



Map showing path of floodwaters from Alvord Lake to the Owyhee River and Rome Valley 13 to 18 thousand years ago.

First Rhyolite Lava Gorge *(mile 6.5)*

Mile 7: First rhyolite lava gorge. About 12-million-years old. Looking downstream.

First Rhyolite Gorge *(mile 6.8)*

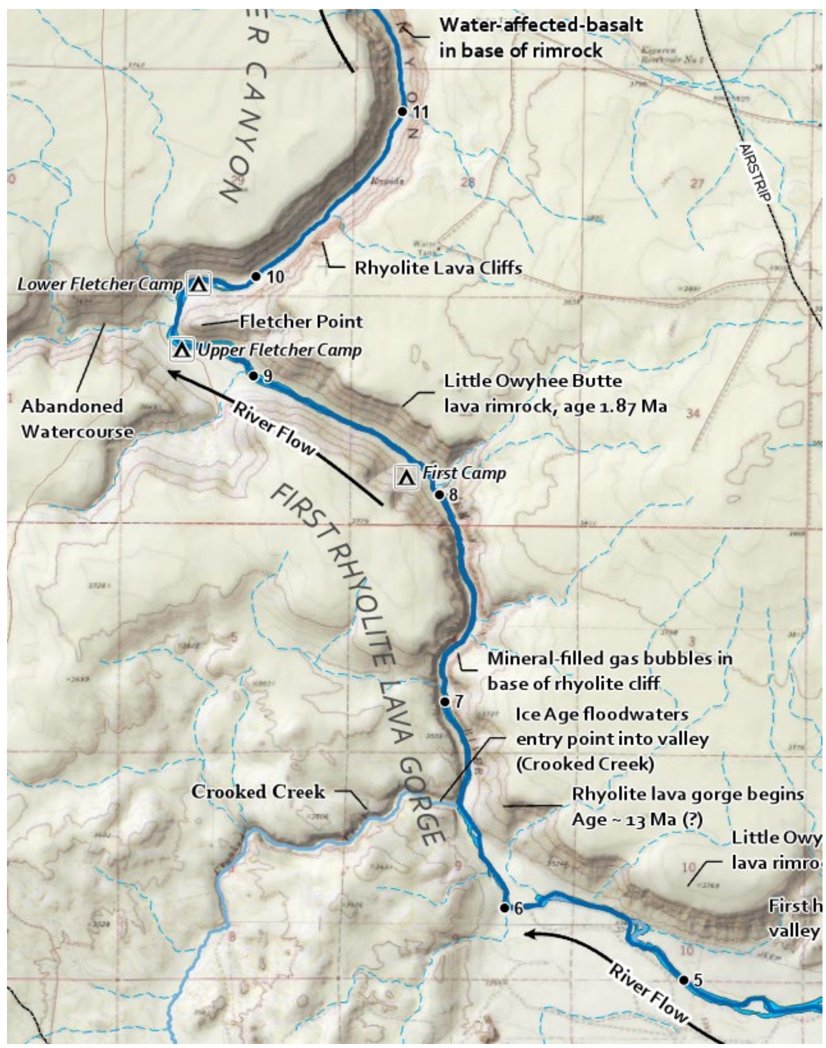
The narrow, orange-colored canyon just downstream of the mouth of Crooked Creek is informally named First Rhyolite Gorge. (There is another rhyolite gorge downstream.) This is a very short gorge, a little over one mile long, which allows only 20-30 minutes to see it by boat at typical river speed.

The 150-foot-high vertical walls are a single layer of rhyolite lava, a variety of volcanic rock frequently erupted along the path of the Yellowstone Hotspot. (See Key Events.)

It flows like toothpaste squeezed from a tube, piling up on itself, forming flow patterns visible as curls or swirls or bands. All those flow patterns are visible in the cliff face as you pass through the gorge. Also notice the vertical rock fractures called "jointing" caused by contraction as the hot volcanic rock cooled.

If you stop and walk along the base of the cliff, you can find several places where the cliff face looks like Swiss cheese, loaded with gas cavities of assorted sizes and shapes (vesicles). The vesicles are often filled with secondary minerals that formed long after the lava cooled and was buried.

Studies show the lava flow underlies the sediments in the Rome Valley and is



First Rhyolite Gorge map

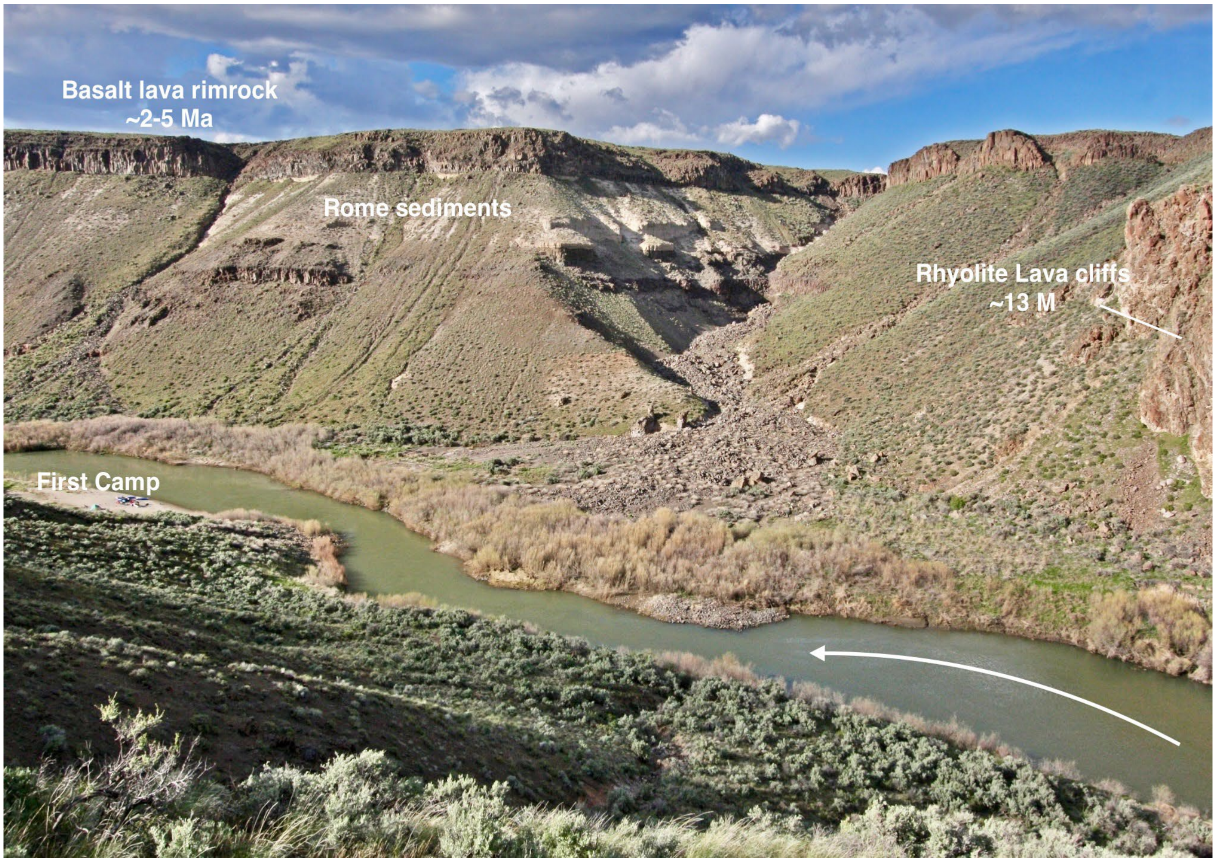
Mile 6.8 on river-left: Prominent swirl patterns and vertical cooling joints in the rhyolite lava cliff face.

therefore more than 9.3 million years old. It may be around 12 million years old, the same age as several rhyolite lava flows to the north (downstream) that have been laboratory dated. At least 24 different rhyolite volcanic centers were active in this corner of Oregon around this time.

The source vent has not been located, but rhyolite lava is so viscous and slow moving that it usually only flows a few miles before it solidifies into rock.

Several geologists who studied the Rome valley stratigraphy think the rhyolite lava flow is more extensive than what we see and probably underlies the entire Rome basin at depth, out of sight. We can see it today because this portion of the lava flow was uplifted by ancient east-west faults as sediments were filling up the basin. The rhyolite lava flow was buried for millions of years until the Owyhee River encountered the erosion-resistant rock and cut a gorge through it. The base is not exposed so we are not able to determine its total thickness.

Mile 7 on river-right: Flow banded rhyolite lava cliff with abundant mineral-filled gas cavities.

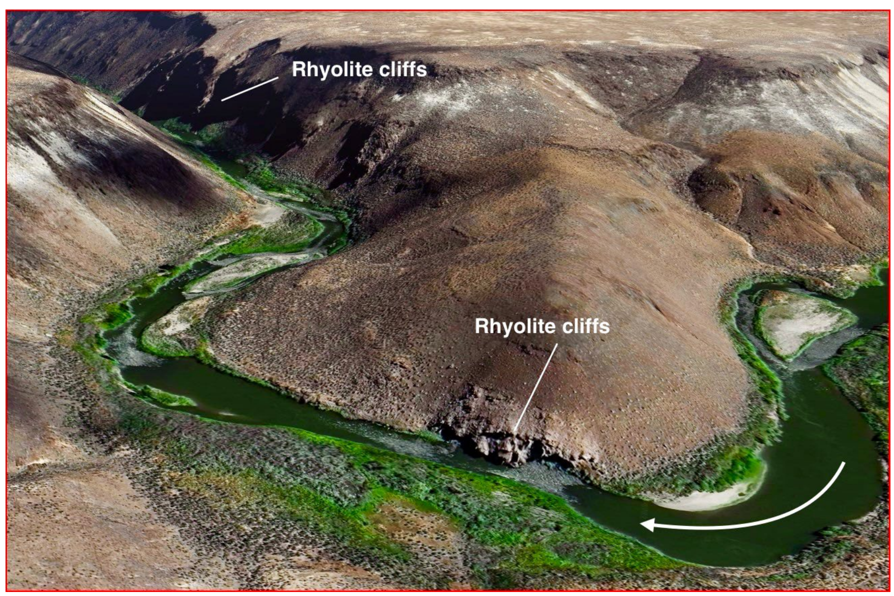


Mile 8.0: Little Owyhee Butte lava rimrock across from First Camp. (From Google Maps; photo contributed by Sonny Thornborrow.)

Little Owyhee Butte rimrock *(mile 8)*

The canyon rimrock across from First Camp is a basalt lava flow from a nearby volcanic vent named Little Owyhee Butte located about 2 miles to the northeast. Its most recent eruption is dated 1.9 million years ago. Upriver, the rimrock contains features called “lava deltas”—evidence the hot lava flow encountered water. The water was probably the lake that temporarily filled the Rome Valley after the river was blocked downstream by a lava dam. (See section “Lava Delta in Ancient Lake” for details.)

First Camp marks the end of the rhyolite gorge and the beginning of a basalt-rimrock-lined canyon that typifies this reach of the river. From First Camp we can look across the river and see where the cliffs of First Rhyolite Lava Gorge end and interbedded basalt lava flows and sediments begin.



Mile 9.5: Fletcher Point. The river curves around an erosion-resistant rock (probably rhyolite lava), creating a dogleg bend and a small shoreline cliff, before resuming its northward course. (Google Earth image.).

Mile 9.5: Spectacular boulder of glassy flow-banded rhyolite lava on riverbank at Fletcher Point. Possibly eroded from the rhyolite riverside cliff just upstream.

Fletcher Point (dogleg bend at mile 9.5)

At Fletcher Point, the river makes an abrupt dogleg bend before resuming its north-flowing course. The riverside cliff at the apex of the dogleg bend is rhyolite lava, as are the 100-foot-tall cliffs immediately downstream and the 150-foot-tall cliffs one mile upstream. A likely explanation for the presence of the dogleg bend is that Fletcher Point conceals a layer of erosion-resistant rhyolite lava beneath its cover of sediment.

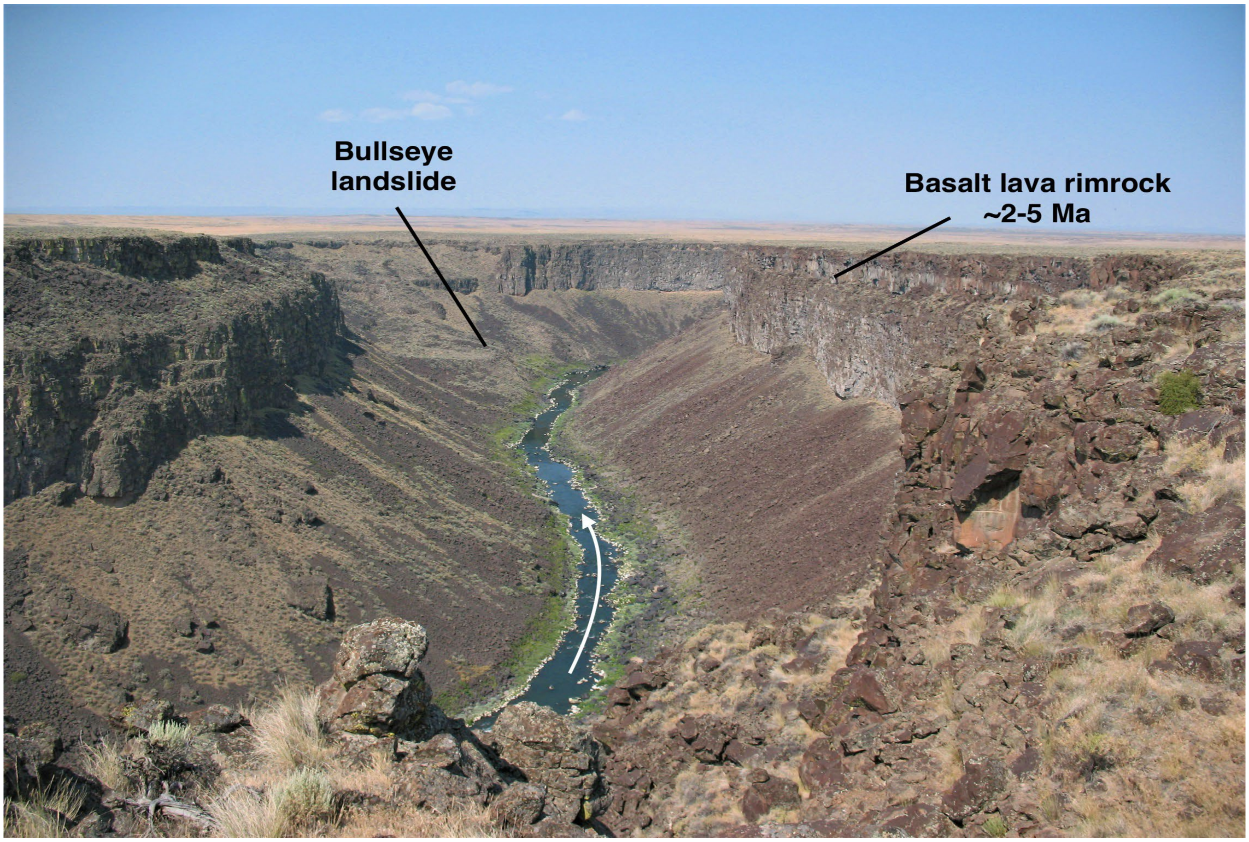
Abandoned Watercourse *(mile 9.5)*

The side-canyon located across the river from Fletcher Point is an abandoned watercourse that loops back to a lava divide above the Rome Valley near Crooked Creek. This channel could be a former course of the Owyhee River or Crooked Creek, or it might represent an overflow from the Rome Valley caused by a lava flow that blocked the Owyhee River downstream. The head of the watercourse near Crooked Creek is situated at an elevation of 3,700 feet, approximately 350 feet above the current river channel, suggesting its formation occurred in ancient times. Further research is required to ascertain the specifics regarding the origin and timeline of this canyon.

Sources: (Orr, 1985), (Evans, et al., 1990), (Evans, 1991), (Ellison, 1968), (ODGMI Map, 2021), (Wolf & Ellison, 1971), (Shoemaker, 2004), (Swenton, et al., 2022)

Mile 10: Rhyolite lava cliff immediately downstream of Fletcher Point on river-right.

Mile 9.5: Abandoned watercourse from Rome Valley joins the Owyhee River at Fletcher Point (Google Earth image.).



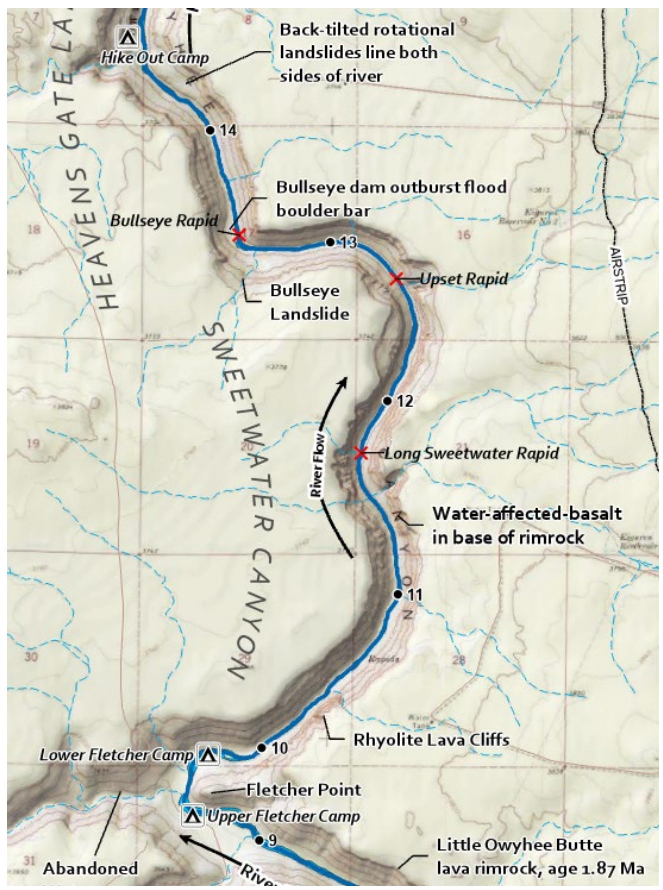
Mile 13: Sweetwater Canyon, looking downstream. Bullseye Rapid is just around the distant bend. Notice a section of the rimrock on river-left is missing—it collapsed and triggered Bullseye Landside that dammed the river.

Sweetwater Canyon *(mile 10.5)*

The Owyhee River incised through 150 feet of basalt lava and 300 feet of underlying soft sediments to create the narrow-walled, 450-foot-deep Sweetwater Canyon, an excellent example of a high lava plains canyon. The rimrock cliffs and steep, talus-covered slopes make hiking difficult, if not impossible.

The reason scenic Sweetwater Canyon exists here instead of an open, sediment-filled valley like Rome is because its spectacular 150-foot-thick basalt lava caprock protects the underlying layers of soft sediments from erosion. The lava that created the caprock consists of dozens of relatively thin layers of basalt lava that may be from different flows of different ages. It likely erupted from one of the volcanic vents at Owyhee Butte on the lava plateau about three miles west. The most recent eruption from Owyhee Butte occurred 1.9 million years ago.

The high lava plateau on both sides of the river is covered with dozens of volcanic vents (now extinct) and overlapping basalt lava flows of various ages, only a handful of which have been laboratory-dated and mapped. The dated lava flows range in age from a few thousand years to over 10 million years old, and new flows bury older ones, making study difficult.



Sweetwater Canyon map

Deposits of fluvial (carried by water) conglomerate up to 100 feet thick are scattered on both sides of the rimrock; evidence that after the lava flow(s) occurred and before the modern Owyhee Canyon existed, the ancestral Owyhee River flowed on top of the plateau, in roughly this same location.

The base of the lava rimrock sits at approximately the same elevation as traces of an ancient riverbed in the Rome Valley, so it's plausible that when the lava flow(s) arrived, the lava may have dammed a through-flowing river.

Baked sediments *(mile 11.3)*

The lava rimrock overlies hundreds of feet of light-colored lake and stream sediments like those found in the Rome valley upstream. The heat of the incoming lava was so intense that it baked the topmost sediments into hard, orange-colored clay-like bricks, creating the distinctive orange/pink-colored band of rock that underlies the canyon rimrock.

The base of the lava rimrock in this reach of the river has extensive zones of unusual, brown-colored minerals in the cliff face. The zones are about 10 to 20 feet high; you can see them with binoculars or by hiking to an exposed base of the rimrock during about the next six river-miles. The brown-colored minerals have not been studied but are thought to be a form of "water-affected basalt." The basin floor here was likely saturated or covered with water when the first lava flows arrived, causing the hot lava to absorb water and chemically alter into the brown-colored minerals. (Water-affected basalt is relatively common throughout this reach of the river and is described more fully in the Chalk Basin section of this book.)

Mile 11.3: Baked sediments at base of canyon rimrock. Overhead is a brown-colored zone of water-affected basalt.

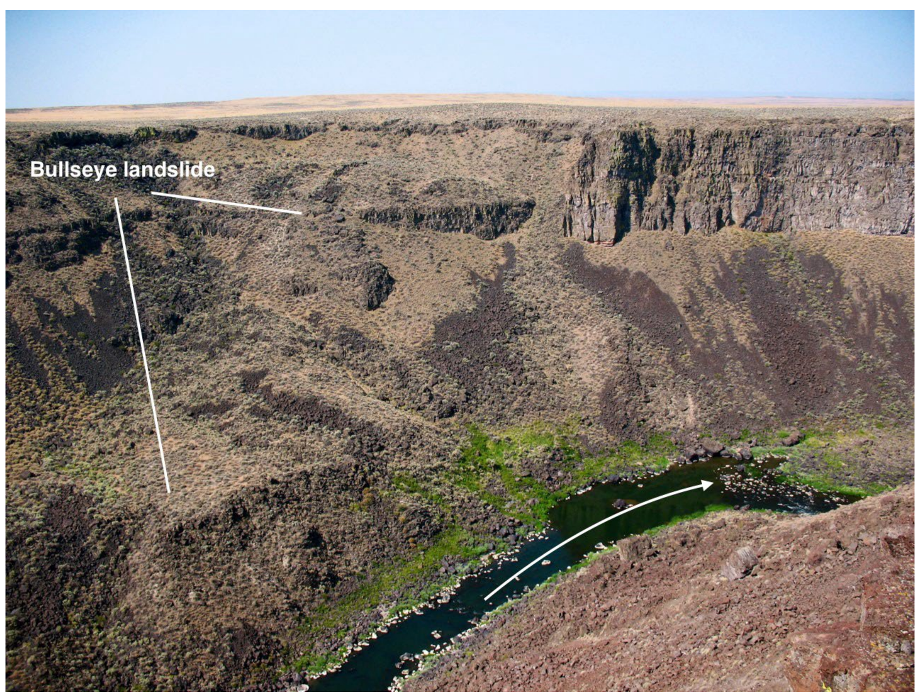
Mile 11.3: Close-up of "water-affected-basalt" zone in base of basalt lava flow. (The brown minerals.) The underlying strata is "baked sediment".

Mile 13.5: Bullseye Rapid from the rimrock. Rafts are being lined through the rapid at extremely low water. The rapid was created by debris from an outburst flood when the Bullseye Landslide dam failed. Looking upstream.

Bullseye Landslide and Rapid *(mile 13.4)*

At the 90-degree bend in the river, Bullseye landslide descended from the rimrock and blocked the river with an earth and rock dam up to 150 feet high. (Based on the height of the landslide toe remaining next to the river.) After water overtopped the dam, the dam catastrophically failed. The resulting outburst flood carried boulders and debris downstream and deposited it on a boulder-bar that creates today's Bullseye rapid, just around the corner. There's a chance the landslide was caused by the Alvord Lake outburst flood (described earlier), but that would need to be confirmed by future studies. There are dozens of these landslides on the river.

Source: (Evans, 1991), (Ely, et al., 2012), (Skilling, et al., 2002), (Godchaux & Bonnichsen, 2002), (Bondre, 2006)



Mile 13.4: Bullseye Landslide descended from the rim, leaving a notch in the canyon wall. It blocked the river with a landslide dam. Looking downstream.

Heavens Gate Landslide Complex *(mile 14)*

Mile 14: Heavens Gate Landslide Complex. Back-tilted rotational landslides line both sides of the river. View downstream.

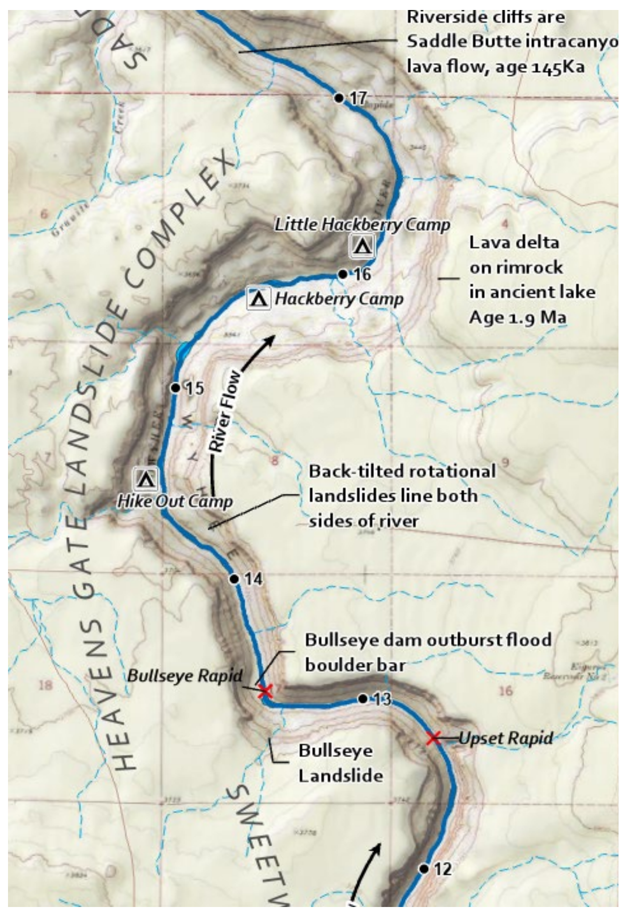
Heavens Gate landslide complex *(mile 14)*

The scenic narrow canyon abruptly widens to a broken landscape called the "Heavens Gate landslide complex." Here the river is lined on both sides with massive blocks of basalt lava that have broken off the canyon walls and slid down. Many of these landslides once blocked the river with dams over 100 feet high.

Though difficult to see from river level, notice the large broken blocks of rimrock are tilted at a back angle to the river. Geologists call these "rotational landslides". They look like the underlying white sediment "rug" was pulled out from under them, causing them to collapse, spread, and rotate, creating a messy broken landscape in a widening canyon.

This type of landslide occurs when a stronger material such as basalt lava overlies a weaker material such as sediment and the river undercuts the weaker lower layer, causing large blocks of rock to break off and slump down, tilted at a backward angle. Best seen by hiking a short distance up and away from the river, as the tilted blocks block the view from the river.

The Heavens Gate landslides include some good examples of simple rotational failures with obvious intact stratigraphy, but also some weird forward-rotational/cantilever type, and various composites.



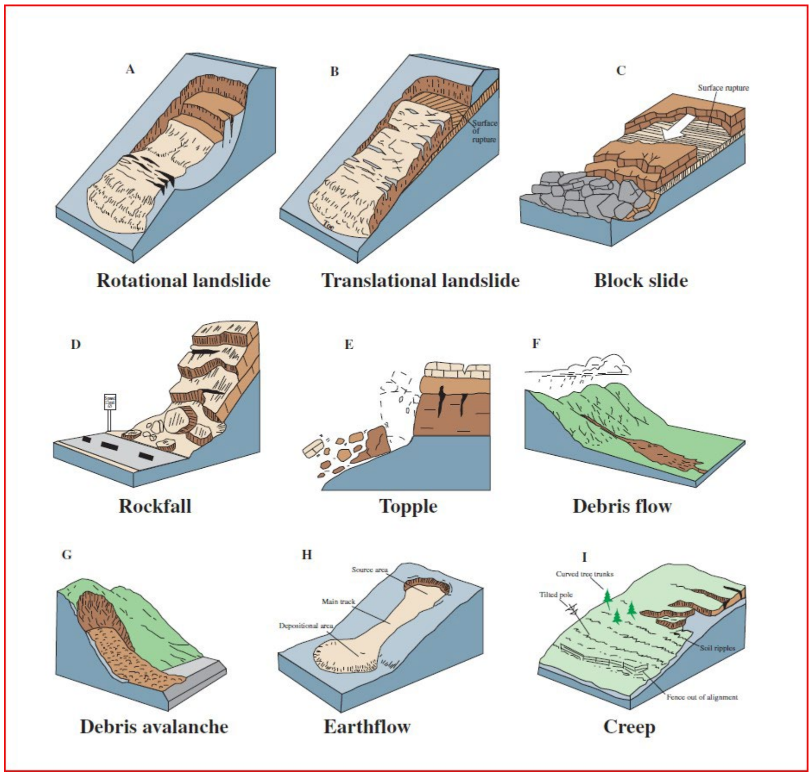
Heavens Gate Landslide Complex map

Mile 15: Blocks of rotational landslides as seen from river. Looking downstream.

Mile 14.5: Aerial view of valley-widening "ping-pong" effect of landslides. Looking downstream to Hackberry Camp, located on right bank in center of photo.

These landslides are recent in the life of the 1.9-million-year-old canyon. Some are quite young, there are actively expanding cracks in the canyon walls overlooking Hike Out and Hackberry camps. Geologists have determined the landslides occurred roughly between 7,600 and about 140,000 years ago. The 7,600 years minimum age is based on a layer of Mazama volcanic ash (the eruption that formed Oregon's Crater Lake) found in core samples taken from several landslides. The maximum age of 140,000 years is based on landslides of similar morphology found 7 miles downstream at the Artillery Landslide Complex.

The largest landslides interact with each other in a "ping-pong" manner (over time) to redirect the river's course to other parts of the canyon and to widen the valley—creating lasting impacts on the canyon geomorphology. When a large landslide redirects the river to the opposite bank, the resulting incision into soft sediment on that opposite canyon wall can induce additional landslides on that side. That new landslide in turn redirects the river back to the original bank, triggering landslides there—like a ping-pong game—constantly widening the valley. These back-and-forth events that began tens or hundreds of thousands of years ago continue to redirect the river and widen the valley even today.



Types of landslides. (From USGS fact sheet.)

Hike Out Camp geology hike *(mile 14.5)*

Hike Out Camp has two excellent hikes. From camp if you bear slightly left (upstream) and follow the dry wash, it takes you up the canyon wall and ultimately out of the canyon onto the rimrock. There are great views looking down on the landslides, and you can see a lava delta across the river (described in the next section). Also visible across the river is a landslide with a closed (filled-in) depression that has been breached (eroded through) and has a great exposure of sediments including a layer of Mazama ash. One can also find ancient Owyhee River gravel that has been transported from the surrounding rim by the landslides.

If you hike all the way to the rimrock, along the way there are several places where you can find a layer of trapped sediment and gravel between the layers of lava, indicating that the canyon wall is made of multiple lava flows and sufficient time passed between flows for sediment to accumulate. It could be tens or hundreds of thousands of years between flows.

From camp, if you bear slight right (downstream) and follow the small draw between the two landslide slump blocks, an easy hike takes you about halfway up the canyon wall to the top of an extensive landslide slump block that has great views. You can see the lava delta across the river from here. A short walk upstream on the slump block brings you to the lava rimrock cliff-face where you can see a great example of "water-affected-basalt" described earlier in this section.

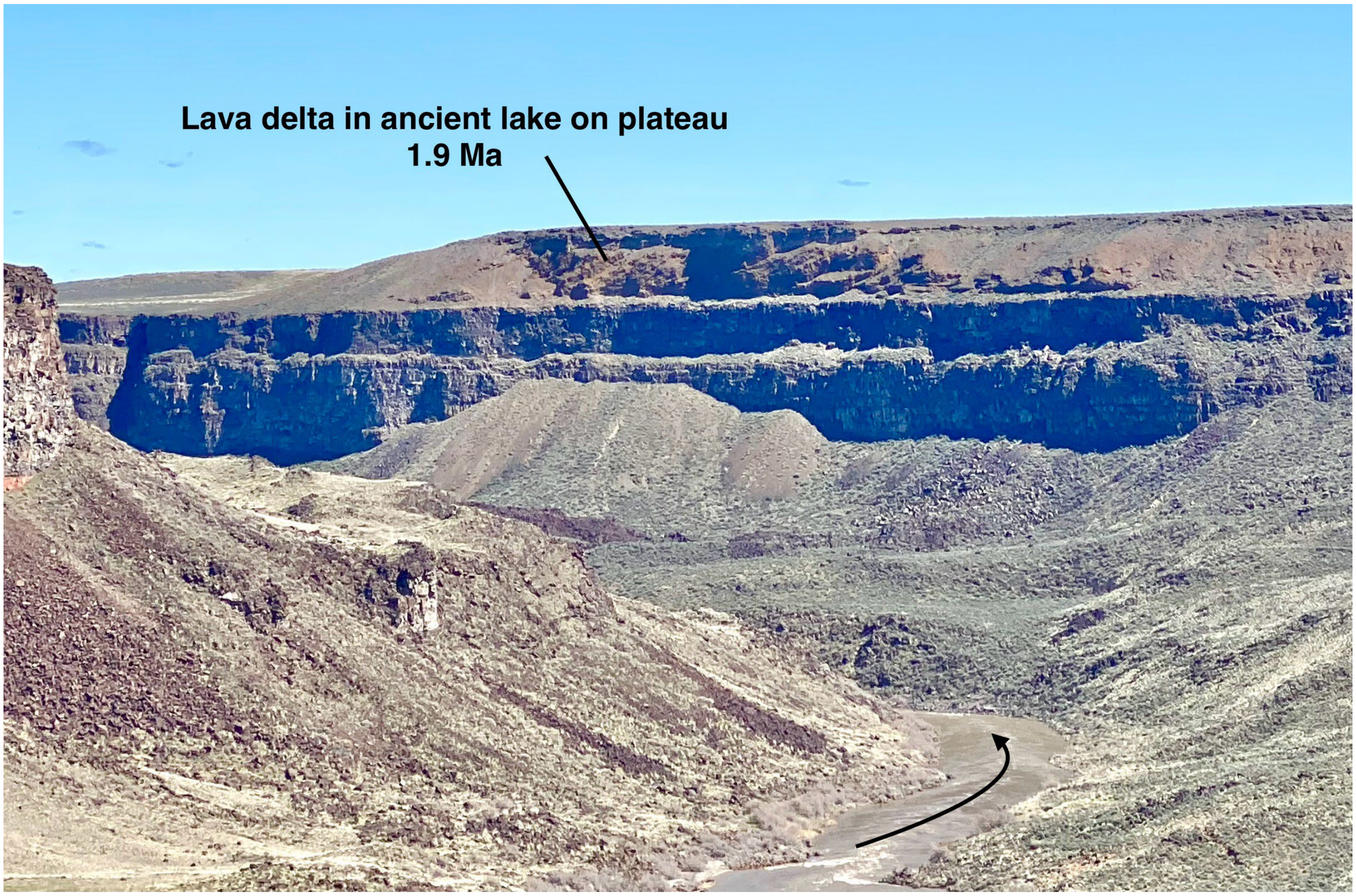
Mile 14.5: Hike Out Camp hike geology hike. The pillar consists of two different lava flows separated by a thin white layer of sediment.

Hackberry Camp hikes *(mile 15.7)*

Hackberry camp has a short easy hike to an actively spreading crack at the head of a small landslide located about 500 feet east and 60 feet elevation above the campsite. The crack is large enough to be seen in Google Earth satellite images and it looks recent.

Mile 14.5: Hike Out Camp geology hike. Zone of "water-affected-basalt" in the lava flow base.

Mile 15.8: Hackberry Camp geology hike. Active recent landslide crack; visible in satellite images.

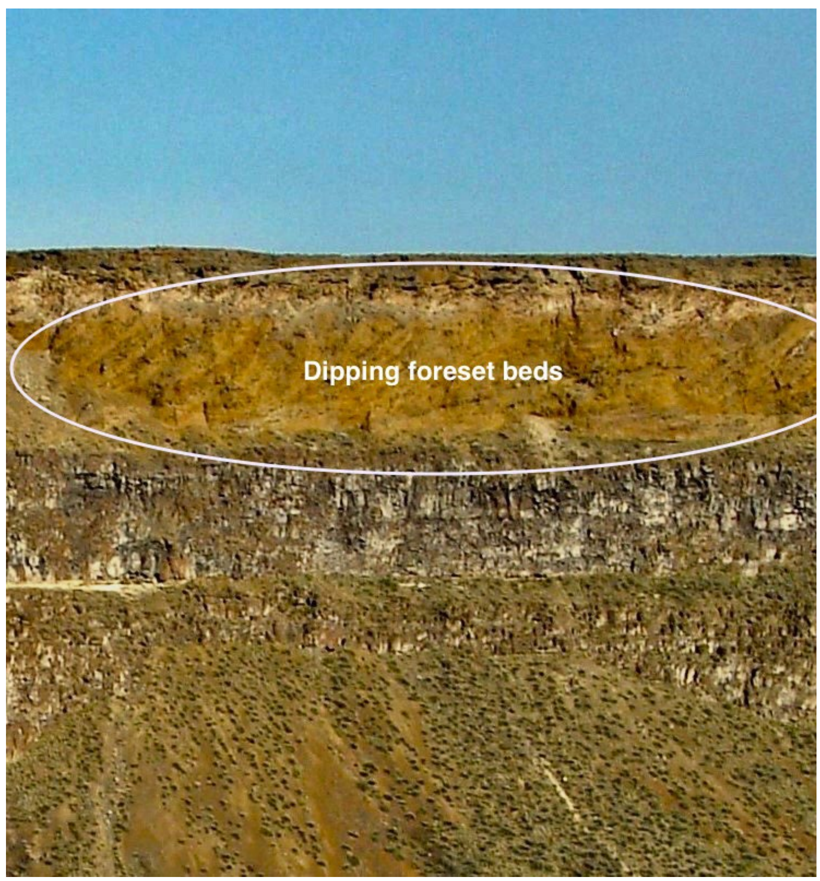


Mile 16: A "lava delta" in the topmost lava flow. Slanted, orange-colored layers mark the location of an ancient lake.

Lava Delta in Ancient Lake *(mile 16)*

After Hackberry camp, look at the top lava flow with orange layers on the canyon's rim to the right. These are "foreset beds," part of the "lava delta" that forms when lava enters a large water body. These layers show there was an 80-foot-deep lake located on the plateau 1.9 million years ago, before the modern canyon existed. The Owyhee River is famous (among geologists) for the number of lava deltas it contains.

Where did the lake come from? Geologists think the ancient lake was created by a lava dam located 15 miles downstream near Sleeping Dragon Gorge (aka Iron Point). There, geologists found evidence that a lava flow blocked the river with a large dam that created a huge lake overlapping onto the plateau and extending many miles upstream to today's Burns Junction on Highway 95.



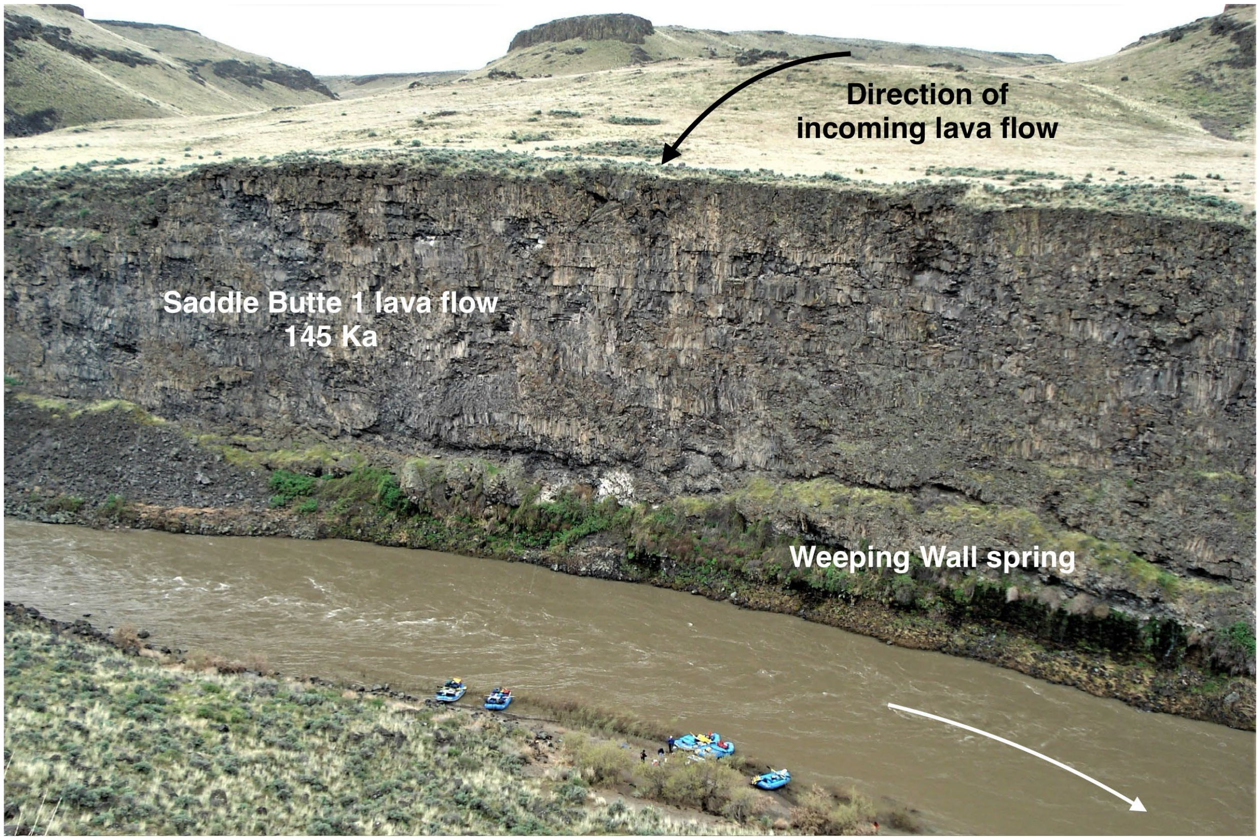
Mile 16: Close-up of slanted lava foreset beds on canyon rimrock.

1.9-million-year-old Owyhee Butte shield volcano about 6.5 miles north of Rome, Oregon. (Google Earth image)

The lava flow erupted 1.9 million years ago from Owyhee Butte, 5.2 miles away on the lava plateau. It was a 110-foot-high shield volcano (a broad domed volcano with gently sloping sides) with a 1,500-foot diameter bullseye crater filled with a lava plug or a solidified lava lake. The easily crumbled volcanic material surrounding the bullseye has since eroded away, leaving a moat-like circular depression around the crater. Nearly all the lava flows that cover the Owyhee plateau originated from small shield volcanoes like this one, or from simple fissures in the earth.

Source: (Bondre, 2006), (Ely et al, 2012)

Saddle Butte Lava Dam *(mile 18)*



Mile 18.1: The Saddle Butte lava flow entered the Owyhee Canyon here 145,000 years ago. Thickness is about 150 feet.

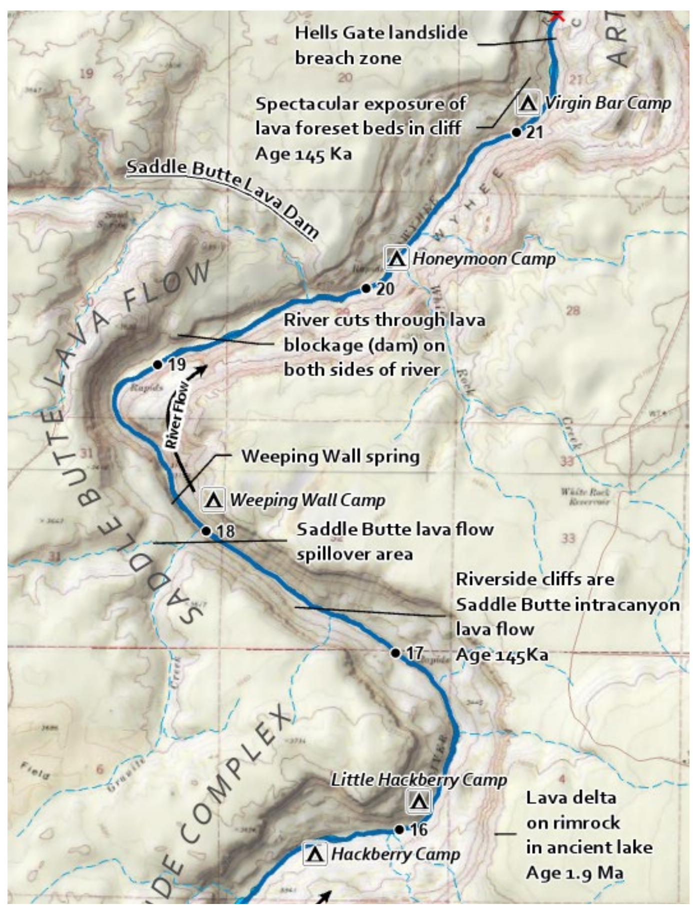
Saddle Butte Lava Flow *(mile 18)*

The basalt cliff at Weeping Wall spring is the "Saddle Butte lava" flow. It spilled into the canyon here from the lava plateau, extending one mile upstream and at least two miles downstream. The lava flow blocked the river with a well-studied lava dam.

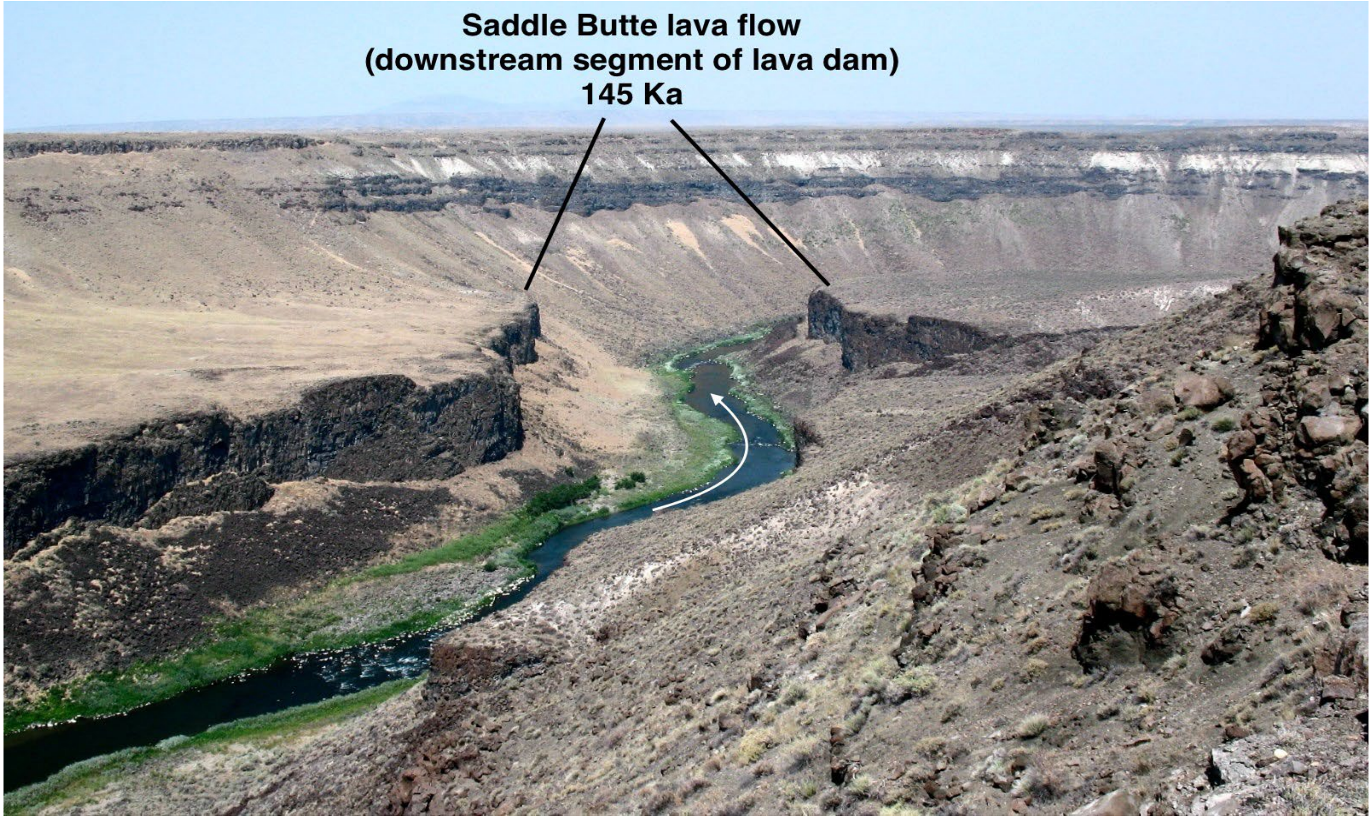
The lava erupted 145,000 years ago from a volcanic vent in the Sheepshead Mountains, flowing 20 miles eastward to the river. It divided into two lobes: one lobe entered the canyon at Weeping Wall Spring, the other lobe entered about two miles downstream where the two flows overlapped. These lobes are considered one damming episode.

The two entry points created a tiered lava dam. At Weeping Wall spring, the blockage reached approximately 150 feet in height. Further downstream, where the two lava flows overlapped, the height of the dam increased to about 260 feet.

The lava cliffs along the river upstream of Weeping Wall Spring display several exposures of foreset beds, which consist of fragmented rock and pillow lavas resulting from lava-water interactions. These foreset beds indicate that the Saddle Butte lava flow was progressing in an upstream direction against the flow of the river water.



Saddle Butte Lava Flow map



Downstream of Weeping Wall spring, the river incised through the Saddle Butte lava flow that once blocked this reach of the river with a 150-foot lava dam. The distant rimrock contains two basalt lava flows (undated)–enough time passed between eruptions for a thick layer of white sediments to accumulate between them. (Looking downstream/north).

Weeping Wall spring *(mile 18.1)*

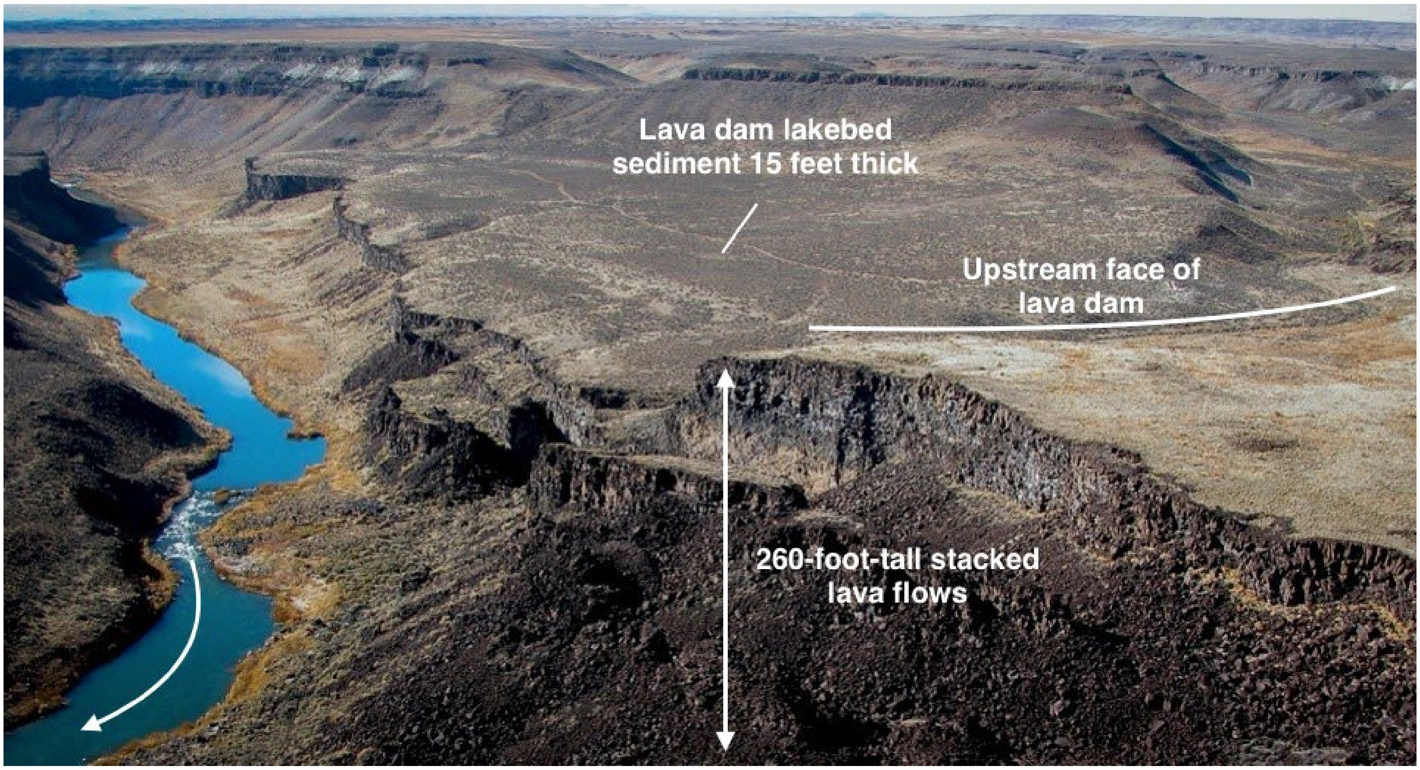
Cold, clear spring water emerges from the canyon wall at Weeping Wall spring, the only reliable water supply for miles around. The source of the spring water is probably rain and snowmelt from higher elevations many miles away. This region is underlain by a layer-cake stack of basalt flows and relatively impervious high-clay content sediments. When water flows along the boundary between the layers, it emerges as springs where a river canyon intersects the underground flow.

The spring water emerges from a thick layer of Owyhee river-rounded boulders and gravel trapped under a laboratory-dated lava flow. The contact zone between the overlying lava flow and trapped river gravel marks the elevation and location of the Owyhee riverbed 145,000 years ago.

Geologists seek out locations like this where river-rounded gravel is trapped under lava flows. Trapped river gravel tells them the "where" of the ancient river channel. The date of the lava flow tells them the "when." The combination of these allows for incision rates to be calculated. These are the metrics of the pace of canyon cutting and the evolution of landscapes connected to the river.

At this location, the riverbed elevation has changed little during the past 145,000 years and the river channel location not at all, despite the thick lava flow that once filled the river channel here. This is interesting because the river "rediscovered" this level after being blocked by two major canyon-filling lava flow events (Saddle Butte and West Crater), both of which affected the profile of the river channel here. The fact that the river quickly cut back down to the same base level, but no farther, reveals that the river's long-term base level is probably controlled by the elevation of the Snake River.

Mile 18.1: Weeping Wall spring emerges from Owyhee River gravel trapped under the 145,000-year-old lava.



Mile 19.8: Saddle Butte Lava Dam. Looking upstream/south.)

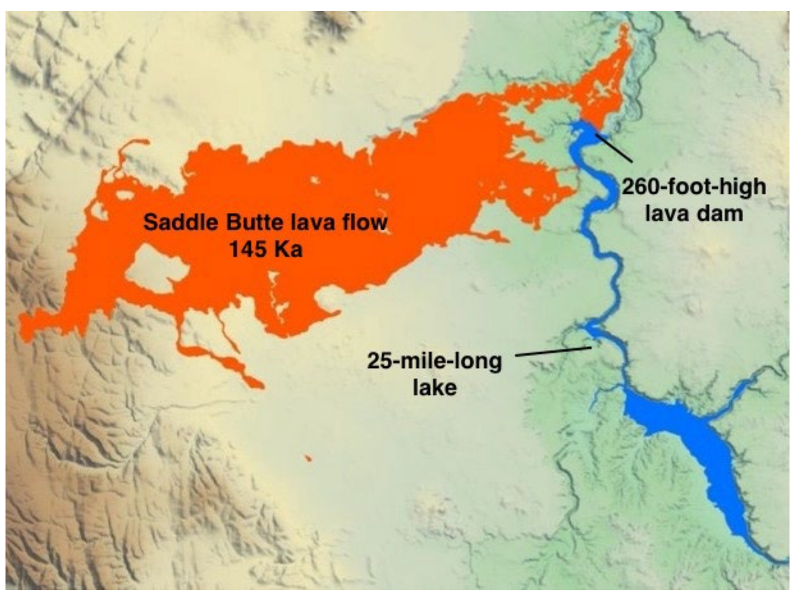
Saddle Butte Lava Dam *(mile 19.8)*

The 260-foot-high canyon rimrock lining the west (left) riverbank at mile 19.8 is one of the best examples of a lava dam in the Owyhee Canyon. Named the Saddle Butte lava dam after the lava flow that created the dam, geologists have studied it well. The dam lasted for thousands of years and created a large upstream lake estimated to stretch 25 miles upstream past Rome. Evidence of the lake's existence includes approximately 15 feet of sediments and gravel that accumulated upstream of the dam and now covers the floor of the semi-circular basin behind the lava dam.

The dam was created 145,000 years ago when two separate lobes of Saddle Butte lava met and overlapped at this location, creating a layer-cake lava dam with a combined thickness of 260 feet. The bottommost flow entered the canyon upstream at Weeping Wall spring and then flowed down the river channel; the topmost flow entered the canyon downstream and then flowed upstream; the dam is where the two flows met.

Lava flows have repeatedly entered and dammed the river canyon, blocked the river, and directed water over or around the dam crest, often redirecting the river. Saddle Butte is the first of the lava dams that geologists have studied between here and Birch Creek takeout: Saddle Butte, West Crater, Bogus Rim, and Deer Park. There are indications of at least six and as many as nine damming events based on other types of evidence.

How long did the dam last? It took less than 74,000 years to cut through and around the 240-foot-high blockage; an incision rate of at least 1 mm/year, the thickness of 10 sheets of paper each year. We know this because the river channel was eroded back down to near its former elevation (i.e., Weeping Wall spring) by the time another intracanyon lava flow entered the river downstream, dating to 70,000 years ago, from a volcano called West Crater.



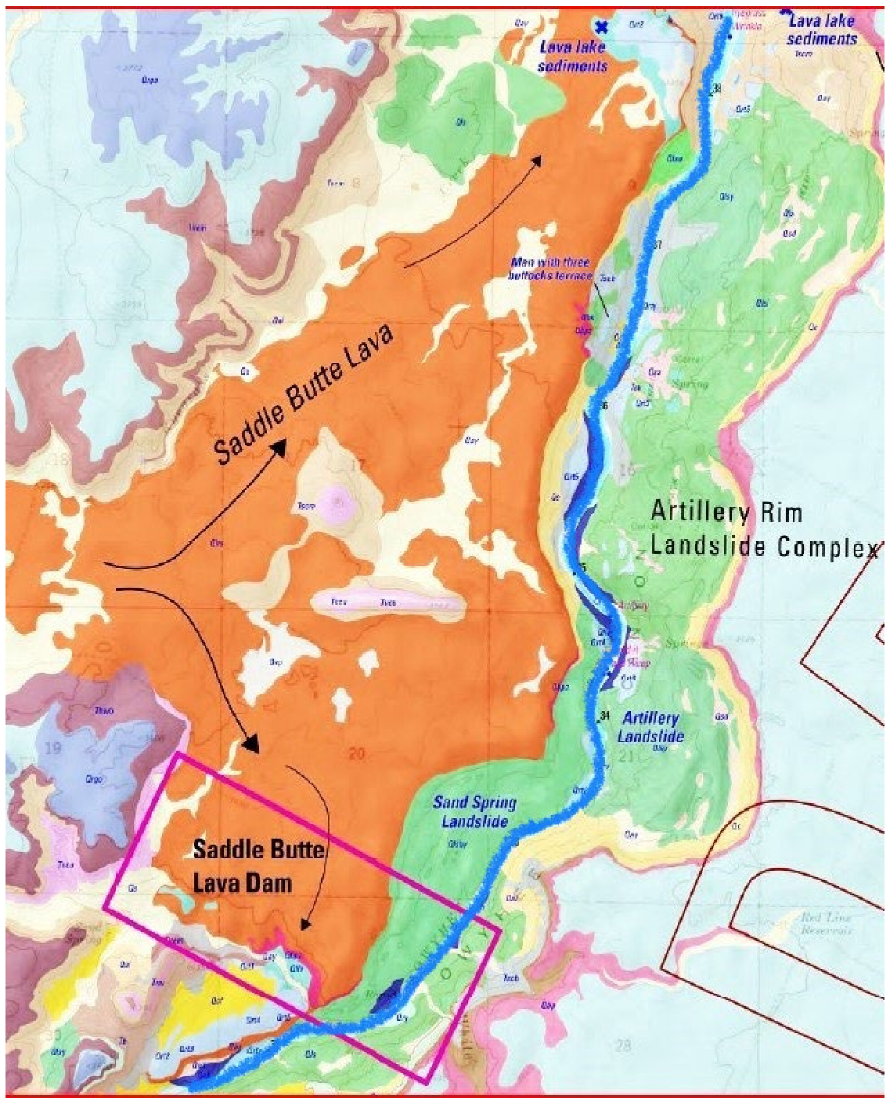
Mile 19.8: Saddle Butte lava flows 20 miles to river and blocks it, creating a lake stretching 25 miles upstream past Rome.

Mile 22: Profile of Saddle Butte lava flow shows where the molten lava encountered river water. (Looking west.)

Foreset beds and pillow lavas: As the hot lava flowed into the growing upstream lake, the submerged portion of the lava flow underwent rapid cooling into pillow basalt shapes; and steam explosions fragmented the lava into slanting orange-colored foreset beds. These are important features to geologists: the water's depth is marked by the contact line between the slanted orange-colored foreset beds and the overlying basalt cap-rock. The direction in which the lava flow is advancing is marked by the direction in which the foreset beds are slanting.

This reach of the river has several excellent exposures of foreset beds and pillow lavas, evidence the lava flowed into water and displaced the river. Look for unusual orange-colored, slanting layers beneath a caprock of solid basalt along the rimrock on river-left. The first exposure is in the face of the lava dam at mile 19.8, the second exposure is in the rimrock wall just below Hells Gate and Read-it-and-Weep rapid at mile 21.5.

New river channel: As you travel downstream (north), notice that Saddle Butte lava covers the left bank but little, if any, lava is on the right bank. This is because today's river course approximately follows the seam where the Saddle Butte lava flow once abutted the canyon wall of Artillery Rim.



Mile 19 to 24: Geology map of Saddle Butte lava flow and dam. North is up and the river flows from bottom-to-top/south-to-north.

Sources: (Ely, et al., 2012)

Artillery Rim (mile 21)

Mile 21.5 Hells Gate rockfall: A rockfall dammed the river here and left a large block of lava stranded on the right bank. When the dam failed, rock debris left in the river channel created today's Read-it-and-Weep rapid. (In center of photo). Looking downstream/north.

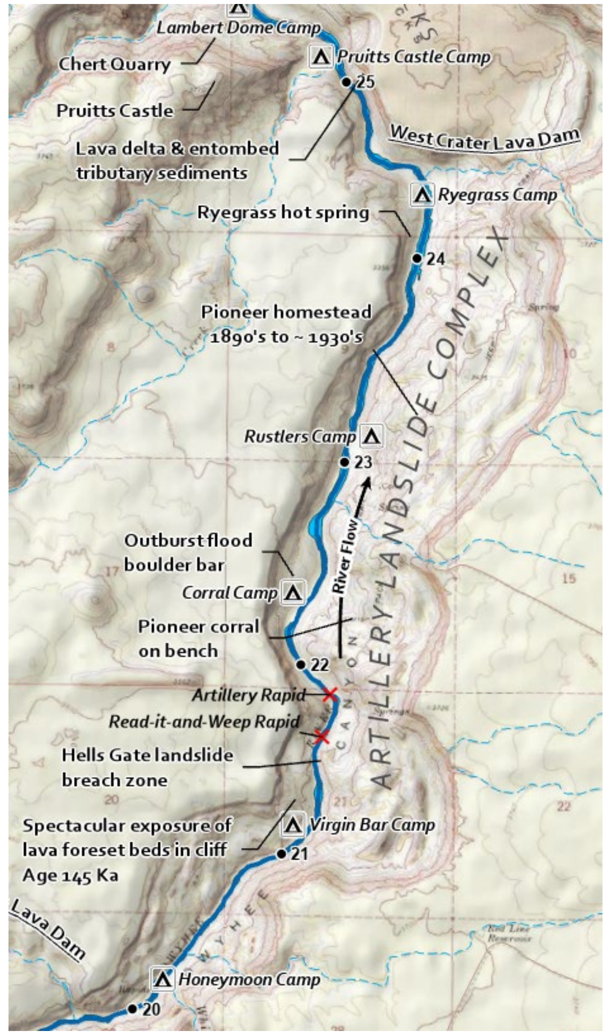
Hells Gate rockfall *(mile 21.5)*

The dramatic pinch in the river at mile 21.5, "Hells Gate rockfall", was caused by a recent rockfall of Saddle Butte lava from the rimrock on river-left. It created a rockslide dam that failed catastrophically and left a huge block of Saddle Butte basalt stranded on the river-right where it looms over the river, tilted to a nearly vertical position.

Just upstream was once another dam, slightly older and much larger, created when a massive landslide composed mostly of tan-colored sediments descended from the east canyon rim ("Artillery Rim") and blocked the river, leaving a large scallop-shaped "bite" in the rimrock above.

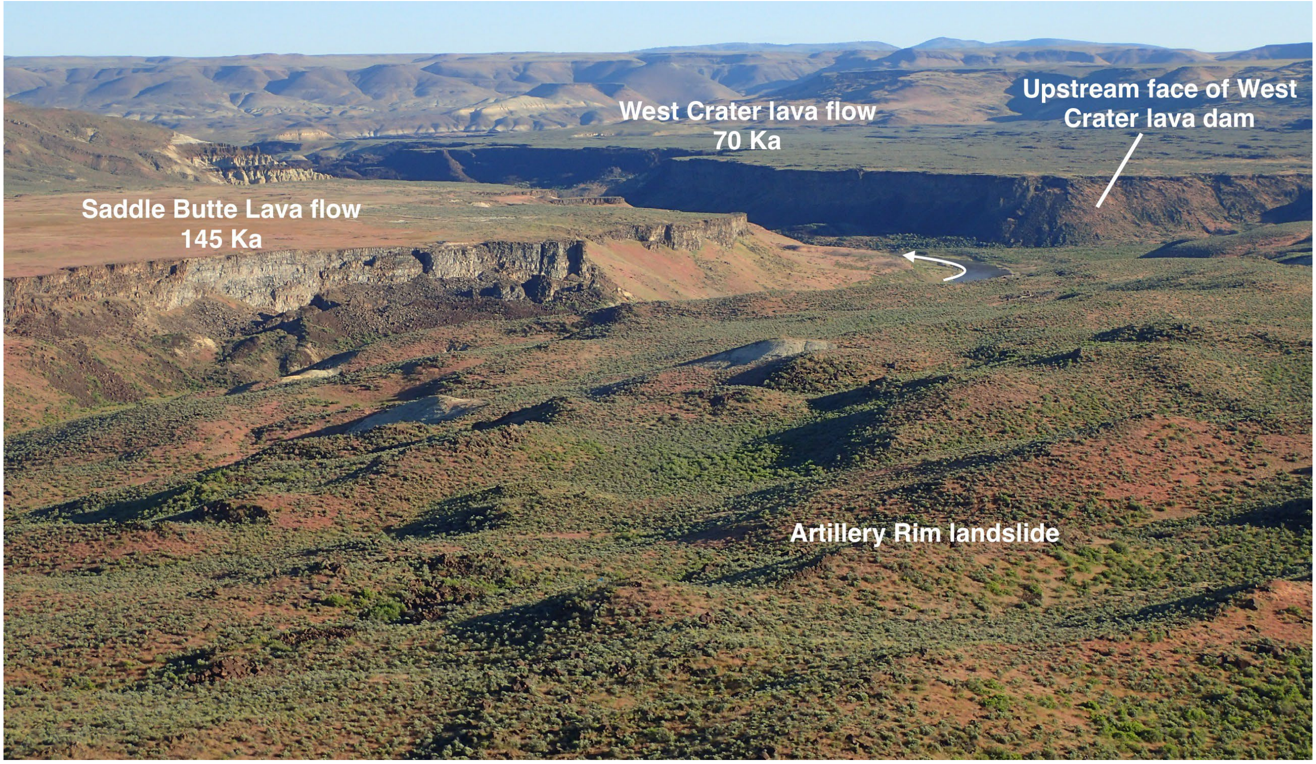
Geologists believe these are among the youngest landslides and dams on the river, estimated to be about 10,000 years old based on the youthful morphology of the landslide surfaces. Unlike lava dams, landslide dams are very short-lived (80% fail within a year), so neither of these blockages existed long enough to deposit any noticeable lakebed sediments upstream of the dams. However, evidence of high-energy outburst floods tells us the dams did survive long enough to create sizable temporary lakes.

The outburst floods from the failed dams left trails of boulders downstream in the river channel, creating Read-it-and-Weep and Artillery Rapids. Some boulders have abraded into fantastic shapes by the Owyhee River which has not been able to move the clasts since the flood. Others are covered by percussion marks from collisions with other rocks in the powerful floodwaters.



Artillery Rim map

Mile 22.3: Abraded boulders from outburst floods at Corral Camp.



Mile 23: View downriver from above Rustlers Cabin. During the last 145,000 years, two different lava flows dammed the river and altered its course. In foreground is the hummocky surface of a large landslide slump block from Artillery Rim.

Artillery Rim Landslides

Downstream of Hells Gate rockfall, the river cuts through a series of landslides that blocked the river with short-lived dams and widened the canyon. The most impressive are on the right bank, massive rotational landslides consisting of a 50/50 mix of sediments and basalt, originating nearly 500 feet above the river on Artillery Rim and traveling up to 0.8-mile to the river. They overlap and form a distinctive hummocky surface as they weather. (Best seen by hiking away from the river, the toes of the massive landslides block the view from the river.) On the left bank are smaller basalt rockfalls from the Saddle Butte rimrock, much like the rockfalls seen upstream.

These are all recent landslides that get progressively older as you go downstream. The youngest (at Hells Gate) is estimated to be about 10,000 years old, the oldest (across from Ryegrass Hot Springs) is between 70,000 and 145,000 years old. If you walk up to Rustler's Cabin, you are walking on a landslide that occurred about 42,000 to 70,000 years ago.

Neither the landslides nor this canyon existed 145,000 years ago. At that time, the Saddle Butte lava flow filled the river valley with lava, creating a large flat lava plain that pushed the river to the east, pinning it against Artillery Rim. The river gradually incised today's channel along the seam between the hard lava plain and the soft sediments in Artillery Rim's canyon wall. In the process it undercut the basalt rimrocks on both sides of the river and triggered the landslides that continue to this day.

Mile 21-22: Saddle Bute lava flow pinned the river against Artillery Rim where it incised a new channel and triggered a series of landslides and rockslides. (Aerial view downriver/north.)

Rustlers cabin *(mile 23)*

By the late 1890s, a pioneer homestead occupied about two miles of the east (river-right) riverbank. The original 1901 Land Office survey shows a home and two fields located here. Access was by a wagon road/trail that went about two miles north to another homestead at Bogus Creek ("Horn's House") and then climbed out of the canyon to Jordan Valley. The survey shows another road (pack-trail?) fording the river at Ryegrass hot spring and heading west across the lava plateau to distant "Harney City".

In 1912 Jose Navarro obtained a homestead patent (legal title) and raised sheep on the land. Later it was abandoned, but it remains in private ownership today, perhaps the only privately owned riverfront left in the Wild and Scenic corridor. Google Earth images show the remains of two pioneer corrals, one near the remains of the stone house and another upstream on a high bench across from Corral Camp. The corrals were both located near springs providing year-round water.

Owyhee historian Bill Crowell says on his blog (OwyheeMarginalia.com) that after the homestead was abandoned, "during the pre-WWII period, its remoteness and remaining buildings and corrals made it an excellent hideout for rustlers…"

Mile 23: Remains of "Rustlers Cabin", a late 1890s to early-1900s homestead.

Ryegrass hot spring *(mile 24)*

The main tub at Ryegrass hot spring is a popular stop along the river and conveniently located for those staying overnight at one of the nearby Ryegrass campsites. A smaller bath is located a short walk upstream of the main bath.

According to geologist L. Kittleman: "Hot springs are evidence of volcanic heat below the earth's surface. The water is not itself of volcanic origin. It is ordinary rainwater that seeps into fractures in the earth's surface, circulates as groundwater, and comes to the surface again at favorable places (such as faults). In recently active volcanic areas, hot rock is unusually close to the surface. In the Owyhee region the rise in temperature with depth is in places as much as 13 degrees F per 100 feet, which means the boiling point of water could be reached at a depth of only 1,100 feet."

The hot spring waters feeding the main bath emerge from a rock formation consisting of thin layers of hard, brittle mudstone. Hot groundwater probably hydrothermally altered what were originally soft layers of mudstone into these hard erosion-resistant rocks.

Mile 24: Main bath at Ryegrass hot spring. The frothy riffle cutting across the river is created by a ledge of erosion-resistant hydrothermally altered mudstone. On the opposite bank are mounds of tan-colored lakebed sediments deposited 43,000 to 70,000 years ago behind a lava dam.

At low-to-medium river levels, you can see a horizontal ledge of this hardened mudstone along the shoreline below the main bath. The hardened mudstone formation extends across the river and at low water forms a frothy obstruction that's clearly visible in satellite images and lines up perfectly with the springs feeding the main bath.

Lakebed sediments: While soaking in the hot springs, look across the river at the rounded mounds of white/tan-colored sediments on the opposite bank. These mounds are remnants of lakebed sediments that were deposited 43,000 to 70,000 years ago when a large lake existed here. The lake formed behind a lava dam located just a half mile downstream, described in the next section.

Water-affected basalt lava flow: The nondescript slope behind the hot spring is an ancient lava flow on the mudstone, now heavily altered into a crumbly rock that disaggregates to small fragments upon exposure to weathering. Known by geologists as "water-affected basalt", this crumbly rock is common throughout Chalk Basin.

Mile 24: Ledge of erosion-resistant hydrothermally altered mudstone at Ryegrass hot spring exposed during low water. The brush-covered slope is an ancient lava flow, now heavily altered to a crumbly rock called water-affected basalt.

Sources: (Kittleman, 1973), (Ely, et al., 2012), (Markley, 2013), (Othus, 2008), (BLM General Land Office Records Search, 2024), (Crowell, 2022),

Mile 24.5: West Crater lava dam. Across river from Ryegrass Hot Spring, looking downstream/north.

West Crater Lava dam *(mile 24.5)*

Just downstream of Ryegrass Hot Spring, notice the 270-foot-tall dark basalt cliffs on river-right. These cliffs are the upstream face of another well-studied lava dam. At 70,000 years old, the West Crater lava dam is the youngest lava dam on the lower Owyhee River.

The lava erupted from a volcanic vent named West Crater on the high lava plateau about 8 miles SE. It traveled down Bogus Creek into the Owyhee Canyon, creating the lava dam and a 6-mile-long lava plain, parts of which have eroded into the scenic basalt badland named "Lambert Rocks".

The lava flow pushed the river out of its channel and redirected it to the west. The old river channel (before the incoming West Crater lava flow buried it) continues due north, somewhere under the basalt cliffs in front of you. This is the second time the river has been redirected by a lava flow. The first was 145,000 years ago when the Saddle Butte lava flow came downriver and blocked the river here.

Over a period of tens of thousands of years, the river incised a new channel in the lava. A unique geological feature downstream named Dogleg Bend has allowed researchers to study how it took for the river to incise through the lava flow and establish its present course.

Upstream lake: A large lake 270 feet deep formed behind the lava dam, extending upstream to the Rome valley where the water was 30 to 50 feet deep. The lake persisted for tens of thousands of years, during which time the river's new course was over the top of the new lava dam and downstream on the surface of the lava flow. The dam overflow waters left behind shallow water channels eroded in the rim top lava and river-rounded boulders on the rim top.

Some of the lakebed sediments still exist. Across from Ryegrass hot springs, you can see rounded mounds of white/tan colored lakebed sediment on the sagebrush flats near the basalt cliffs. In the lakebed sediments, geologists found two layers of Mount St. Helens ash that were deposited 55,000 and 47,000 years ago, evidence the lake existed for at least 23,000 years after the dam formed.

Buried tributary: The cliff-face across from lower Ryegrass camp at mile 25 contains a lot of geological history starting with a blob of white sediment high in the canyon wall. This is the paleochannel of a small tributary that was buried 70,000 years ago by the West Crater lava flow. Its near perfect alignment with Ryegrass Creek on river-left is compelling evidence the Ryegrass Creek paleochannel extends east (under the lava) to reach where the old Owyhee River channel now lies buried. The tributary sediments were exposed when the river cut its present channel through the West Crater lava, truncating Ryegrass Creek on river-left. (Best seen by a short hike upstream from Pruitts Castle camp or a slightly longer one from Ryegrass camp.)

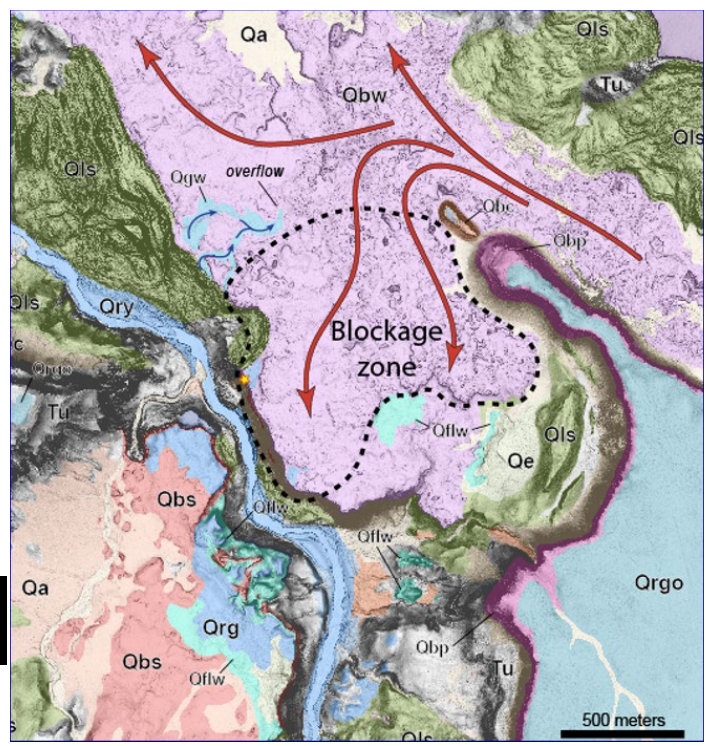
Pillow lava and slanting foreset beds: In the same canyon wall as the buried tributary, you can see a stop-action snapshot of the West Crater lava dam as it is being formed. A wall of West Crater lava was flowing upstream, pushing the lake water in front of it, leaving a trail of chilled rocks in slanted layers, until

Mile 25: Profile of West Crater lava dam. A spectacular exposure of stacked lava flows with pillow lavas, slanted foreset beds, and a buried tributary streambed. About 1 mile downstream of Ryegrass Hot Spring.

eventually halting near Ryegrass hot spring. Beneath the topmost layer of lava, notice the thick, orange-colored, dipping foreset beds and pillow lava created by contact with the lake water. The contact line between the dipping foreset beds and lava cap-rock marks the elevation of the water's surface.

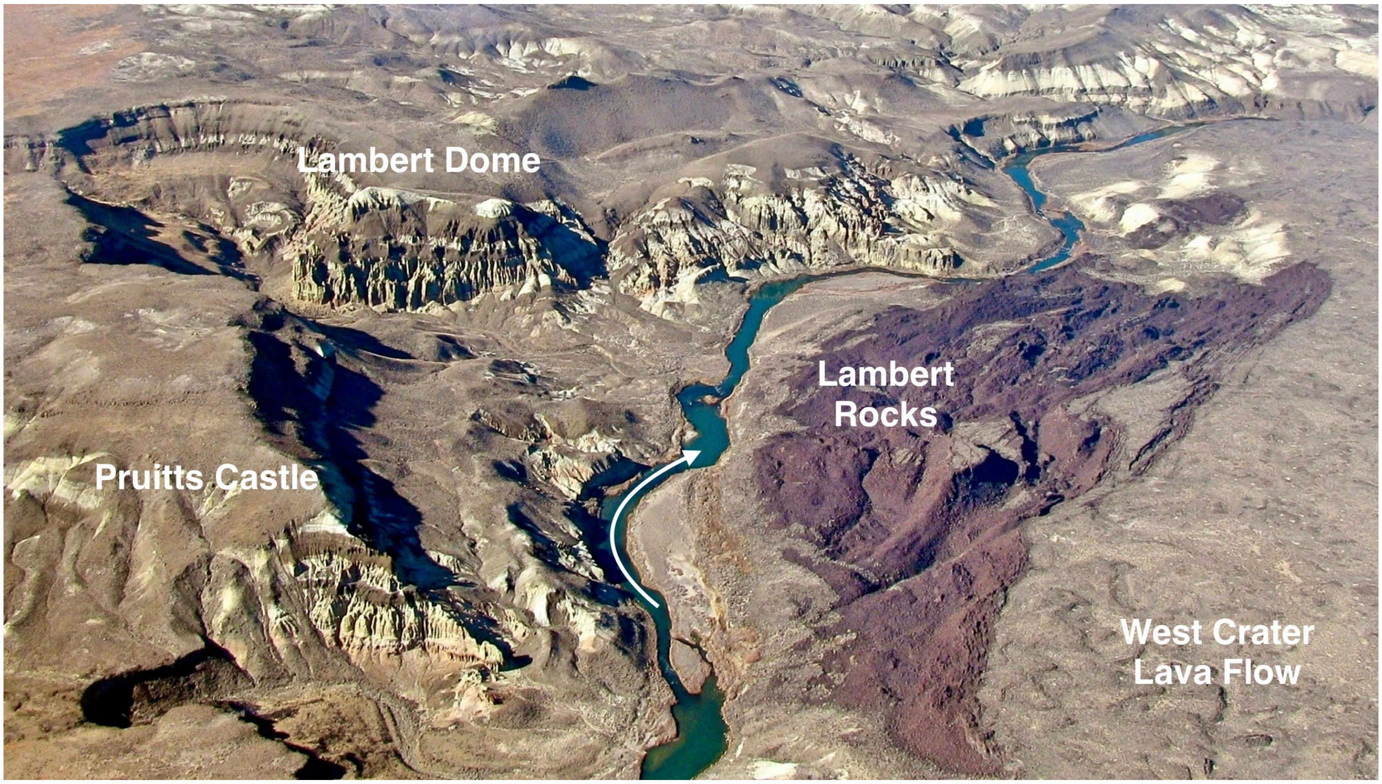
Chalk Basin sediments exposed: Downstream, you are following the new river channel carved about 40,000 to 50,000 years ago when the lake behind the West Crater lava dam drained. Notice that different strata are exposed on each side of the river: soft sedimentary layers on the river-left and hard erosion resistant lava flows on river-right. The river avoided the hard lava and carved its new channel in the soft sediments of Chalk Basin.

Sources: (Ely, et al., 2012), (Brossy, 2006), (Orem, 2010),



Mile 24.5: West Crater lava flow is shown with red arrows and purple color. Lava dam blockage is outlined with dotted line. (North is up and river flow is from bottom to top.)

Chalk Basin *(mile 25)*

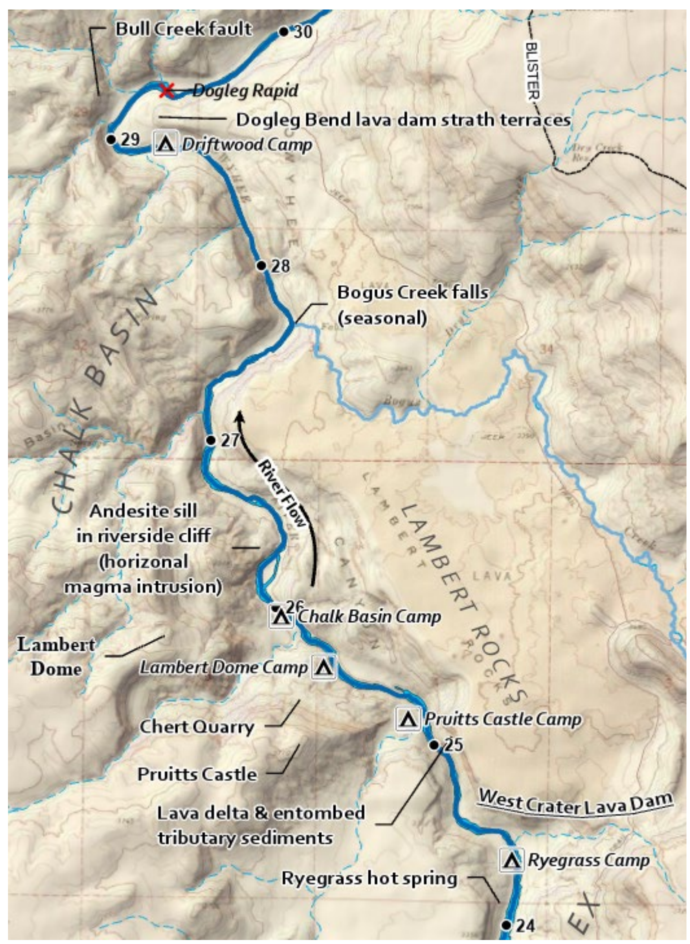


Mile 25: Aerial view of Chalk Basin. (Looking north.)

Pruitts Castle/Lambert Dome *(mile 25/ 26)*

Overview: Hikers and photographers love the picturesque hoodoos, spires, and domes found in Chalk Basin. The most well-known formations are named Pruitts Castle and Lambert Dome. Both are excellent places to camp and hike. Chalk Basin covers an area extending about 5 miles downstream and about 2 miles west of the river, but only the first 2 miles are easily accessible from the river. Road access by 4WD across the high plateau is possible in dry conditions, but difficult.

We know this was an ancient lakebed because most of the sediments here are silt, clay, and mud. Shell fragments and ripple marks show the lake environment. Shrinkage cracks in clay-rich layers suggest the lake periodically dried up; other layers were deposited in a quiet lake setting. Fossils (horse, beaver, and shells) found in the sediments are dated from the same geologic period as fossils found upstream in the sediments of the Rome Beds. The upper strata have been tentatively dated at 9.7 million years old based on the age of a layer of overlying Devine Canyon volcanic tuff; the bottommost strata near river level are possibly several million years older. The sediments are clay-rich and super-susceptible to erosion (basically lubricated muds), easily eroding into the canyons, ravines, gullies, hoodoos, spires, and other formations that make up the Chalk Basin.



Chalk Basin map

Mile 25: Pruitts Castle lakebed sediments.

Geology hikes: Pruitts Castle is best seen by hiking up to it. A short hike from the river leads to stunning spires and hoodoos eroded from the multicolored cliffs of lakebed sediments and ancient lava flows. Bear right (north) and follow the dry wash through scenic rock formations and on to the chert quarry described later.

Excellent views of Lambert Dome can be had from any location on the sagebrush-covered bench near the river. Spires and notable rock formations are located at its base, accessible via an easy hike from the river. Proceed towards Lambert Dome and then bear slightly right (north).

It's possible to do a loop hike to the base of Lambert Dome and Pruitts castle in a few hours of moderate walking. The route goes over the 200 to 300-foot-high sagebrush-covered hills on the north flank of Pruitts Castle, not along the river.

From the river, it's possible (but not recommended) to hike to the top of either Pruitts Castle or Lambert Dome via steep, hazardous paths of loose rocks. Hiking poles are essential, and a rope is advised for descending. Reach Pruitts Castle's summit through the dry wash on its south side. Reach Lambert Dome's summit through the dry wash on its north side. The summits offer sweeping views but have few geological formations to explore.

From Ryegrass Camp, one can hike 2 to 3 miles each way over the lava plateau to reach the summit of Pruitts Castle or Lambert Dome (no hazardous climbing). There is, however, no safe passage along the riverbank from Ryegrass Camp downstream to the lower camps.

Mile 26: Lambert Dome spires of red oxidized sediment.

Mile 26: Geology hike on north flank of Lambert Dome.

Mile 26: Lambert Dome lakebed sediments and interbedded basalt layers. Lambert Rocks in lower right corner. Looking west.

Lambert Rocks: The colorful landslide across the river from Chalk Basin is Lambert Rocks. The broken rock surfaces are still very raw and fresh looking, suggesting the landslide is recent. The lava rimrock that collapsed is part of the West Crater lava flow that dammed the river and re-directed the river into its present channel 70,000 years ago. As it incised its present channel, the river undercut the soft sediments and caused them and their heavy load of overlying lava rimrock to collapse. The original river channel (before it was redirected here) lies to the river-right (east), beneath the still-intact sections of West Crater lava.

Red "baked" layers: As the lakebed sediments built-up, lava sometimes poured out from nearby vents and covered the lake flats, creating alternating light and dark layers of sediments and basalt. The hot lava often baked and stained the underlying fine-grained water-saturated sediments into vivid shades of red or brown "natural bricks." The baking and staining dies away at a depth of a few inches to a few feet beneath the lava flow.

"Water-affected basalt": The basalt here is typically soft, crumbly, easily pulverized rock that turns to sand in your hand. In the 2000s, researchers investigating lava flows into lakes on Idaho's Snake River Plain observed similar phenomena. They coined the name "water-affected basalt" to describe basalt flows that have been high altered (chemically) by water or steam into a soft,

Mile 26: South face of Lambert Dome consists of two thick lava flows covered with a "hat" of lakebed sediments. A thin line of baked sediment separates the two lava flows.

Mile 26: The thick, dark layer in the cliff is a horizontal intrusion ("sill") of molten andesite or basalt into the lakebed sediments millions of years ago. View downriver/north.

easily-eroded rock. It has a low resistance to weathering and disintegrates into angular, coarse-grained particles of sand and gravel.

Conditions that favor development of water-affected basalt flows, rather than pillow basalts, are gently sloping lake bottoms, high rates of low-viscosity (runny) lava flow into the water, and rapid solidification but slow cooling of the emplaced lava. We find water-affected basalt at all elevations and locations in Chalk Basin, suggesting the basin floor was saturated or covered with water most of its life.

Local magma system: The lakebed sediments are also laced with layers of fused fragments of volcanic rock, baked rock, volcanic intrusions, and hydrothermally altered rocks. All strong evidence that a near-surface magma system was active here as the basin was filling with sediments.

There are also extensive reddened zones in the sediments that were not baked by lava (there is no lava/igneous material on top of it to do the baking). These zones are oxidized sandstone, a layer of permeable rock that has been altered/oxidized by circulating hot mineral-rich water from igneous activity.

Intrusive igneous layers: Besides surface lava flows, magma traveled underground, oozing through cracks and fractures in the earth, muscling its way into the lakebed sediments, and solidifying within the sedimentary layers into layers of basalt and andesite rocks called "intrusions". An easy-to-see example is the riverside cliff face with the reddish pinnacles on top just downstream (north) of Lambert Dome. (Not accessible on foot.)

Mile 25.5: Oxidized sandstone caprock near Pruitts Castle.

Mile 26: Lambert Rocks is a fresh-looking landslide of West Crater lava.

The sloping 20 to 30-foot-thick layer of dark rock in the cliff face near the water is an intrusion of basalt or andesite magma. Notice the matching offsets in the floor and ceiling of the intrusion as it forced the layers of sediment apart and worked upwards. And the chilled margins in floor and ceiling from contact with the cold sediments.

Cap rocks: Most of the protruding pinnacles and towers are capped with black or red rocks. This is because basalt flows, consolidated tephra, oxidized sandstone, and strongly baked rock all are more erosion-resistant than the soft lakebed sediments.

Thickness: Along the river at Pruitts Castle and Lambert Dome the exposed sediments and basaltic layers are about 400 feet thick. Away from the river, the ancient lakebed sediments are covered by layers of subsequent lava flows and sediments another 200 to 300 feet thick, probably about 3 to 5 million years old.

Sources: (Plumley, 1986), (Evans, et al., 1990), (Walker, et al., 1966), (Ferns, et al., 1993), (Godchaux & Bonnichsen, 2002)

Mile 27.8: Bogus Falls cascades down from Lambert Rocks after a heavy rainfall. A rare sight—usually a dry streambed. View east, on river-right.

Mile: 25.6: A prehistoric camp site was on the sagebrush flat on river-left near middle of image. The dark layer in the distant cliff is an intrusion of basalt or andesite.

Mile: 25.6: Large nodules of milky-colored chert exposed in ravine on north flank of Pruitts Castle. Raw material gathered by prehistoric hunter-gatherers for stone tools.

Chert Quarry Archeological Site *(mile 25.6)*

The Owyhee Canyon has been home to prehistoric people for almost 10,000 years based on dated archaeological sites located downstream at Birch Creek and upstream at Dirty Shame Rockshelter. Near today's Lambert Dome rafting campsite, Washington State University anthropologists uncovered evidence of a chert quarry and accompanying camp area used by hunter-gatherers to make stone tools.

Anthropologists studied the site over two field seasons, 2004 and 2005. They found abundant flakes and fragments of chipped rocks from chert processing, but few accompanying cultural artifacts, and no cooking hearths, suggesting this was an occasionally used surface campsite.

By analyzing thousands of tiny chert flakes and fragments found at the camp area, researchers learned the raw chert was processed in two steps. Up at the quarry, the large (and heavy) raw chert nodules were roughly worked down into smaller "cores" before being transported down to the camp area. At the camp area, the chert cores were then carefully converted into "hafted bifaces" (cutting tools such as knives and projectile points).

No organic material was found for carbon dating, so the site's age was estimated from the styles of six identifiable projectile points recovered. The projectile point styles were in use from approximately 7,000 to 650 years ago, coinciding with when prehistoric hunter-gatherers are known to have lived 18 miles downstream at the Birch Creek archeological site.

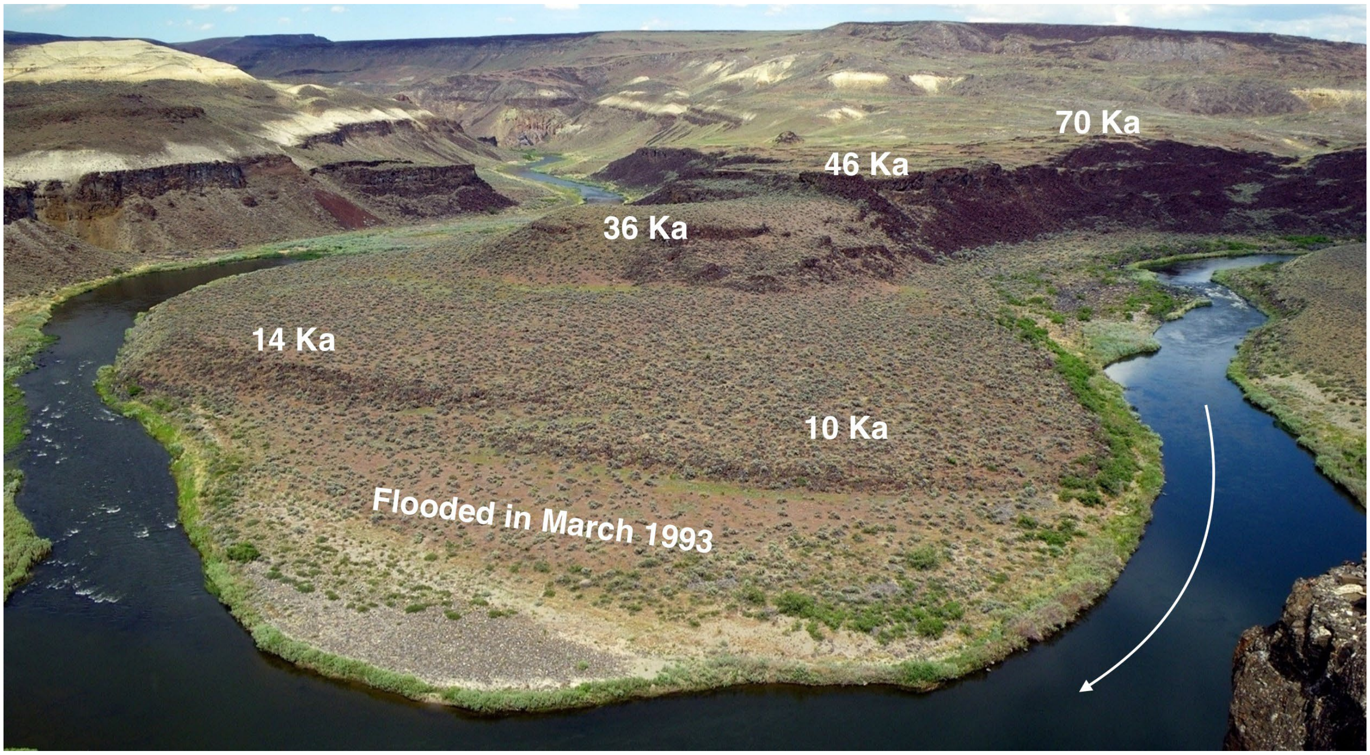
Chert: The chert found here is a tool-quality, milky-white rock nodule that looks like agate. It was created when hydrothermal fluids circulated through voids and cracks in the buried layers of volcanic sediments and tuffs, and silica precipitated out of the fluid, forming solid nodules and veins of silicate minerals (the chert).

The quarry location is believed to be a thick vein of chert exposed in a ravine on the foothill between Lambert Dome and Pruitts Castle, about one-half mile south of the prehistoric camp area and about 200 feet elevation above the river. Abundant fist-sized to boulder-sized chert nodules are scattered about on the ravine floor.

Farther downstream (from Birch Creek to Red Butte) a different variety of tool-quality chert was used by the prehistoric hunter-gatherers living there. Known to archaeologists as "Owyhee silicified mudstone", it is readily available as river cobble in gravel bars lining the river. It was used as far back as 6,600 years ago to make stone tools found at the Birch Creek archeological site. It was also used as recently as 450 years ago in stone tools recovered at the Lost Dunes bison butchering camp archeological site near Malheur Lake, Oregon.

Archeologists broadly use the term "chert" to include any stone that fractures conchoidally (with smooth, curved surfaces) and is suitable for flaking into stone tools, composed of crystalline quartz (silicon dioxide). Examples are flint and agate.

Sources: (Wilson, 2007), (Lyons, et al., 2003)



Mile 29: Ages of boulder deposits at Dogleg Bend mark how long it took to remove the West Crater lava dam. View east. Source: Ely et al, 2012

Dogleg Bend Lava Dam Terraces *(mile 29)*

This didn't start out as a dogleg bend. 70,000 years ago, the river's course was around a gentle bend 165 feet above today's river channel, on top the West Crater lava blockage. As the river incised through the lava blockage, its course gradually moved to the outside of the bend, creating the dogleg, and leaving behind boulder-covered stairsteps called "strath terraces" on the riverbank.

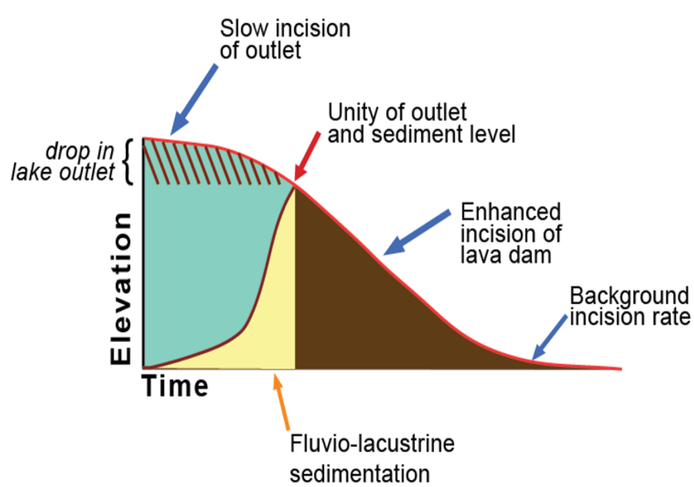
The strath terraces are a way to date the lava dam removal process. Geologists used surface-exposure-dating techniques to determine how long the river boulders have been exposed on the surface of each terrace, and thus the terrace's age.

During the first 25,000 years of the dam's life, little to no erosion of the lava blockage occurred. It wasn't until after the reservoir behind the dam had filled up with sediment that incision began. It then took about another 30,000 years for the river to cut down through the lava to its pre-dam elevation. That job was completed only about 15,000 years ago.

Once the river water contained sediments, incision took off and quickly started creating the terraces, averaging about 1 mm/year (the thickness of a credit card or 10 sheets of printer paper each year), which seems slow but is about 10X faster than the river's average incision rate over the last 2 million years.

Geologists explain that new lava dams start off with a slow rate of incision because the dam overflow water has lost most of its abrasive power. Abrasive particles suspended in the incoming river water don't make it to the dam outlet, they settle out in the calm waters of the lake behind the dam, slowly building up layers of lakebed sediments. Enough time must pass for the lakebed sediments to reach the height of the dam outlet and then be picked up by the overflow water. Once that happens, the dam overflow water becomes abrasive, the rate of dam incision increases dramatically, and it quickly (in geological time) incises through the blockage.

Sources: (Ely, et al., 2012), (Brossy, 2006), (Orem, 2010),



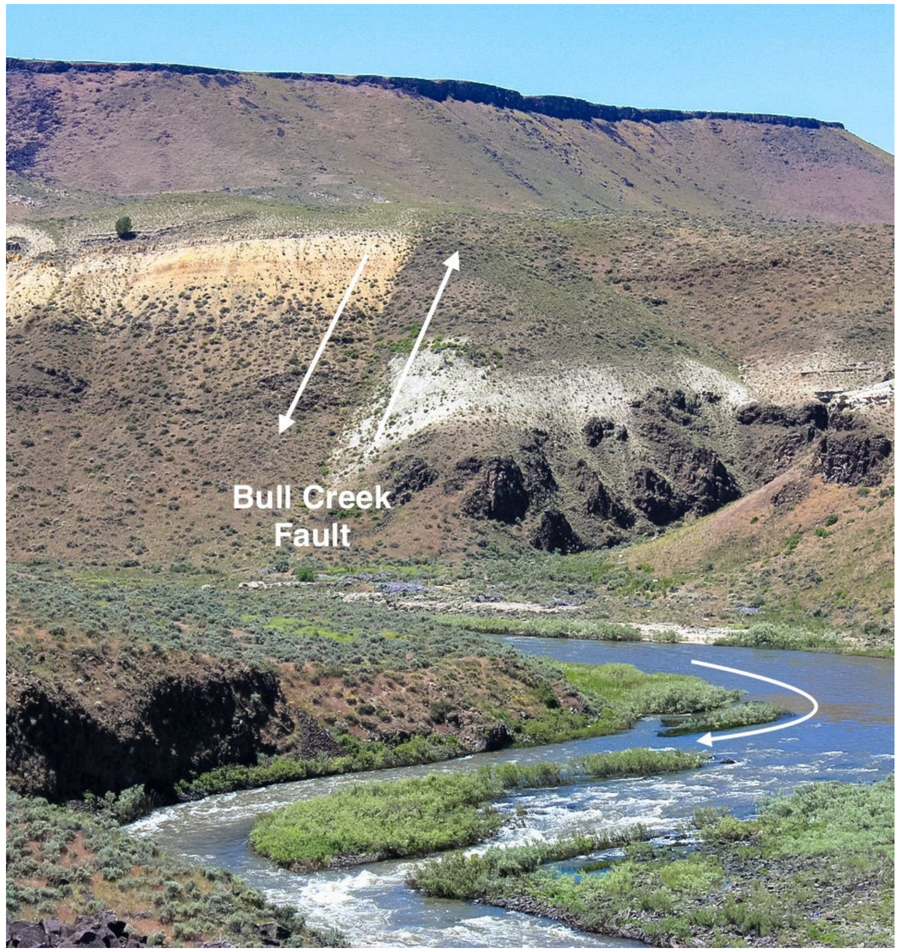
Lava Dam Incision/Removal Model

Bull Creek fault *(mile 29.3)*

At Dogleg Bend, observe the misaligned light-colored sedimentary layers in the canyon wall on river-left (west). This marks the Bull Creek fault. The fault moved upward to the north (right side in the photo), uplifting the strata on the right by over 100 feet relative to the leftt.

This is the most obvious of several faults that geologists have mapped in this reach of the river, others cross the river upstream near Pruitts Castle and another crosses the river downstream at Hoot Owl Creek at the north end of Whistling Bird Canyon. The Hoot Owl Creek fault has about 130 feet of offset.

As we move downstream past these faults, older strata appear in the canyon walls due to the uplift. Examples include rhyolite lava and tuff just around the next bend in Whistling Bird Canyon.



Mile 29.3: Bull Creek fault. Strata on the right are uplifted over 100 feet relative to the strata on the left. (Looking upstream/south from Dogleg Bend.

Whistling Bird Canyon *(mile 30)*

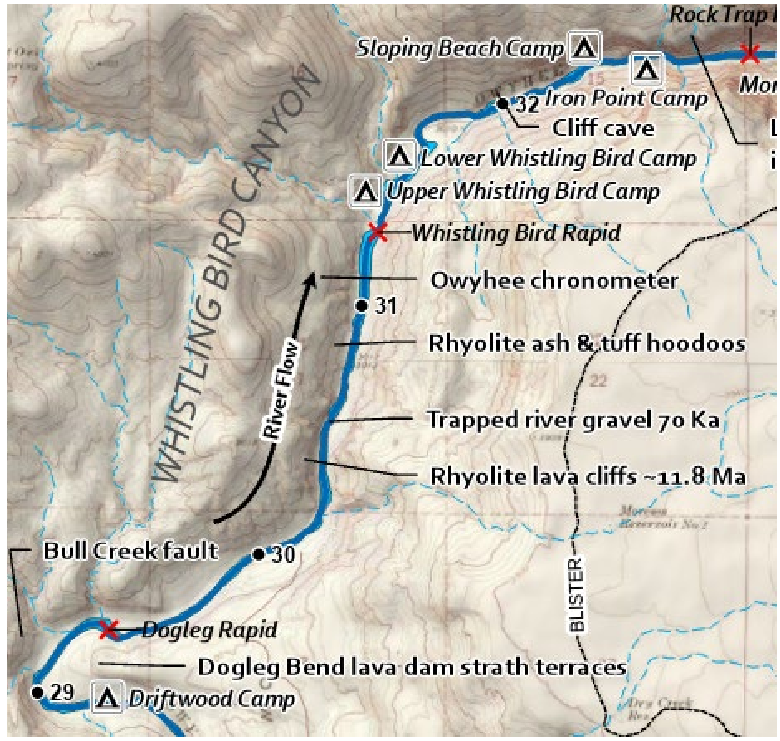
Rhyolite cliffs and hoodoos

In Whistling Bird Canyon, the river incised through strata from an ancient volcanic eruption, exposing long-buried layers of rhyolite ash and tuff, and intermittent formations of hard rhyolite rock. The ash and tuff layers are relatively soft and easily eroded and have weathered into orange-colored hoodoos and caves in the valley walls. The erosion-resistant rhyolite rocks form eye-catching, orange-colored vertical cliffs at the water's edge.

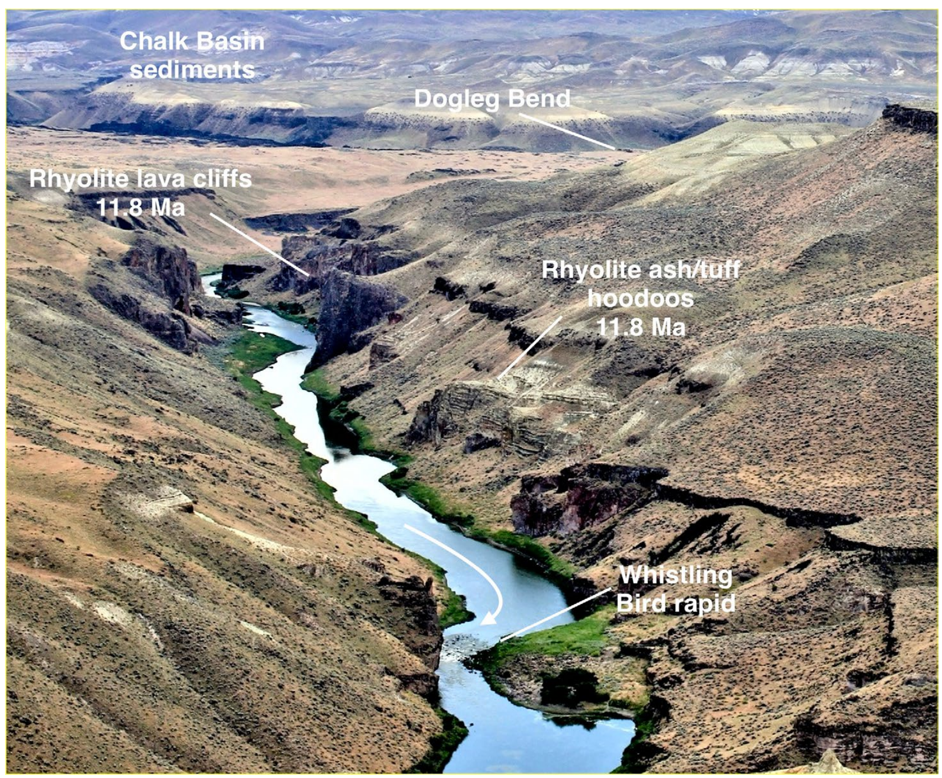
Researchers think the rhyolite rocks here were created 11.8 million years ago by the same volcanic eruption that created the 1,100-foot-thick rhyolite lava dome in Sleeping Dragon Gorge just two miles downstream. Geologists have collectively named all the rhyolite in Whistling Bird Canyon and in Sleeping Dragon Gorge the "rhyolite of Iron Point", named for the highest basalt rimrock above Sleeping Dragon gorge.

The volcano's explosive phases spread a thick layer of pyroclastic materials over the area. Embedded in the rhyolite tuff bluffs are assorted fragments of rhyolite and basalt rocks, indicating the volcanic tuff was deposited by turbulent pyroclastic flows along the ground, not by air-fall deposits. An explosive gas eruption probably ripped rocks from the volcano's vent walls and ejected the fragmented rocks, along with huge quantities of ash, into the air, and descended to form a ground hugging chaotic pyroclastic flow that later lithified (solidified) into the volcanic tuff here.

After the rhyolite eruptions ended, Chalk Basin filled with almost a thousand feet of lakebed sediments and basalt lava flows that buried the rhyolite lava and tuff. It remained hidden, out of sight until the Owyhee river incised today's canyon.



Whistling Bird Canyon map



Mile 30: Whistling Bird Canyon cuts through rhyolite lava and pyroclastic deposits from a volcanic erupion about 11.8 million years ago.

Mile: 30: 150-foot-tall rhyolite lava cliffs.

Mile 30: Pinnacles of rhyolite ash and tuff.

70,000-year-old riverbed marker *(mile 30.5)*

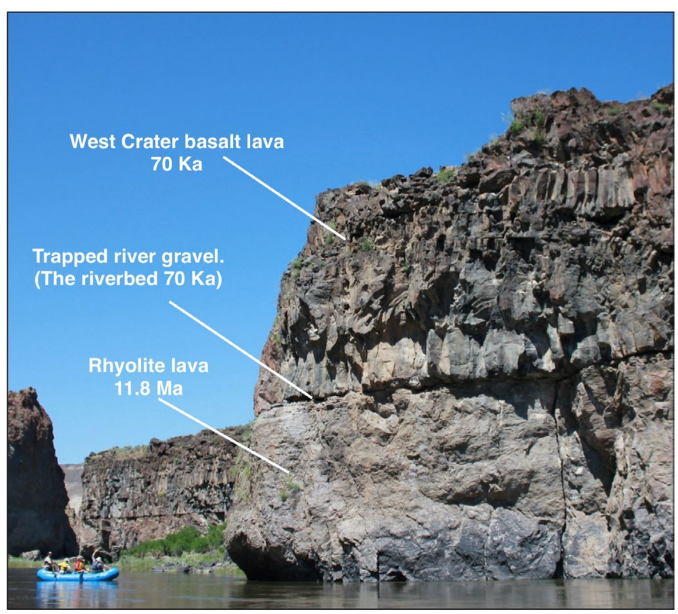
Researchers discovered remnants of the West Crater intracanyon lava flow here in Whistling Bird Canyon. The lava overlies a distinctive rhyolite riverbed strath with trapped river gravel between the them, only 28 feet above the water. This easy-to-see rock formation shows the river has not changed its course here in the last 70 thousand years.

Whistling Bird Rapid *(mile 31.2)*

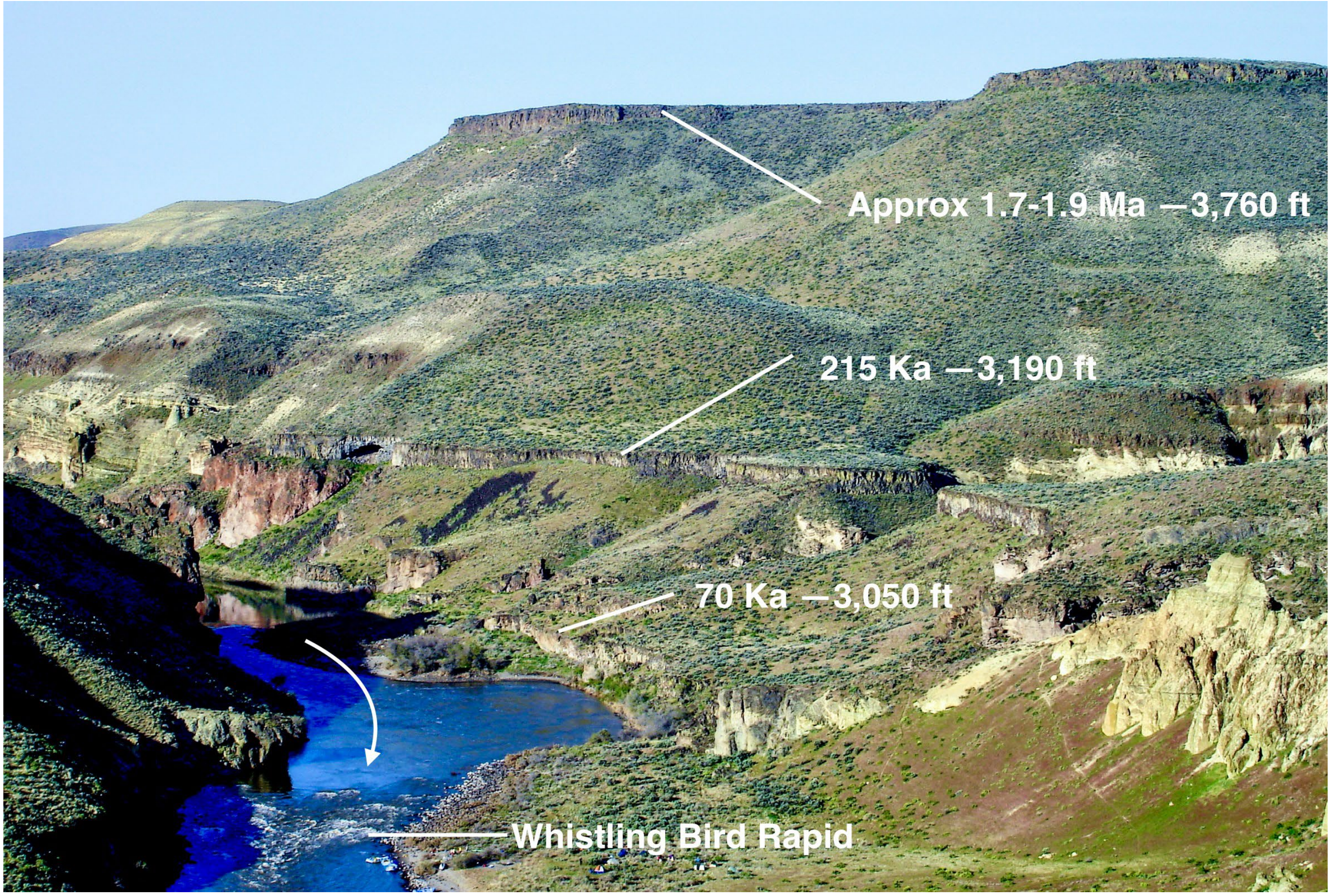
One of the Owyhee's most challenging rapids, Whistling Bird Rapid was created when rock debris from a flooding tributary on river-left redirected the river against the cliff on the right, eventually undercutting the rhyolite rock cliff face and triggering a rock-fall, creating the "rock sieve" that now blocks that side of the river. Rafters must carefully thread between the dual hazards of the boulders on river-left and the rock sieve on river-right.

Mile 31.2: Whistling Bird rapid at low water. The cliff is an erosion-resistant rhyolite intrusion (or lava flow).

Mile: 32: Large fragments of erupted rhyolite rock are embedded in cave roof.



Mile 30.2: West Crater lava flow overlies a rhyolite riverbed strath. Horizontal seam 28 feet above river marks riverbed location 70,000-years ago. Raft for scale.



Mile: 31.3: View upstream of "Owyhee Chronometer" in Whistling Bird canyon. At this location, three different intracanyon lava flows are visible in the canyon wall, each one marking the riverbed's former elevation and age.

Owyhee Chronometer *(mile 31.3)*

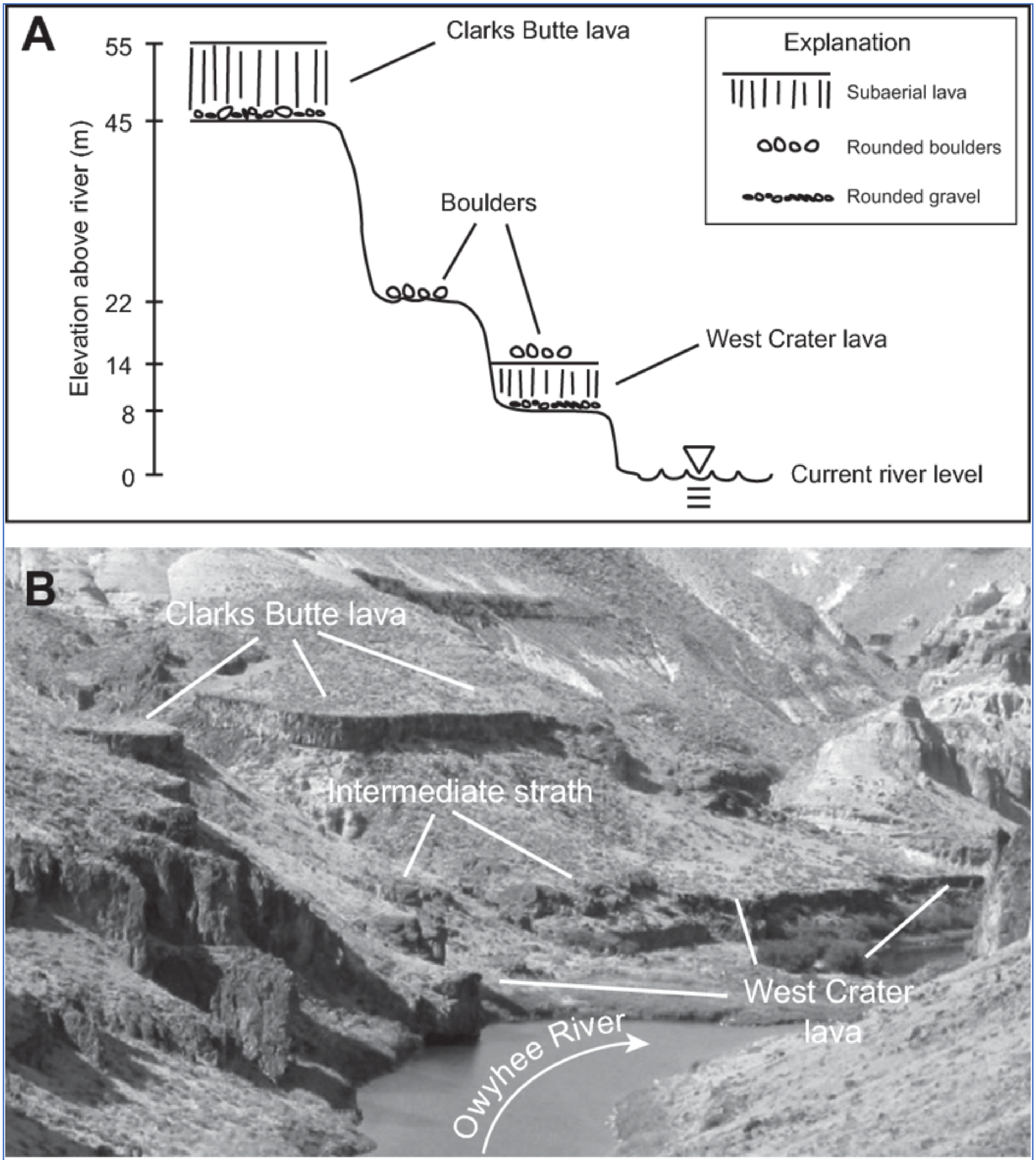
The "Owyhee Chronometer" contains lava remnants from three different valley-filling lava flows showing where the riverbed was located 70,000 years ago, 215,000 years ago, and 1.7-1.9 million years ago. Researchers used this information to reconstruct the river channel immediately prior to the date of each eruption and to calculate the river channel incision rate between eruptions. (These are the "West Crater", "Clarks Butte" and probably "Bogus Rim" lava flows, from youngest to oldest.)

The two lowest lava flows have a thin layer of trapped Owyhee river gravel at their base, evidence that the river course at this location has remained unchanged for at least 215,000 years, despite the disruptions caused by lava flows twice completely blocking the river channel. Researchers believe the river has little ability to change its course in this reach of the canyon because it is constrained just one mile downstream to pass through a narrow erosion-resistant rhyolite canyon, "Sleeping Dragon Gorge".

Measured over the past 1.7 million years (from the topmost lava flow), the Owyhee Canyon has grown deeper at an average rate of 6.4 inches per 1,000 years, about the thickness of one or two sheets of paper each year.

This is typical of other western rivers, though incision rates vary widely. However, data from intervening lava flows show that short-term incision rates can be very high, incision rates jumped 69 percent after the Clarks Butte lava flow, before returning to just below the long-term average during the most recent 70,000 years. Studies here and at other locations in the canyon have been instrumental in understanding factors that affect river canyon incision rates.

Source: (Ely, et al., 2012), (Brossy, 2006), (Ferns & Evans, 1993), (Plumley, 1986), (Swenton, et al., 2022),



Mile 31.3: Profiles of two former lava dams in Whistling Bird canyon with vertical scale (A). View downstream of the lava dam remnants perched on the canyon wall (B). Each lava flow overlies 1-3 feet of gravel and gravels that rest on rhyolite strath surfaces (the former riverbed)). Rounded boulders rest on the lower lava flow and an intermediate strath surface not covered by a lava flow.

From (Ely, et al., 2012).

Sleeping Dragon Gorge *(mile 32)*

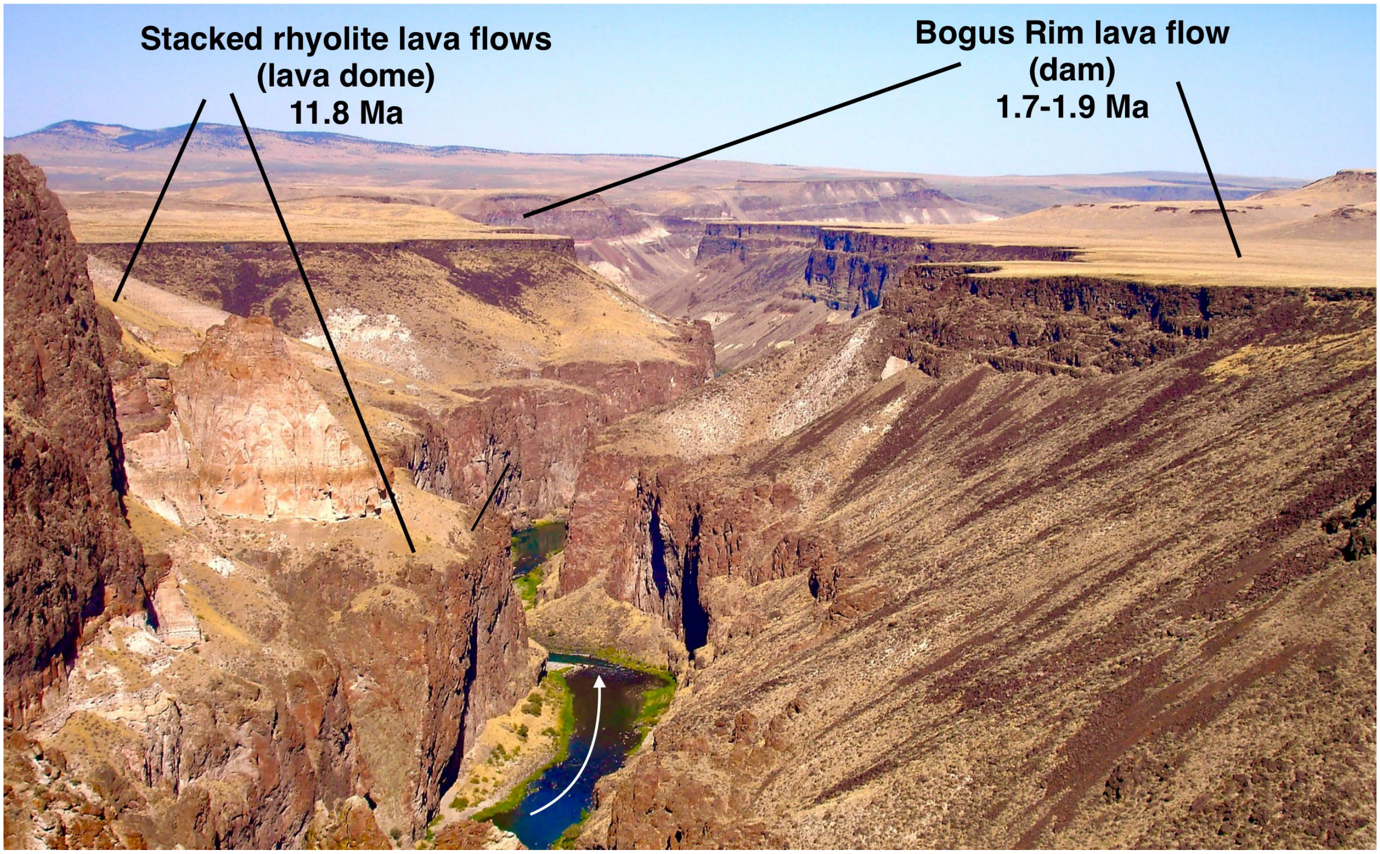
Rhyolite lava gorge *(mile 32)*

Sometime between 2 and 5 million years ago the Owyhee River began carving Sleeping Dragon Gorge, named for the dragon silhouette visible from the rimrock. One of the deepest canyons on the Owyhee River, it measures 1,300 feet deep from the tip of Iron Point to water level. It grows deeper each year by fractions of an inch, about the thickness of a sheet of paper. The canyon walls are rhyolite lava, a hard erosion-resistant rock that forms narrow, vertical canyon walls and weathers to a soft orange color.

In this canyon you pass through the cross-section of a rhyolite volcanic eruption, probably a lava dome. The flowing lava from the eruption left two thick layers of rhyolite lava exposed in the gorge walls, a lower layer 720 feet thick and an upper layer 360 feet thick, separated by a thin layer of pyroclastic material.

Sleeping Dragon Gorge map

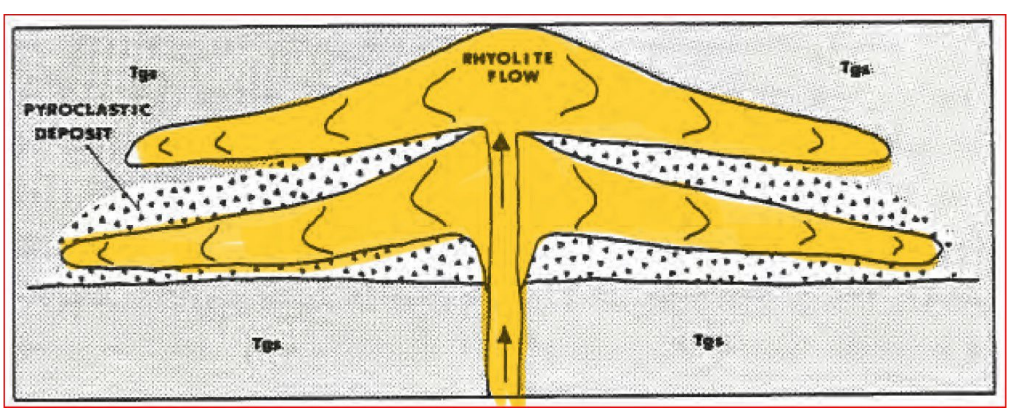
Mile 33: Sleeping Dragon Gorge. Vertical cliffs are rhyolite lava. View downriver. Photo: James Parsons.



Mile 33.5: 1,300-foot-deep Sleeping Dragon Gorge cuts through a dome of 11.8-million-year-old rhyolite lava. Looking downriver/north.

Flowing rhyolite lava is extremely viscous and does not travel more than a few miles before solidifying into rock, usually covering only a small area. Based on exposures in the gorge, it is thought that these lava flows originally covered a roughly circular area, approximately 4 miles in diameter – a dome. The edge of the flow lobes can be traced along the walls of the gorge where the flows gradually thin and then abruptly end. Rhyolite volcanic eruptions often alternate between flowing lava and air-fall ash and rock. The explosive phases of the eruption left hundreds-of-foot-thick layers of ash and tuff upstream at the gorge entrance (Whistling Bird Canyon) and downstream at the gorge exit (Tanager Canyon). Geologists call everything the "rhyolite of Iron Point".

The rhyolite lava is laboratory-dated as 11.8 million years old. Nearby Sacramento Butte, only 5 miles away to the northwest, is the same age, suggesting a possible connection between the two eruptions. Both occurred near the beginning of a 2.5-million-year-long pulse of rhyolite volcanism when at least 24 different rhyolite volcanic centers were active in this corner of Oregon. The basalt plateau ("Iron Point") that overlies the rhyolite dome is dated as 5.0 million years old.



Rhyolite Lava Dome example. (Source Plumley 1986.)

Spherulites (mile 32.5)

As you enter the narrow gorge by boat, watch the rock wall on river-left and try to spot the group of 1-to-2-foot diameter spherulites. While small spherulites less than an inch in diameter are abundant in rhyolite rocks, large spherulites like these are uncommon. Recent research shows that large spherulites, like small ones, grow from crystals that form in molten lava as it cools to its "glass transition temperature" (about 1,350 to 1,560 degrees F), at which point growth halts. Calculations show it takes decades to grow large spherulites of this size, so these spherulites are evidence of an unusually slow lava cooling rate. Research also shows that spherulites expel water as they grow (crystalize) and the excess water often chemically alters the surrounding lava into clay-sized minerals. The odd-looking rock surrounding these spherulites may be the original rhyolite lava now altered into different minerals by the expelled water.

Mile 32.5: Basketball-sized spherulites surrounded by clay minerals in canyon wall on river-left at gorge entrance.

Possible buried caldera

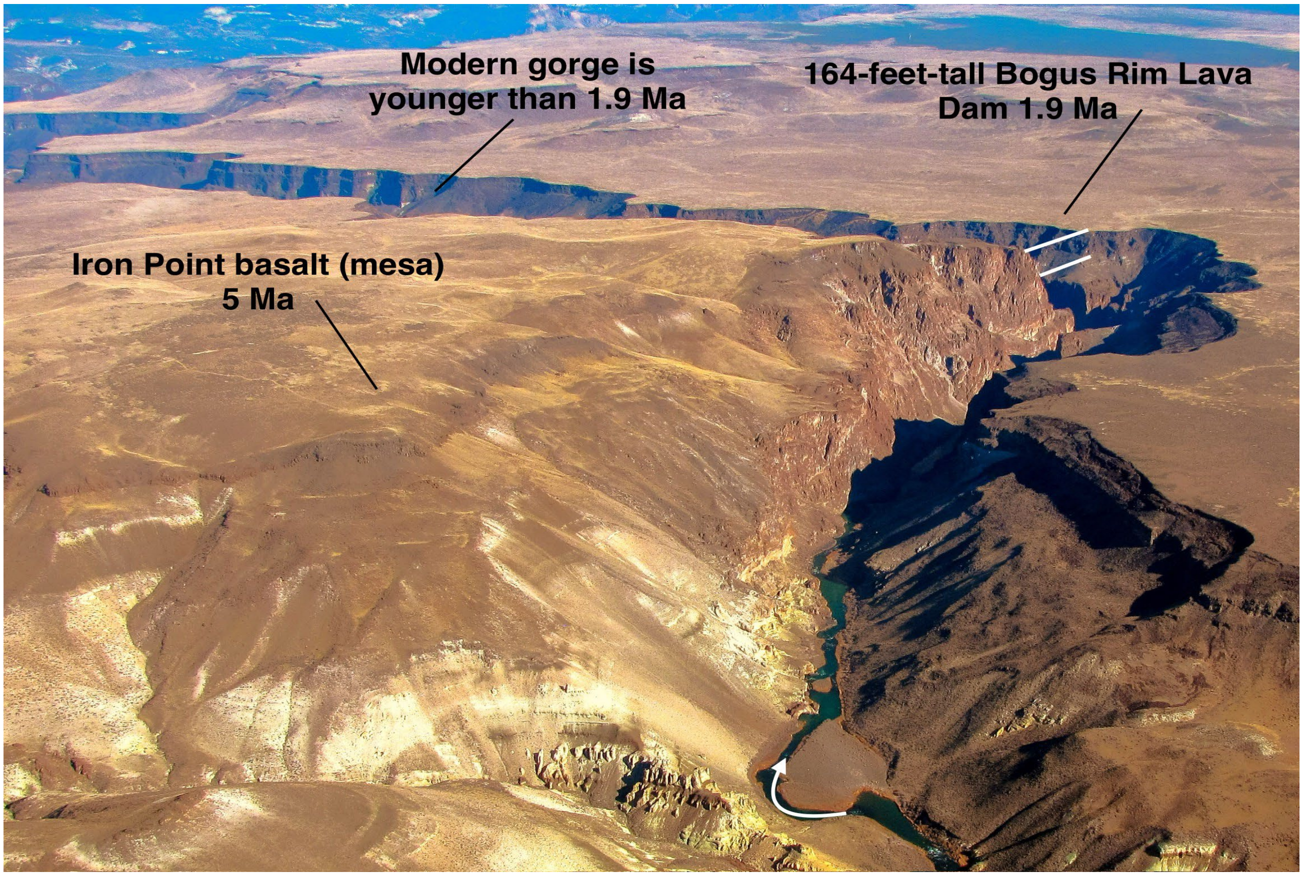
Geologists have proposed that a buried volcanic caldera may be located a few miles northwest. Evidence consists of a gravity survey conducted in 1986-87 by the USGS. The survey identified a semi-circular area of low-density rock extending for 15 miles across the Owyhee River Canyon, with a nadir located about 2 miles northwest of Sleeping Dragon Gorge. A possible explanation for the low-density rock is a concealed older caldera complex containing low-density rhyolite caldera fill.

If so, the eruption that created the rhyolite in Sleeping Dragon Gorge and nearby Sacramento Butte may be a part of a much bigger picture. Much more field evidence needs to be found to prove it did happen.

The "sleeping dragon" *(mile 33)*

If you stand on the south rimrock 1,000 feet above the river, you can look across the canyon and see the silhouette of the sleeping dragon rock formation for which Sleeping Dragon Gorge is named. The views are breathtaking, but access is difficult—on a rough, 2-track, 4-wheel drive road, across the high lava plain from US-95.

The Sleeping Dragon silhouette. View from south rimrock looking across the canyon. The summit of the dragon's back is "Iron Point", a 5-million-year-old basalt lava flow overlying the 11.8-million-year-old rhyolite lava dome.



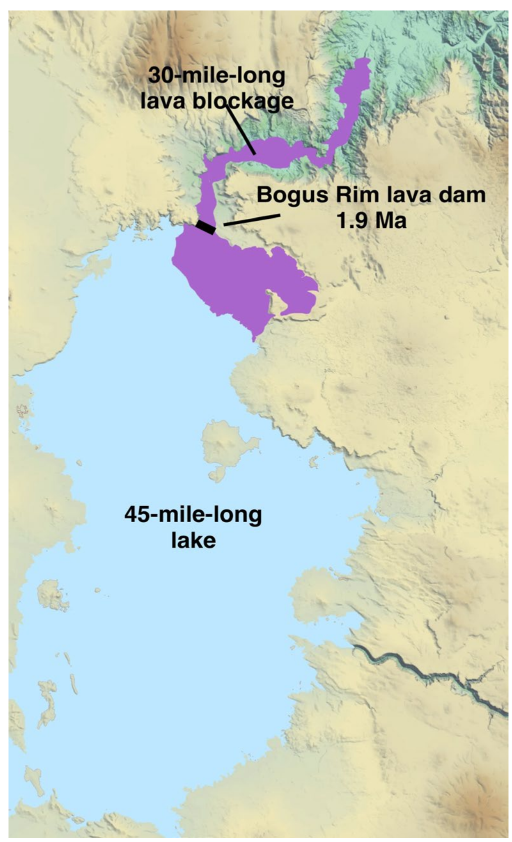
Sleeping Dragon Gorge looking downstream (NE). Site of the nearly 2-million-year-old Bogus Rim lava dam. The riverbed was then wide and shallow and located high above today's river. View upstream/northeast.

Bogus Rim lava dam *(mile 33.5)*

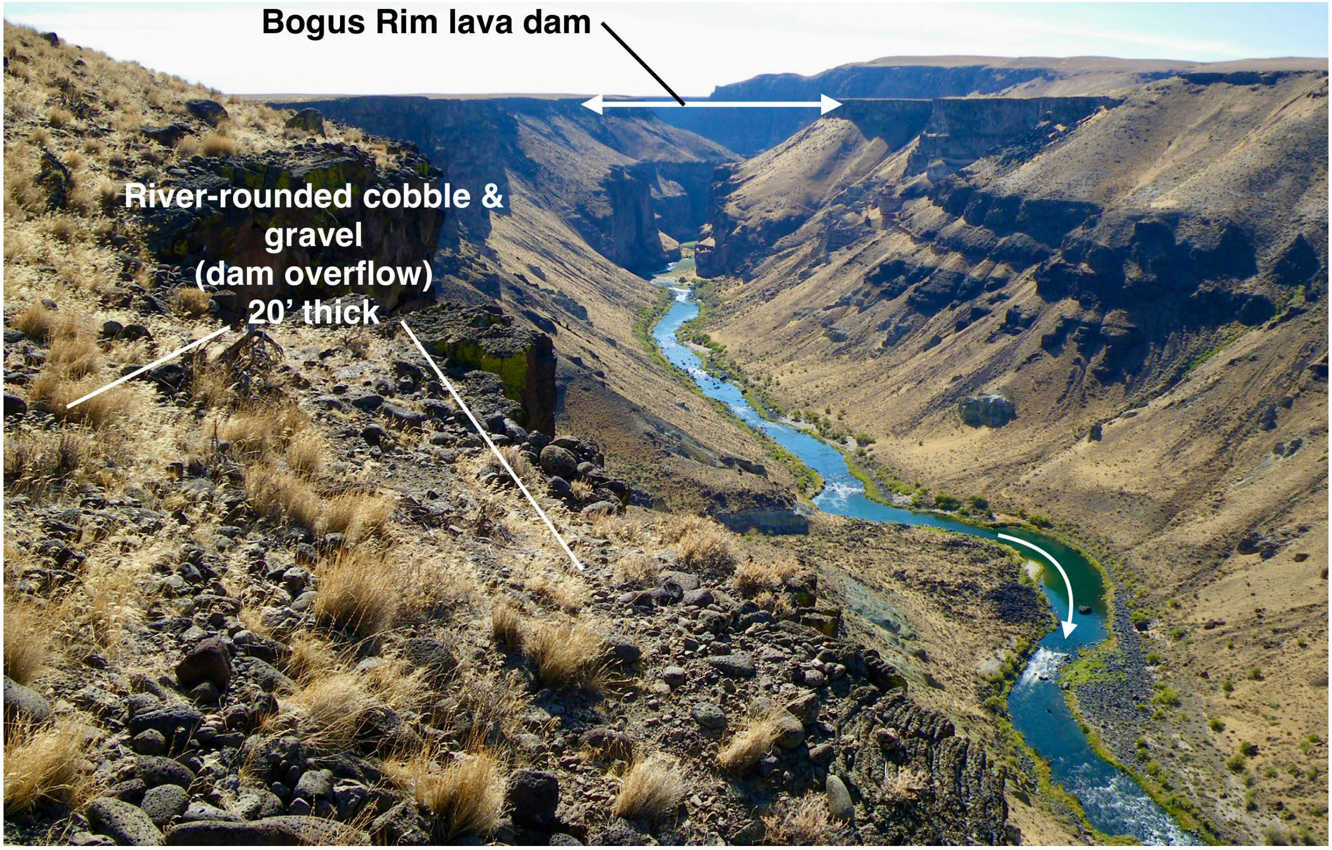
In the early 2000s, a team of researchers investigating ancient lava dams on the Owyhee discovered evidence here of the largest known lava flow and lava dam in the Owyhee River corridor –the Bogus Rim lava dam. This event occurred almost 2 million years ago, before the modern deep and narrow Sleeping Dragon Gorge existed.

The lava dam was 164 feet tall and its base was about 852 feet above today's water level, marking the location of the riverbed at that time. The crest of the dam was about 1,016 feet above today's river. Behind the lava dam, a huge lake formed that extended about 45 miles upstream and flooded the surrounding landscape, covering everything up to an elevation of 3,970 feet!

The lava dam consists of up to four different overlapping basalt lava flows (collectively called the Bogus Rim lava), the first lava flow occurred about 1.9 million years ago and the last one 1.7 million years ago. The lava erupted from a shield volcano on the high lava plateau east of the river and spilled into the river channel just upstream of Sleeping Dragon Gorge (aka Iron Point). The lava flowed downstream for 30 miles, covering an almost 1-mile-wide swath (in places) of the river corridor with erosion-resistant basalt rock up to 400 feet thick.



An immense lake formed behind the Bogus Rim lava dam. The lake was over 45 miles long and the lava blockage about 30 miles long.



Mile 36.5: The rimrock is covered with a 20-foot-thick layer of river-rounded cobble and gravel deposited when the river flowed over the top of the lava dam. In the distance is the exit of Sleeping Dragon Gorge. (Looking upstream/south.)

The lava flows filled up so much of the canyon that they effectively halted river channel incision here for hundreds of thousands of years. About 9 miles downstream, researchers found evidence that the lava blockage (dam) was still in place over one million years after the lava flow occurred, an extraordinarily long time, and that during that time, little, if any incision of the river channel occurred there. In comparison, the other Owyhee River lava dams survived for only tens of thousands of years, a fraction of the Bogus Rim dam's life. Geologists attribute the longevity to the massive thickness and length of the Bogus Rim lava blockage, and the immense lake that formed behind the dam required much more time to fill with sediment before effective incision of the dam could begin.

Mile 31: Pillow lavas and foreset beds 1,000 feet above modern river where the Bogus Rim lava flow encountered river water as it built the dam. (Notebook for scale.)

Source: (Plumley, 1986), (Evans, et al., 1990), (Ferns, et al., 1993), (Cummings, et al., 2000), (Ely, et al., 2012), (Swenton, et al., 2022), (Breitkreuz, et al., 2021), (Orem, 2010), (Brossy, 2006), (Ely, et al., 2012),

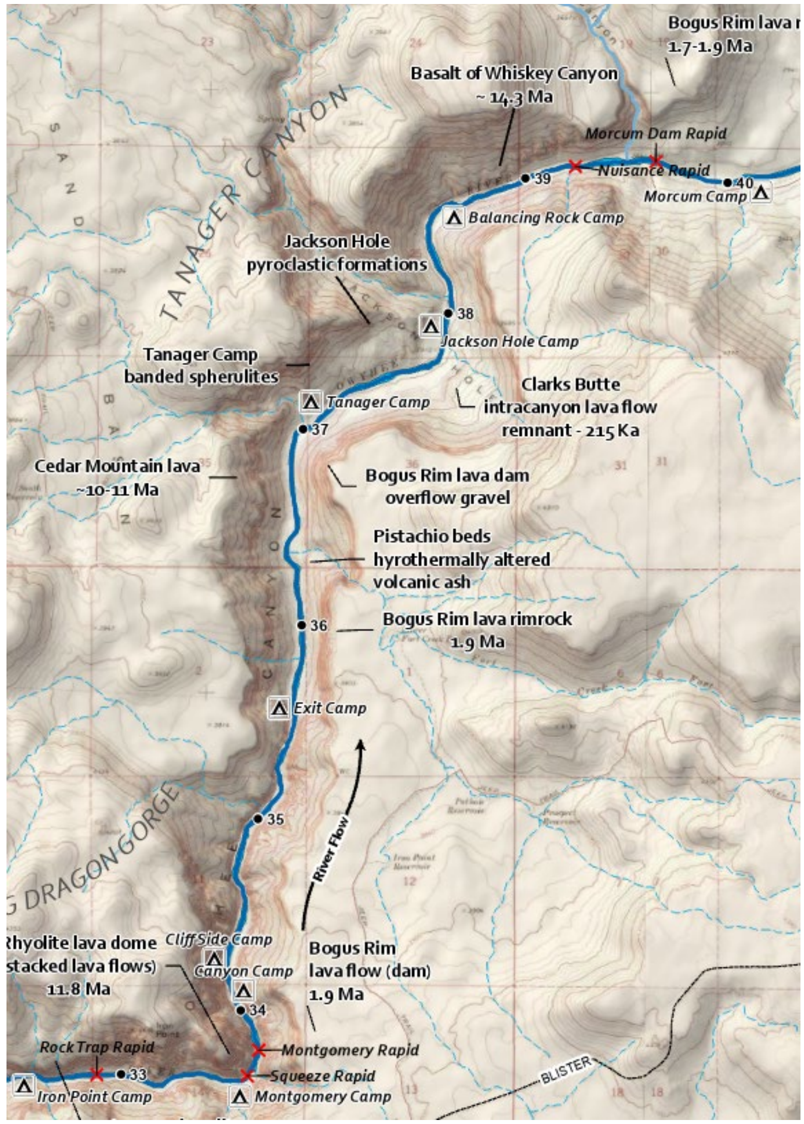
Tanager Canyon *(mile 35)*

Tanager Canyon *(mile 35.5)*

The 900-foot-deep Tanager Canyon reveals volcanic events back to about 14.3 million years ago, the oldest so far in this guidebook. The bottom 450-foot strata in the 4-mile-long canyon are colorful ash, tuff and volcanistic sediments. The volcanic ash and tuff layers interfinger with the rhyolite lava flows of Sleeping Dragon gorge, evidence they were probably all produced about the same time by the same rhyolite eruptions. There are excellent geology hikes into the ash and tuff formations from Tanager camp and Rinehart camp.

Bogus Rim Lava rimrock *(mile 36)*

The imposing canyon rimrock on the right (east) side of the river is the Bogus Rim lava that flowed into and dammed the river channel 1.7 to 1.9 million years ago. Its age and location tell us when the deep and narrow modern Owyhee River canyon was formed. We can look up at the lava rimrock and readily see the bulk of the modern canyon lies below it. We also know the ancient river channel was much wider and shallower than today because portions of the ancient canyon topography are visible beneath the rimrock. (See preceding section for description of the Bogus Rim lava flow and the dam it created upstream at Sleeping Dragon Gorge.)



Tanager Canyon Vicinity Map

Mile 36: The rimrock on river-right (east) is a thick layer of Bogus Rim lava 1.7 to 1.9 Ma. (Looking downstream.)

Mile 35.5: Looking downstream (north) into 4-mile-long Tanager Canyon from the rimrock near Sleeping Dragon Gorge. Cedar Mountain shield volcano is about 5 miles away.

Cedar Mountain lava *(mile 36.5)*

From river level, the skyline on the left (west) side of the river is dominated by a dark-colored, 300-foot-tall cliff with a thin, horizontal, orange-pink line in the middle. The cliff consists of a series of andesite and basalt lava flows that erupted from Cedar Mountain, a large shield volcano about 5 miles to the northwest, collectively known as the "Cedar Mountain lava". The extensive lava flows covered an area of about 300 square miles to a depth of as much as 300 feet. The Cedar Mountain lavas are undated but were estimated to be 10 to 11 million years old as of 1992, the most recent study. This was many millions of years before the Owyhee River existed. Several other large andesite shield volcanos were active in the Lake Owyhee region during that time.

The orange-pink line is a layer of sediment that was baked brick-red and fused by the heat of the thick overlying andesite lava flow. This shows that enough time elapsed between eruptions of lava for layers of sediment to accumulate between the flows. Above the orange-pink line is a single andesite lava flow almost 200 feet thick covered with a layer of reddish scoria (rocks filled with large gas bubbles). Beneath the orange-pink line is another 120-foot-thick formation consisting of 5 to 6 individual flows of basalt lava.

Closeup of Cedar Mountain andesite lava flow about 10 to 12-million-years-old. The orange-pink line is layer of baked sediment.

Mile 36.2: "Pistachio rocks" – Green-colored volcanic tuff formation chemically altered after burial, probably by local hydrothermal activity. (On river-right.)

Green Pistachio Beds *(mile 36.2)*

The green pistachio-colored formation at mile 36.2 is an example of hydrothermal alteration from a magmatic geothermal system (circulating hot water).

This was a lake basin during much of the several million years that it took to accumulate the strata in the canyon walls. Many pyroclastic layers show evidence of being deposited into water, and enough time elapsed between eruptions that layers of sedimentary rock (sandstone and mudstone) sometimes accumulated between the layers of volcanic ash, tuff, and lava flows.

Because of the lake water environment, the ash and tuff layers have undergone extensive chemical weathering and alteration, and the rocks do not have their usual color, texture, or hardness. Rhyolite ash is inherently unstable, and, over time, reacts chemically with water, gradually altering its atomic structure to clay minerals.

Tanager Camp geology hike *(mile 37.2)*

Tanager camp is a terrific spot to stop and hike up to colorful beds of ash, tuff and volcanistic sediments. And unusual beds of baseball-sized soft spherulites in pyroclastic rock formations. One bed contains concentrically banded spherulites, the other contains solid (unbanded) spherulites. (Note: These spherulites are made of soft minerals and will crumble into pieces if moved or handled.) Like any other spherulite or thunderegg, they were probably rock-hard 11 to 12 million years ago when they crystallized out of hot ash or tuff. Afterwards they were probably chemically altered into soft clay-like minerals by long-lasting immersion in the lake that existed here then, or from local hydrothermal alteration. The beds of volcanic ash and tuff surrounding the spherulites have also been chemically altered into clay minerals.

Mile 37: Bed of banded spherulites above Tanager Camp.

Mile 37: Geology hike above Tanager camp.

Mile 37: Banded soft spherulite about 10 inches in diameter above Tanager camp.

Mile 38: Baked river gravel and sediment trapped beneath 215,000-year-old Clarks Butte lava flow. Across from Jackson Hole camp, 150 feet above river.

Clarks Butte lava geology hike *(mile 37.8)*

Besides the campsite hikes, there is a good geology hike across the river from Jackson Hole campsite. You can see an excellent exposure of Owyhee River gravel that was trapped beneath a 215,000-year-old flow of Clarks Butte lava. The trapped river gravel marks the location of the river channel at that time as being about 150 feet above today's elevation. The river sediments and gravels beneath the lava were baked into a strongly consolidated mass by the overlying hot basalt. There are no clear indicators of any lava-water interaction, this suggests that when the lava flow reached here, the river-water was already blocked off somewhere upstream by a lava dam.

The trail continues upslope to a spectacular view from the top of the Bogus Rim lava rimrock.

Jackson Hole Camp geology hike *(mile 38)*

A short hike upslope from Jackson Hole brings you to colorful formations of volcanic ash, tuff and lakebed sediments. Some of the formations are a brick-red color from hydrothermal alteration. An easy trail up Jackson Creek leads to several interesting sites.

Mile 38: Jackson Hole Camp has colorful rhyolite ash, tuff, and lakebed sediments.

Mile 39: "Basalt of Whiskey Canyon" forms ancient riverside cliffs downstream of Jackson Hole camp. A useful age marker estimated about 14.3 million years old.

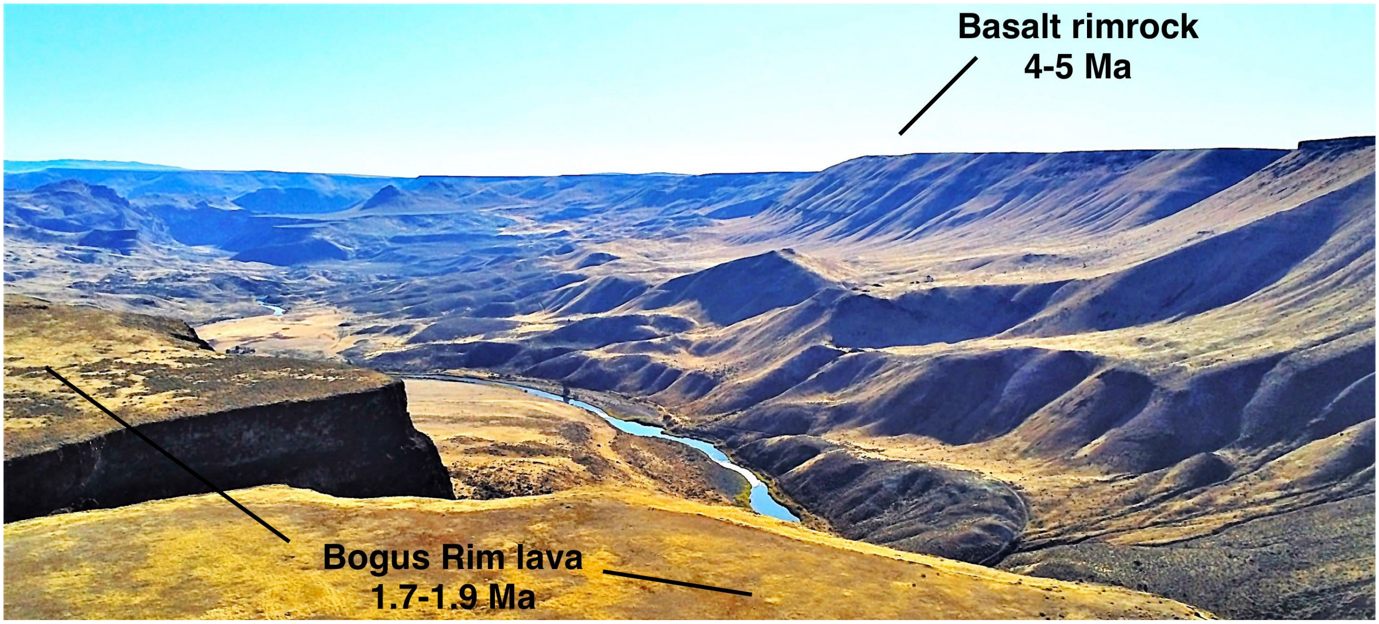
Basalt of Whiskey Canyon *(mile 39)*

The oldest rock formation exposed in Tanager Canyon is the riverside lava cliff that begins behind Jackson Hole camp and continues down-river, past Nuisance Rapid and into The-Hole-in-the-Ground. The riverside rock formation consists of a series of lava flows collectively named Basalt of Whiskey Canyon. Its correlative with the well-known 14.3-million-year-old Owyhee Basalt found throughout the Lake Owyhee Volcanic Field. The formation here is about 500 feet thick and consists of multiple individual lava flows interbedded with layers of sediment and siltstone. Pillow lavas and other features indicate the lava flows entered lake water, evidence that a lake basin existed here as long ago as 14.3 million years.

The Basalt of Whiskey Canyon lava is a useful riverside 14.3-million-year-old age marker. The strata below are older, and everything above is newer. The lava flow was originally laid down horizonal, but faults and uplift have now tilted the formation and its surrounding strata noticeably upward about 3 to 5 degrees to the north (downriver). This means that as you go downstream, the strata exposed along the river gets older.

Sources: (Swenton, et al., 2022), (Cummings, et al., 2000), (Ferns, et al., 1993), (Ferns & Evans, 1993), (Plumley, 1986), (Breitkreuz, et al., 2021), (Breitkreuz, 2013)

The Hole in the Ground *(mile 40)*



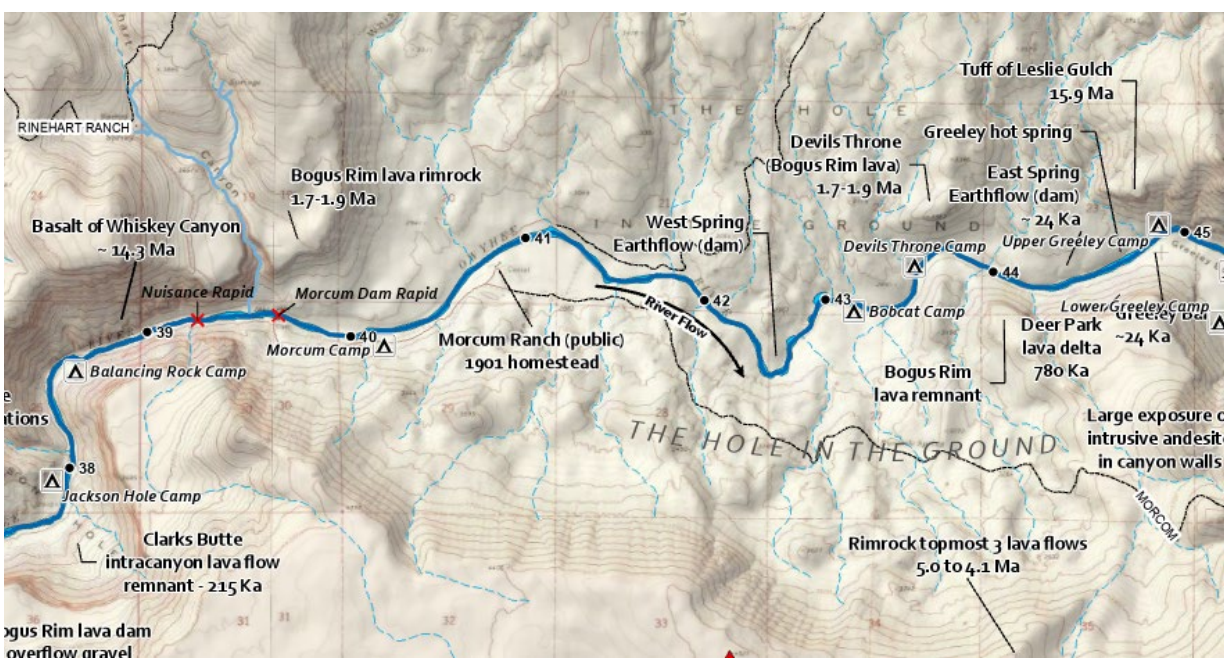
Mile 40.5: The Hole in the Ground is the widest and deepest part of the Owyhee Canyon. Extensive landslides line both sides of the river. Looking downstream (east) from Bogus Rim.

The Hole in the Ground *(mile 40)*

Aptly named The Hole in the Ground is the widest and deepest part of the Owyhee Canyon, 5 miles wide and 1,700 feet deep at its north and south rims. It grew to its present size because of repeated and extensive landslides, mostly after the river incised through the valley-filling Bogus Rim lava flow. The rolling hills and depressions covering the valley floor are remnants of the landslides and the S-shaped bends in the river channel are where the river was blocked and redirected.

This vast valley may have begun forming up to 5 million years ago, with the last 600 feet excavated in the past two million years. The location of the valley floor about two million years ago is marked by 600-foot-tall Devils Throne and basalt rimrocks on the east and west side of the valley, they are remnants of the well-studied Bogus Rim intracanyon lava flow.

The strata in the distant canyon walls are tilted upward to the northeast, indicating that basin-wide uplift was occurring throughout the millions of years it took for the basin to fill with sediment. The river traverses almost two million years of geological history in about 6 river-miles as it flows downstream (eastward). Starting from the cliffs of 14.3-million-



The Hole in the Ground map

Mile 42.5: Remnants of earthflow dam on both sides of the river. Looking downstream.

year-old "Basalt of Whiskey Canyon" at Jackson Hole camp to the cliffs of 16-million-year-old "Tuff of Leslie Gulch" at Greeley Bar. (It traverses about 16 million years if you include the river's deposits and landslides.)

The flat-lying basalt lavas in the rimrocks arrived long after the basin was filled with sediments. The topmost lava flows in the rimrock roadcut were dated in 1982; three of them yielded ages of 4.06, 4.09 and 4.49-million-years-old.

The geology story here is one of landslides. The north side of the basin (river-left) is particularly susceptible to earthflows; liquid-like flows of mixed sediments and rocks that can quickly transport large amounts of accumulated debris and weathered material away from the rimrock down to the valley floor.

The most recent one, East Spring Earthflow, occurred only about 24,000 years ago. The sediments on the north side of the basin contain an unusual 600-foot-thick bed of slick, gooey bentonite clay deposited in a lake that existed here. It swells when wet and can absorb up to ten times its own weight in water. Heavy rainfall onto the clay sediments triggers new earthflows and reactivates old ones. The presence of this localized lake deposit may explain why The Hole in the Ground exists—instead of a narrow canyon.

A different type of landslide occurs on the south side of the river because that canyon wall has a lower concentration of bentonite clay sediments. The landslides there are old, inactive rotational style landslides (slumps) with a highly weathered and filled-in topography.

Outburst flood boulder on riverbank downstream of West Spring Earthflow. Note percussion marks on boulder. Geologist yellow notebook for scale.

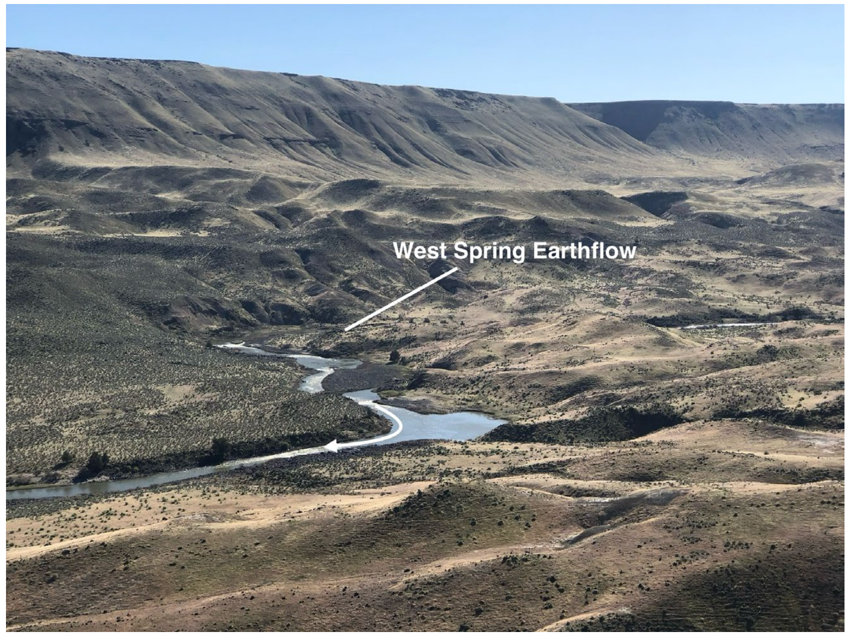
West Spring Earthflow *(mile 42.5)*

West Spring Earthflow diverted the river and created the distinctive horseshoe bend in the river about two miles downstream of the historic Morcum ranch buildings. It descended from the north rim and completely blocked the river with an earth dam, remnants of which are visible today, and created a long-lived upstream lake that eventually filled up with sediments, resulting in fine-grained fill-terraces along the modern riverbank. The dam is undated, but it likely occurred over 24,000-years-ago, before the East Spring Earthflow.

Devils Throne *(mile 43.5)*

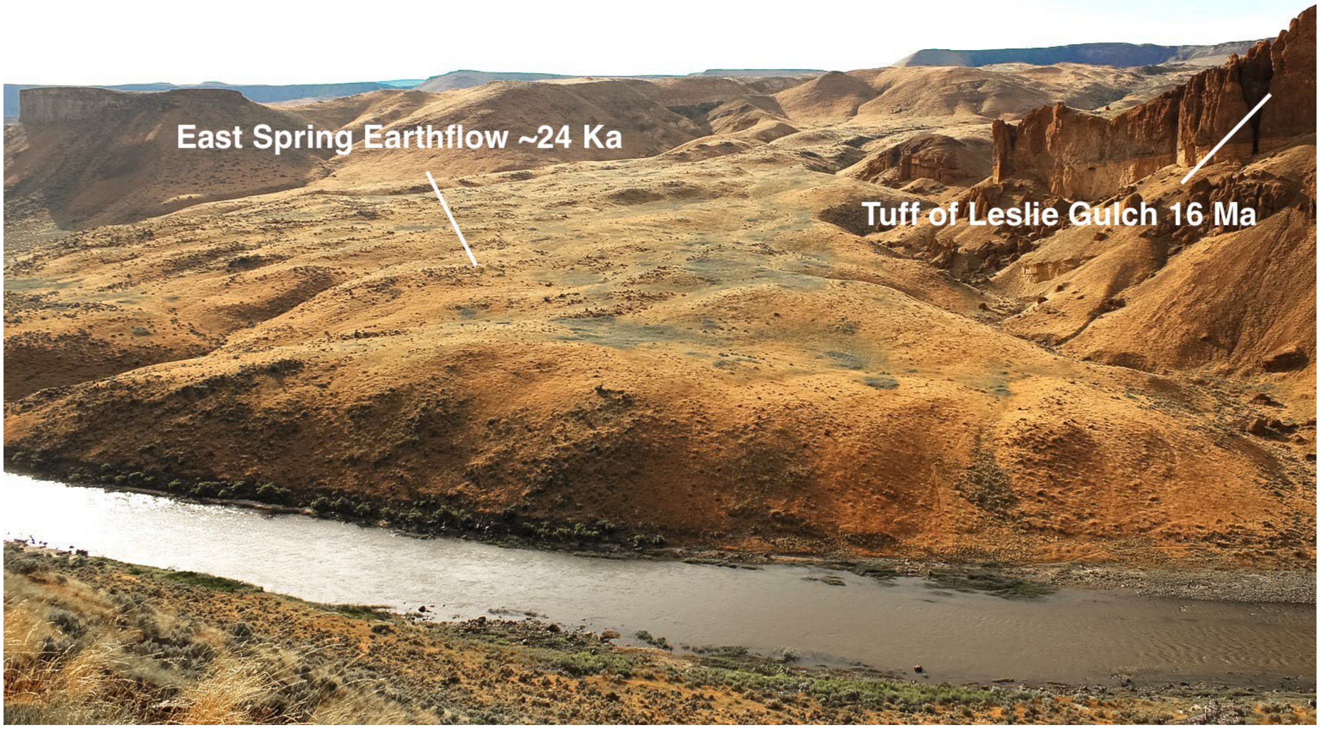
Devils Throne is the impossible to miss oval-shaped columnar basalt mesa on river-left (north), standing almost 600 feet above the river. This now-isolated rock formation is a small remnant of the massive Bogus Rim lava flow(s) that 1.7 to 1.9 million years ago filled about 30 miles of the river channel with a thick layer of basalt lava. At the tower's base we can see orange-colored sediments baked by the heat of the overlying lava.

Another remnant of this same lava flow is visible on the opposite side of the river just one quarter mile downstream. Look for the prominent basalt rimrock close to the river. Judging by the distance between the two lava remnants, the ancient lava flow once bridged a roughly 1-mile-wide swath of the basin floor. While it lasted, the thick layer of lava would have protected the basin from landslides and erosion, but once the river incised through the lava, erosion quickly removed all evidence of the once-extensive lava flow other than these few remnants. Then the valley-widening landslides resumed and created the huge valley called The Hole in the Ground.



Mile 42.5: West Spring Earthflow (View upstream/west.)

Mile: 44: Devils Throne in distance and matching rimrock in foreground are remnants of same lava flow and mark the valley floor location almost 2 million years ago.



Mile 44: East Spring Earthflow descended 1,300 vertical feet and 2.5 miles from the rimrock. It blocked the river with a 70-foot-tall earth dam. The outburst flood created Greeley Bar downstream. (View to river-left/north.)

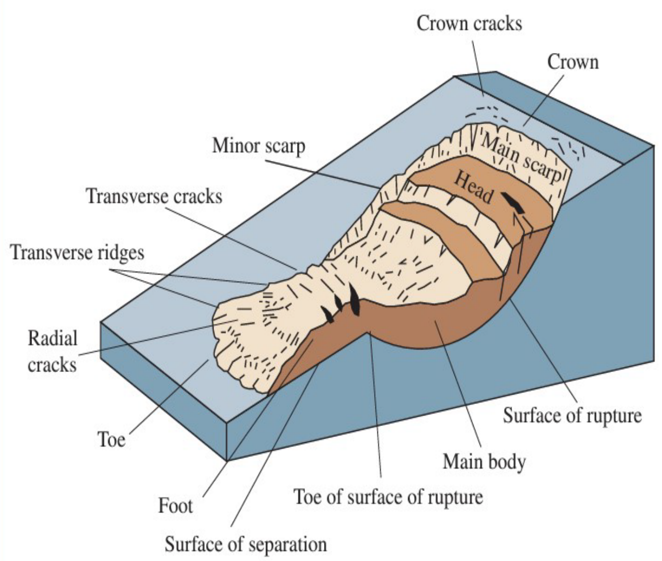


Figure 1. An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide.

Diagram of an earthflow. (Source: USGS.)

East Spring Earthflow *(mile 44)*

The largest and most recent landslide in The Hole in the Ground, named East Spring Earthflow, completely blocked the river with a 70-foot-tall earth dam about one half mile long, located immediately downstream of Devils Tower. The steep, 70-foot-high riverbank on left (north) side of the river near Greeley hot spring is where the river incised through the dam.

The earthflow originated 1,300 feet above from the north canyon wall and flowed about 2.5 miles to the basin floor, where it pinned the river against the right side of the canyon. The earthflow dam persisted for many years, long enough for thick layers of sediment to accumulate in the lake behind the dam and form extensive fill terraces upstream along the riverbank.

The East Spring Earthflow dam eventually failed catastrophically, and the resulting outburst flood built a large boulder bar immediately downstream, named Greeley Bar. Geologists studied the flood boulders on Greeley Bar and determined they were deposited there about 24,000 years ago.

Excellent views of the East Spring Earthflow's path can be had by hiking upslope from Greeley campsite. The field of undulating hills and depressions on the gently sloping hillside are the earthflow's toe, and the earthflow extends uphill, out of sight, to its distant source at the base of the canyon rimrock. Another good hike is to the top of Devils Throne.

Source: (Othus, 2008); (Cummings, et al., 2000); (Ferns, et al., 1993); (Ely, et al., 2012); (Plumley, 1986); (Orem, 2010), (Shoemaker, 2004)

Mile 40.8: 1890s Morcum Ranch at The Hole in the Ground. (View downstream.)

Mile 40.8: ca 1930s ranch house.

Mile 40.8: Pioneer stone root-cellar.

Morcum Pioneer Ranch *(mile 40.8)*

Ranching began here in the 1890s when Riley Horn claimed 160 acres that became known as the Hole in the Ground Ranch. By 1898 Riley had a house, irrigated field, rock dam and irrigation ditch here. He built the rock dam across the river at the upper end of the flat, remnants of the dam now create the Morcum Dam Rapid. The first house was probably built of stone since there were no trees in the canyon other than juniper. Riley was granted a homestead "patent" (legal title) in 1901.

According to Owyhee historian Bill Crowell, access was by pack train or horsedrawn wagon until the 1930s when new owners Conley Davis and his wife Stacia blasted and bulldozed a rough, rocky, 2-track road from the south canyon rimrock to the ranch, 1,500 vertical feet below. This road is the only way to access the remote site today. On the opposite (north) side of the river is an old wagon road that went to the pioneer community of Watson (now covered by Lake Owyhee), about 10-15 miles away.

The ranch is named for J.T. Morcom, who owned it from 1944-72. In 1985 a fire destroyed most of the ranch buildings and the remaining buildings give little sense of the size of the original ranch complex—and the grove of cottonwood trees is now gone. The BLM bought the ranch in 1993, and it is now part of the Lower Owyhee Canyon Wilderness Study Area.

Sources: (Crowell, 2022), (BLM General Land Office Records Search, 2024)

Hole in the Ground petroglyph: Great Basin Abstract petroglyph style. Regrowth of varnish indicates great age.

Hole in the Ground petroglyph: Recent light-colored petroglyphs are superimposed on old, faint images.

Prehistoric People

Humans have been living on Oregon's high-desert plateau for about the last 18,000 years according to a recent study at the Rimrock Draw Rockshelter west of Burns, Oregon. People lived along the Owyhee river just 4 miles downstream at Birch Creek almost 7,000 years ago, based on dated archeological excavations described in a later section. Other dated excavations show that almost 10,000 years ago, people were living 50 miles upstream at Dirty Shame Rockshelter.

These people left abundant evidence of their presence throughout the Owyhee Canyon by etching enigmatic images, known as petroglyphs, into the weathered surface of basalt boulders. Most archeologists believe that petroglyphs were meant to be seen—they are usually found located near prehistoric camp sites, seasonal hunting and gathering sites, and along well-traveled routes. The Hole in the Ground area contains petroglyphs of varying ages (based on patina), evidence that ancient people were present multiple times, and may have lived here, though no other archeological evidence has been discovered.

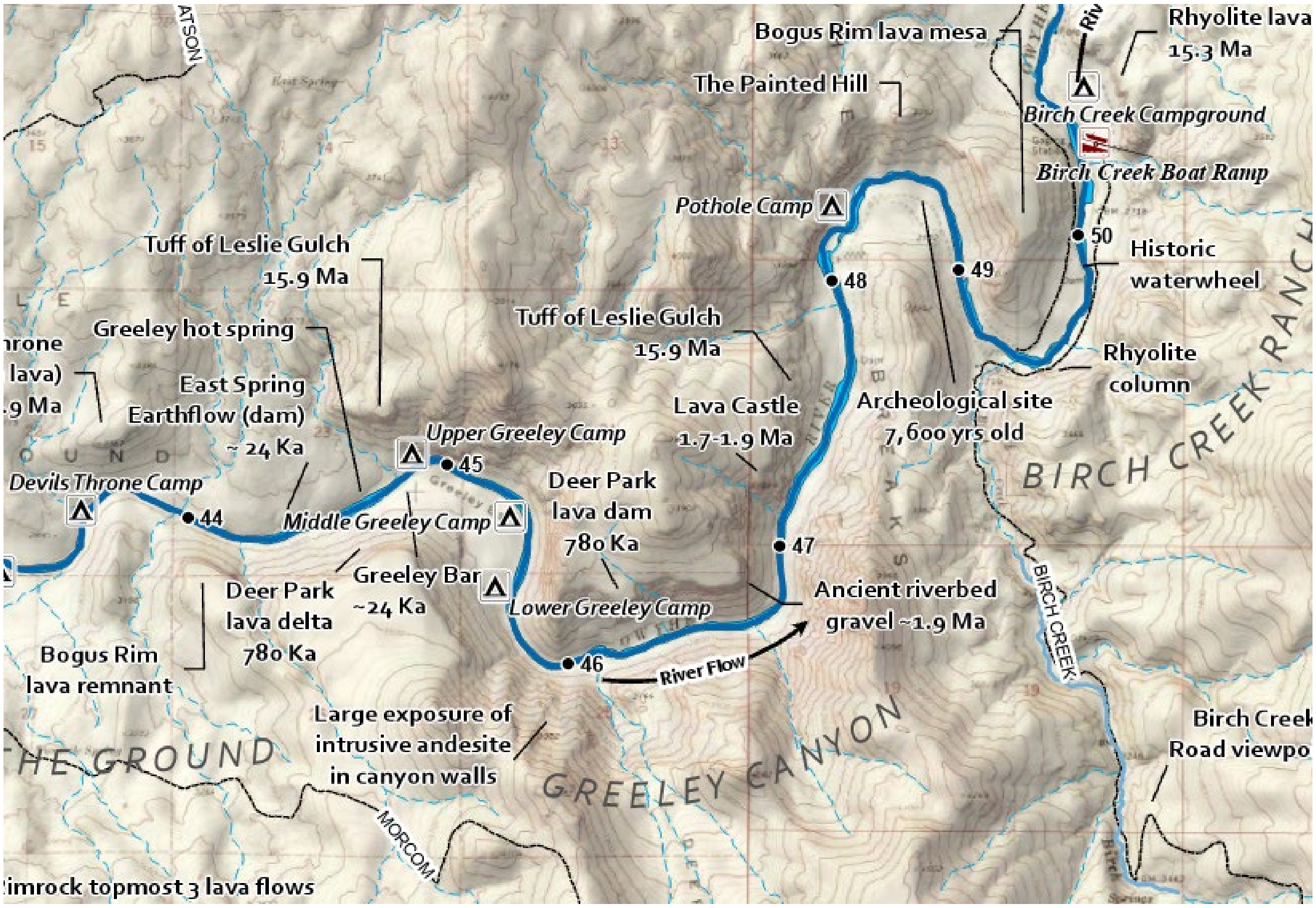
The people were hunter-gatherers—they lived in groups that consisted of several families resulting in a group size of a few dozen people. They moved seasonally from place to place and did not have a year-round settlement. The Birch Creek site downstream was only occupied in the winter, when conditions were too harsh on the high plateau.

The petroglyphs in the Owyhee Canyon are undated. In general, petroglyph ages must be inferred from circumstantial evidence because carbon dating only works on organic material, not on rocks. Petroglyphs are found throughout the world and range in age from about 46,000 years ago to the recent past – the practice was brought to North America by its first people. Similar petroglyph-covered boulders at Celebration Park (Idaho) on the Snake River have estimated dates ranging from about 11,200 years ago to 1,400 years ago, according to a study using a new rock varnish dating method. Two of North America's oldest scientifically confirmed petroglyph sites are Winnemucca Lake (Nevada), dated at 10,500 to possibly 14,800 years old and Long Lake (near Lakeview, Oregon) dated at over 8,850 years old. Large petroglyph sites usually contain a mix of young and old panels created by different people at different times, spanning hundreds to thousands of years. The darkest and most weathered petroglyphs are thousands of years old. Light-colored ones are newer, perhaps only hundreds of years old.

Studies show that petroglyphs had meaning to the people who created them, but it is not a writing system and no one today can interpret them with certainty. Within a given geographic region, petroglyphs share a common, easily recognizable style. Here the style is Great Basin Abstract, consisting of curvy lines, circles, spirals, dots, star patterns, triangles, and squiggles. As well as scattered circular depressions, a few centimeters wide and deep, called pit-and-groove. Stick-figure humans and lizards, deer, and mountain sheep rarely occur. This style is found throughout the Snake River Plain, southeast Oregon, Nevada, and Oregon's Columbia Plateau – where the ancient hunter-gatherer culture survived the longest.

Source: (Aikens, 2022), (Nevada Rock Art Foundation, 2015), (Shock, 2002), (Benson, et al., 2013), (Davis, 2019), (Fisher, 2010), (Kaestle & Smith, 2001), (Loring & Loring, 1996), (Andreae & Andreae, 2022)

Greeley Canyon *(mile 44-49)*



Greeley Canyon map

Tuff of Leslie Gulch *(mile 45)*

Beginning at Upper Greeley camp and continuing downstream three miles, the river passes through a spectacular canyon up to 1,500 feet deep. At sunset, the canyon walls light up with a beautiful orange glow, resulting in terrific photos. These orange-colored cliffs are made of rhyolite tuff, part of the well-studied Tuff of Leslie Gulch, named for the location where it was first identified.

The individual layers of tuff in the canyon wall are from different volcanic eruptions over many thousands of years. Some are well-defined air-fall deposits and others are jumbled pyroclastic flows and surges caused by collapse of the eruption columns. Still others are local mud flows (lahars) and reworked tuff sediments (volcanoclastic) deposited between eruptions.

The volcanic ash and tuff erupted from Mahogany Mountain Caldera, only 15 miles to the east and one of the oldest and most explosive volcanic eruptions along the river corridor. It created a huge caldera estimated to be about 10 to 15 miles diameter, now filled with sediments, tuffs, and lava flows. Recent high-precision rock dates show the eruptions began almost 16 million years ago and continued for tens of thousands of years. The ongoing eruptions blanketed the surrounding landscape with thick layers of rhyolite tuffs and lavas, some layers near the caldera are up to 2,000 feet thick.


Mile 44.8: View downstream from Upper Greeley Camp.

Mile 45: Greeley Canyon. (View NE from rimrock.)

Greeley hot spring *(mile 44.7)*

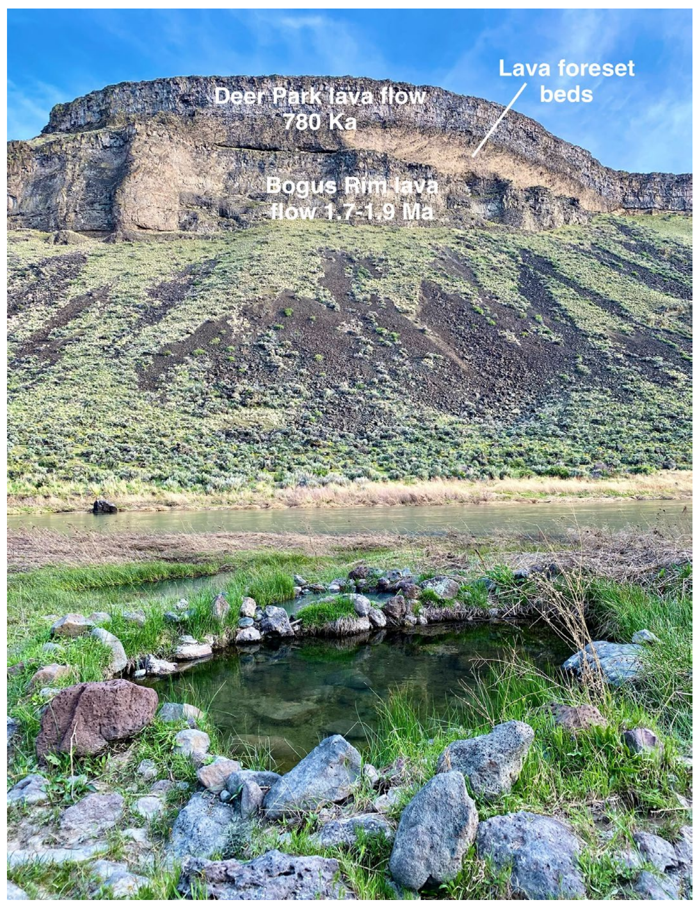
Greeley hot spring is located a short walk upstream of Greeley camp where a tub has been excavated in the riverbank for soaking. At high-water, the hot spring is flooded and not usable. The wetland between the hot spring and river edge is protected toad habitat.

Hot springs are evidence of volcanic heat below the earth's surface. The water is ordinary rainwater that seeps into fractures circulates deep underground in hot strata and comes to the surface again in faults. In recently active volcanic areas, hot rock is unusually close to the surface. Geologists have identified at least two nearby north-south faults, they may be the reason the hot spring exists here.

Deer Park lava delta *(mile 44.7)*

Take a dip in Greeley hot spring and look across the river at the rimrock. You are looking at a valley-filling lava flow (Deer Park lava) that spilled into the canyon here 780,000 years ago. Interaction of the molten lava with river water left a tell-tale layer of brown/orange-colored slanting foreset beds (the lava delta), easily seen in the rimrock.

The rimrock is a layer-cake of two different lava flows with a clear dividing line visible between them. The top layer (with the lava delta) is the Deer Park lava flow, a small flow that only filled in about 3 miles of the canyon. The bottom layer is the 1.7 to 1.9-million-year-old Bogus Rim lava flow(s) that filled the canyon with a 30-mile-long lava blockage.



Mile 44.5: Greeley hot spring tub with view across the river to Deer Park lava foreset beds in layer-cake rimrock.

Greeley Bar *(mile 45)*

The large boulder bar at the bend in the river is Greeley Bar, formed when the East Spring Earthflow dam (one mile upstream) failed catastrophically about 24,000 years ago and the outburst flood deposited boulders and flood debris here. (Described in preceding Hole in the Ground section.) The steep hillside behind Greeley Bar is composed of Leslie Creek Tuff and the overlying canyon rimrock is basalt lava from two valley filling lava flows.

Greeley Bar is named for Andrew Greeley who in 1909 obtained an original homestead patent (title) for 160 acres bordering both sides of the river, stretching from Greeley Bar, across the river to the hot spring and up the hillside onto the rolling hummocks created by the East Spring Earthflow. Access to the homestead was probably by packhorse on a primitive trail that once ran three miles downstream to Birch Creek ranch, portions of the trail still exist today. The remains of a small rock cabin and corral on Greeley Bar are probably nominal improvements made to "prove up" the homestead to obtain title, after living on it for five years. There is no evidence of year-round residence, likely the homestead was used for seasonal grazing of livestock. The property is now owned by the BLM.

Mile 45: Geology hike high above Upper Greeley Camp. In the foreground are sediments eroded from nearby volcanic highlands and deposited in a lake that once existed here. In background are rolling hummocks of East Spring Earthflow that dammed the river and created Greeley Bar.

Mile 45: Remains of small rock "cabin" on 1909 homestead at Greeley Bar, named for Andrew Greeley. Directly across the river from Upper Greeley Camp.

Greeley geology hike *(mile 44.7)*

There is a good geology hike up the ravine behind Upper Greeley Camp, up through the layers of rhyolite and into some lakebed sediment layers, ending at an interesting andesite lava flow with large vesicles (air bubbles) filled with white quartz. It's also possible to hike upstream to the summit of Devils Throne and enjoy a killer view of The Hole in the Ground.

Intrusive sills and dikes (*mile 45-47)*

This canyon is a good place to see the different shapes that intrusive andesite magma can take. Immediately downstream from Upper Greeley Camp (you can walk to it from camp) is a 50-foot-high andesite cliff that intruded the overlying rhyolite strata millions of years ago. It's called an andesite "sill", a sheet-like intrusion parallel to existing rock layers. (Andesite is a type of lava midway between basalt and rhyolite in composition.)

Mile 45: This riverside cliff below Upper Greeley Camp is and intrusion of andesite, a "sill". (View upstream.)

Mile 45.7: The river cut through an andesite intrusion in lower Greeley Canyon. Photo by Kathy Cashman.

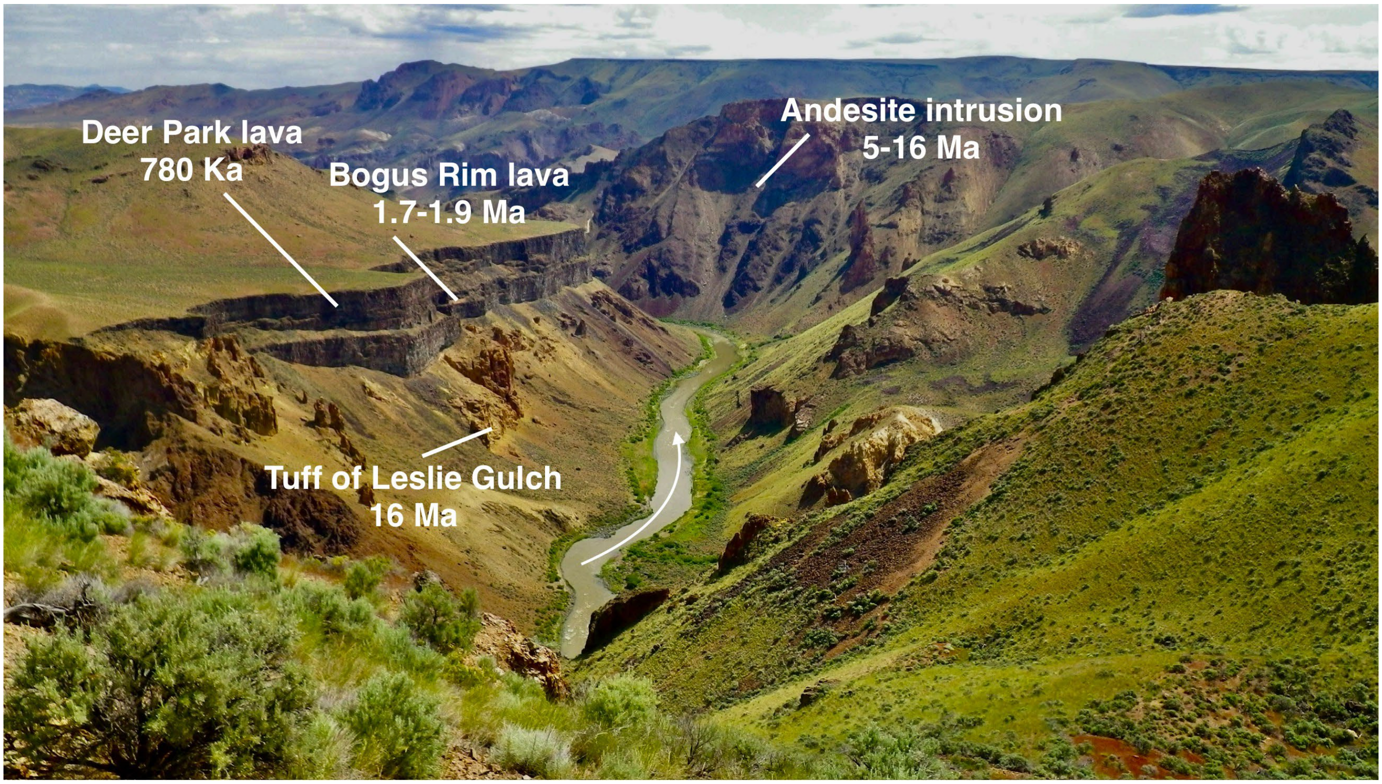
Several vertical andesite intrusions in the canyon wall are visible from the camps at Middle and Lower Greeley Bar. They cut upwards through the rhyolite strata from river level and then branch off into smaller intrusions. These are andesite "dikes", vertical or steeply inclined intrusions that cut across rock layers. Dikes are often conduits through which magma once traveled to the surface to feed lava flows. Unfortunately, the canyon walls are cut up by so many faults that it's not possible to trace the dikes to the surface. (The dikes are easiest to see at sunset, binoculars help.)

Mile 45.7: Pinnacles of rhyolite tuff were left standing on the eroded surface of an andesite intrusion. (River-right, looking upstream.)

Downstream of Greeley Bar the river cuts through two massive, irregularly shaped intrusions of dark andesite lava, each one located at a 90-degree bend in the river. Each intrusion is about half a mile across and hundreds of feet thick.

The intrusions formed millions of years ago when molten andesite rose from a magma chamber deep underground and penetrated the overlying Tuff of Leslie Gulch formation. It did not reach the surface and cooled underground into these solid masses of rock. Millions of years later`, the Owyhee River incised through the overlying rhyolite tuff and encountered the buried andesite rock, creating a deep and narrow canyon. The river stripped most of the overlying rhyolite tuff from the hard, erosion-resistant andesite canyon walls, but in a few places, it left distinctive, orange-colored pinnacles standing along the river.

The intrusions are undated, but its plausible they occurred between 10 and 15 million years ago. Studies show that after the nearby Mahogany Mountain Caldera collapsed, andesite dike swarms emerged along active faults that fed numerous surface andesite flows.



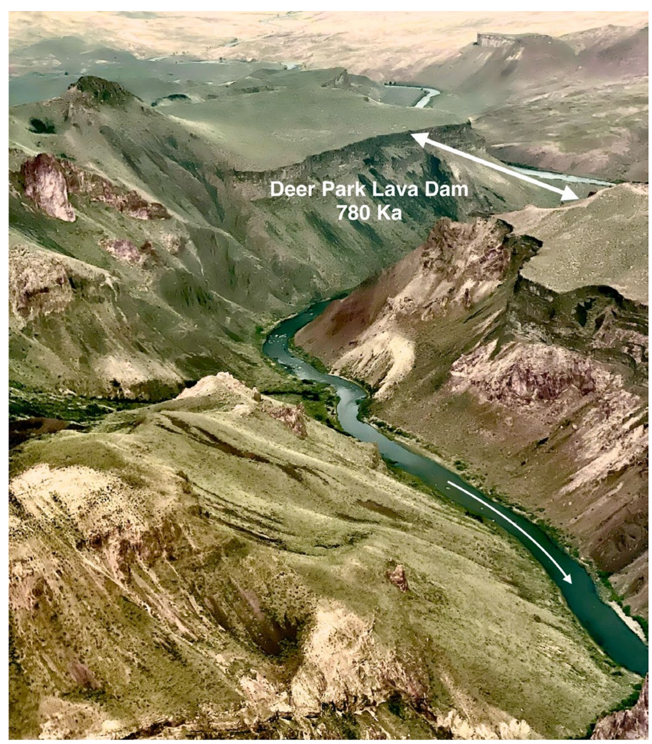
Mile 46-47: Looking downriver (east) into lower Greeley Canyon. The rimrock marks the downstream location of the Deer Park lava dam, formed 780,000 years ago, almost 600 feet above the modern river. Surprisingly, the underlying Bogus Rim lava dam blockage was still intact after hundreds of thousands of years.

Deer Park lava dam *(mile 46-47)*

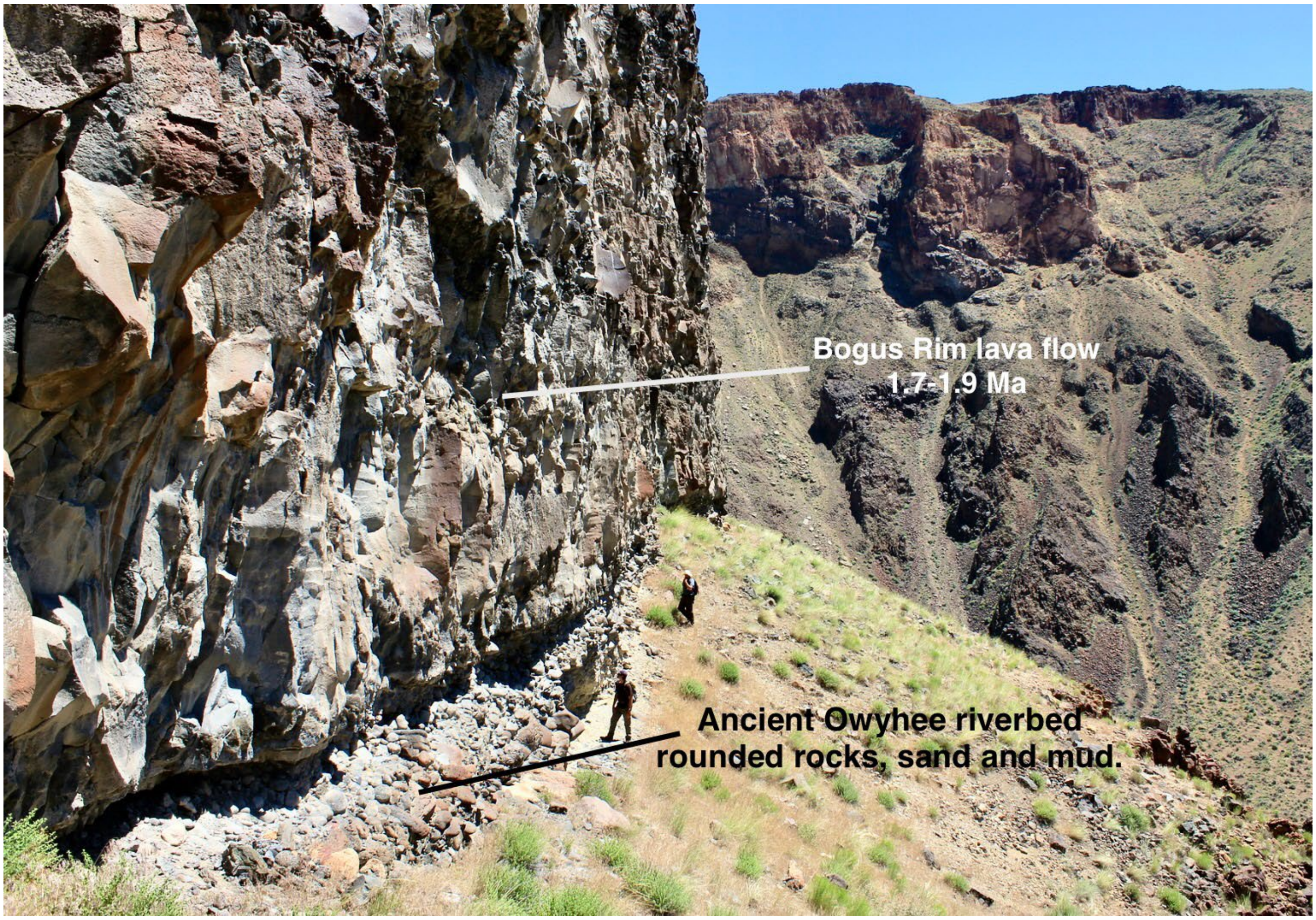
In the 2000s, the team of researchers investigating ancient lava dams on the Owyhee discovered evidence of another lava dam here, the Deer Park lava dam, the second oldest identified. It's almost 600 feet above today's water level and marks the location of the riverbed 780,000 years ago. At just 3 miles long, it had the shortest footprint of any lava dam along the river and probably did not persist long. The remnants of the dam form the basalt lava rimrocks lining the river downstream of Greeley Bar. From river level, we get little sense of the original extent of the lava dam.

Though small and probably short-lived, this lava dam is particularly important to researchers because it formed on top of a preexisting dam, the Bogus Rim lava dam, dated 1.7 to 1.9 million years old, creating a layer-cake basalt rimrock that we can easily see from river level. Lava foreset beds and other evidence show that the old lava dam was still intact and blocking the river here when the new lava flow arrived.

The fact that the Bogus Rim lava blockage (dam) was still present in the river channel when the Deer Park flow arrived is very significant. The age difference between the flows means the Bogus Rim lava dam persisted for hundreds of thousands of years, an extraordinarily long time. In comparison, the other lava dams studied by geologists on the Owyhee River survived for only tens of thousands of years. Geologists attribute the Bogus Rim lava dam longevity to the massive volume and length of the lava blockage, and the immense lake behind the dam required more time to fill with sediment before effective incision of the blockage could begin.



Mile 45-46: Deer Park lava dam location 600 feet above modern river. View upriver NW.).



Mile 46.8: A layer of Owyhee River gravel is trapped beneath the Bogus Rim lava flow. This marks the location of the Owyhee riverbed almost 2 million years ago. Geologists for scale. (A dangerous hike!)

Ancient riverbed gravel *(mile 46.8)*

As you go around the 90-degree bend in the river at mile 46.8, look up to the rimrock on river-left and find the 20-foot-thick layer of Owyhee River gravel, sand and mud stranded 350 feet above the modern river, trapped under the bottom layer of lava. This layer of gravel and mud marks the course and elevation of the ancestral Owyhee River channel when the Bogus Rim lava flow(s) arrived 1.7-1.9 million years ago and blocked the river channel. At this location, the modern river has changed its course little in the last nearly 2 million years.

Mile 46.8: Closeup of ancient ripple marks in thick layer of Owyhee river mud trapped beneath the Bogus Rim lava flow. The heat of the overlying lava baked the mud into "brick". This is at the rimrock site pictured above. Geologist for scale.

Mile 47.2: The Lava Castle marks the location of ancestral Owyhee River almost 2 million years ago. The layer-cake lava flows are perched on a colorful formation of 16-million-year-old Tuff of Leslie Gulch. (View downstream/north.)

The Lava Castle *(mile 47.2)*

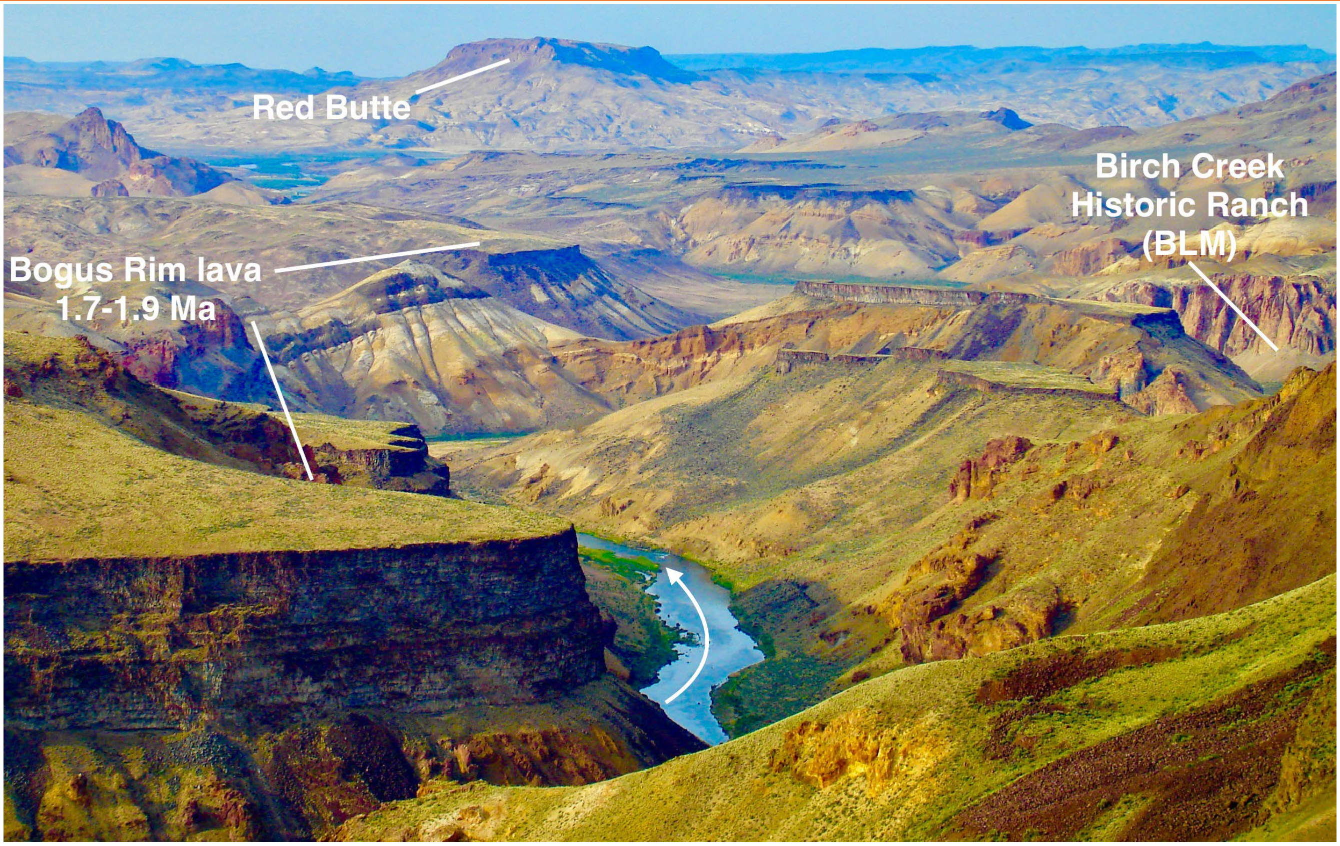
Barely one quarter mile below the 90-degree bend in the river is a dramatic rock formation informally named The Lava Castle, perched precariously on a cliff high above the river. From the river it's easy to see the 20-foot-thick layer of Owyhee river boulders and gravel trapped under the base of the bottom lava flow.

This marks another location of the ancestral Owyhee River almost 2 million years ago. We can also see a segment of the ancient valley wall preserved beneath the protective lava, its gentle curve suggests the ancient river valley was wider and shallower than todays.

The lava castle is perched on Tuff of Leslie Gulch, about 16 million years old. The castle consists of two layer-cake basalt lava flows, a top layer of 780,000-year-old Deer Park lava and a base layer of 1.7 to 1.9-million-year-old Bogus Rim lava.

SOURCES:
(Swenton, et al., 2022), (Black, 2021), (Benson & Mahood, 2016), (Ely, et al., 2012), (Cummings, et al., 2000), (Ferns, et al., 1993), (Vander Meulen, et al., 1990), (Vander Meulen, 1989), (Plumley, 1986)

Owyhee Breaks *(mile 47)*

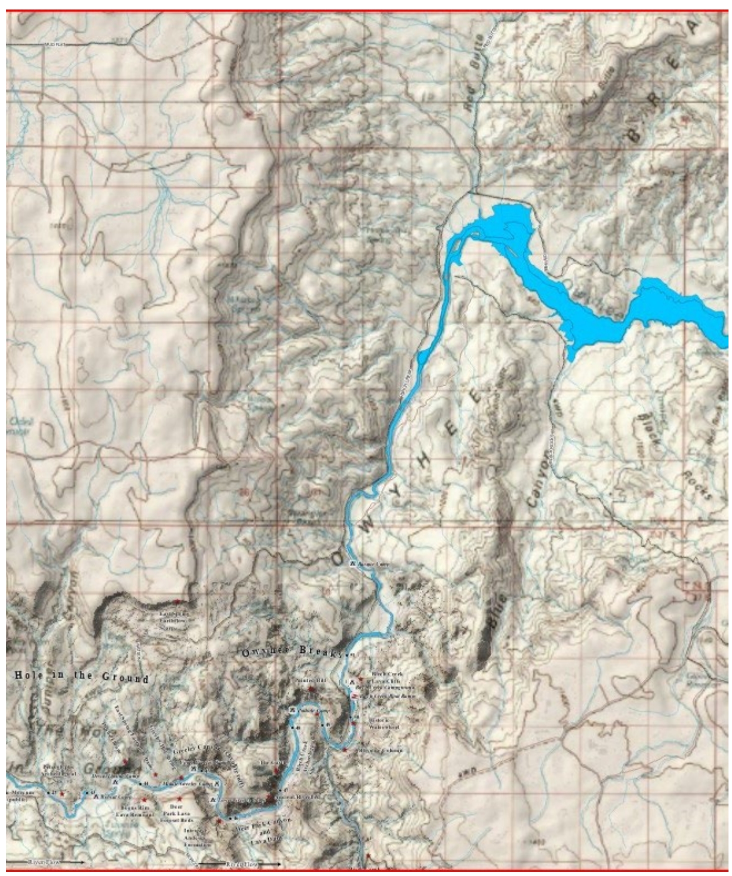


Mile 47: Owyhee Breaks: an ancient, eroded basin filled with faulted and tilted strata. In the distance is Red Butte, an intact remnant of the ancient basin floor. View from rim of lower Greeley Canyon looking north.

Owyhee Breaks *(mile 47)*

Owyhee Breaks is defined by its rugged terrain downstream of The Hole in the Ground, consisting of cliffs, outcrops, landslides, gulches, and ridgelines. The multi-colored layers of ancient sediments and volcanic deposits are tilted due to the underlying grid of faults.

The distant Red Butte (see photo) is a prominent landmark. It gets its name from the red sandstone and mudstone caprock that millions of years ago was chemically altered by hydrothermal activity (hot springs) into a several-hundred-foot-thick, red erosion-resistant rock. The hard caprock protected the underlying lakebed sediments from erosion and preserved intact a tiny remnant of the basin floor and underlying strata. The 4,650-foot summit marks the elevation of the ancient basin floor. Red Butte has been well studied and is the subject of at least one thesis. It's about 10 miles north of the Birch Creek takeout and 13 miles away in the above photo.



Owyhee Breaks map.

Mahogany Mountain Caldera

The story of the Owyhee Breaks began about 16 million years ago when the Yellowstone hotspot passed nearby and left a pool of magma deep in the earth. The magma erupted explosively near present day Lake Owyhee and several other locations in SE Oregon, blanketing the area with thousands-of-feet of rhyolite tuff and lavas.

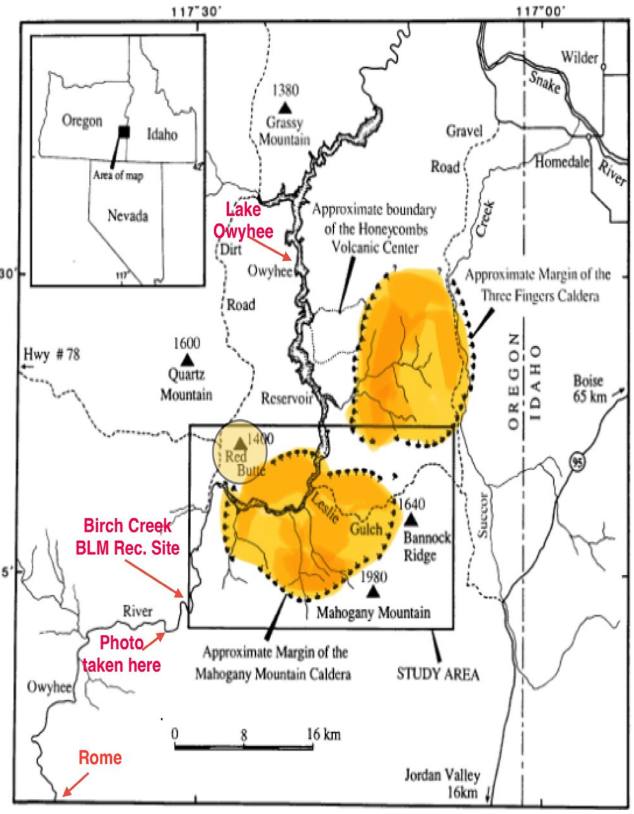
Researchers identified the source of the eruptions as two now-buried calderas on the south side of Lake Owyhee. Mahogany Mountain Caldera erupted first and deposited thick layers of ash-flow and air-fall tuff collectively named the "Tuff of Leslie Gulch". Then, following the collapse of the Mahogany Mountain Caldera, nearby Three Fingers Caldera erupted an ash-flow tuff named the "Tuff of Spring Creek", and it collapsed. (Recent research suggests there may be only a single large, buried caldera in the location, not two, that erupted a single type of tuff, the Tuff of Leslie Gulch. In either case, the Tuff of Leslie Gulch is what we find in this reach of the Owyhee River Canyon and its age and source are unchanged.)

The Tuff of Leslie Gulch has been studied and laboratory-dated many times. Recent studies show the eruptions lasted for about one hundred to two hundred thousand years, from about 15.9 to 15.8 million years ago.

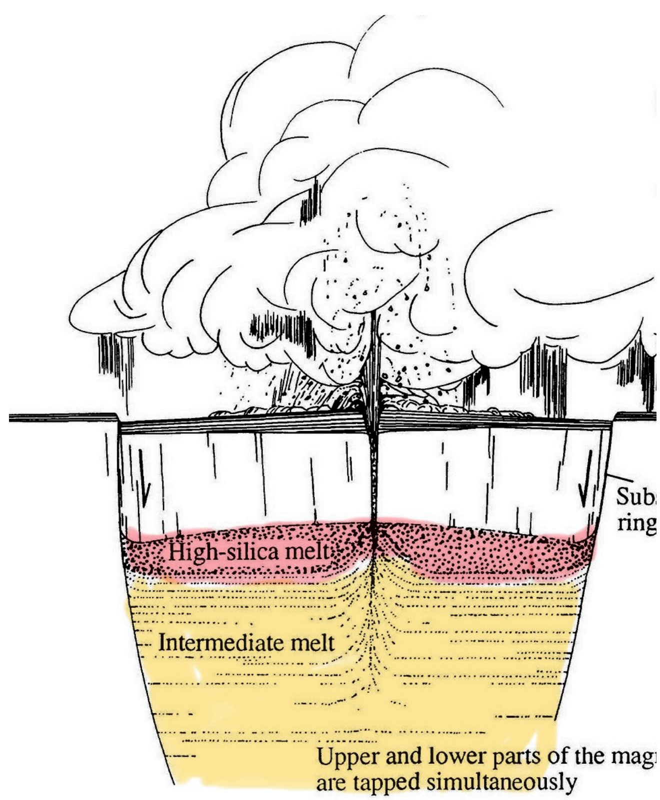
After the caldera(s) collapsed, the earth's crust fractured into a large down dropped basin (graben). (The Owyhee Breaks is in that graben.) The graben gradually filled up with multi-colored beds of eroded volcanic sediments, tuff, and basalt lava flows. At this stage, the Owyhee Breaks was part of a large basin filled with almost 1,000 feet of layered sediments overlying a base of rhyolite lava and tuff up to 1,500 feet thick. The Snake River Plain and ancient Lake Idaho did not yet exist. Researchers think the area to the east was probably a topographic highland that served as a source of sediments to the basin.

Then uplift and associated faults broke the large graben into smaller sub-basins and tilted the multi-colored strata at various angles. Eventually, numerous small shield volcanoes and vents flooded the landscape with overlapping basalt lava flows, creating the rolling lava plateau high above the present river.

After the Owyhee River was born and it became a through-flowing river to the Snake River Valley, large-scale erosion removed huge swaths of the sedimentary strata, leaving the broken landscape that we see today.



Map showing inferred location of Mahogany Mountain Caldera and Three Fingers Caldera (orange-colored), roughly 10-15 miles in diameter. (Adapted from Vander Meulen, 1990, BLM.)



Cartoon sketch of Mahogany Mountain Caldera. (From Vander Meulen, 1989, a USGS report.)

Mile 48.5: The Painted Hill, an ancient, tilted fault-block. Volcanic sediments are interlayered with two columnar-basalt lava flows near the summit. The basalt layers are cut by a fault that offsets them about 150 vertical feet. View from Pothole camp.

The Painted Hill *(mile 48)*

Photographers love the dramatic painted hill near Pothole camp, it's a great example of the broken topography that characterizes the Owyhee Breaks.

The hill stands on a small, tilted fault-block that has subsided hundreds of feet relative to its neighbors. The layers were originally laid down flat about 14 to 15 million years ago in the large basin that formed next to the explosive Mahogany Mountain Caldera. Subsequent faulting and uplift jumbled the landscape and uplifted the canyon rim almost 2,000 feet relative to the same strata on the canyon floor, causing the landscape to slope upwards roughly 20 degrees to the southeast. When you drive uphill along the Birch Creek Road from the Owyhee River takeout, you are following the incline.

From Pothole camp we can easily see two of the faults that contributed to the hill's subsidence. The most obvious fault cuts through the two dark-colored basalt lava flows at the top of the hill and offsets them about 150 feet. A less obvious, but larger fault is in the canyon wall a quarter mile upstream, where the painted hill abuts a pink-colored rhyolite cliff. The odd-looking seam of conglomerate between the two is a vertical fault zone of fractured and compacted rock

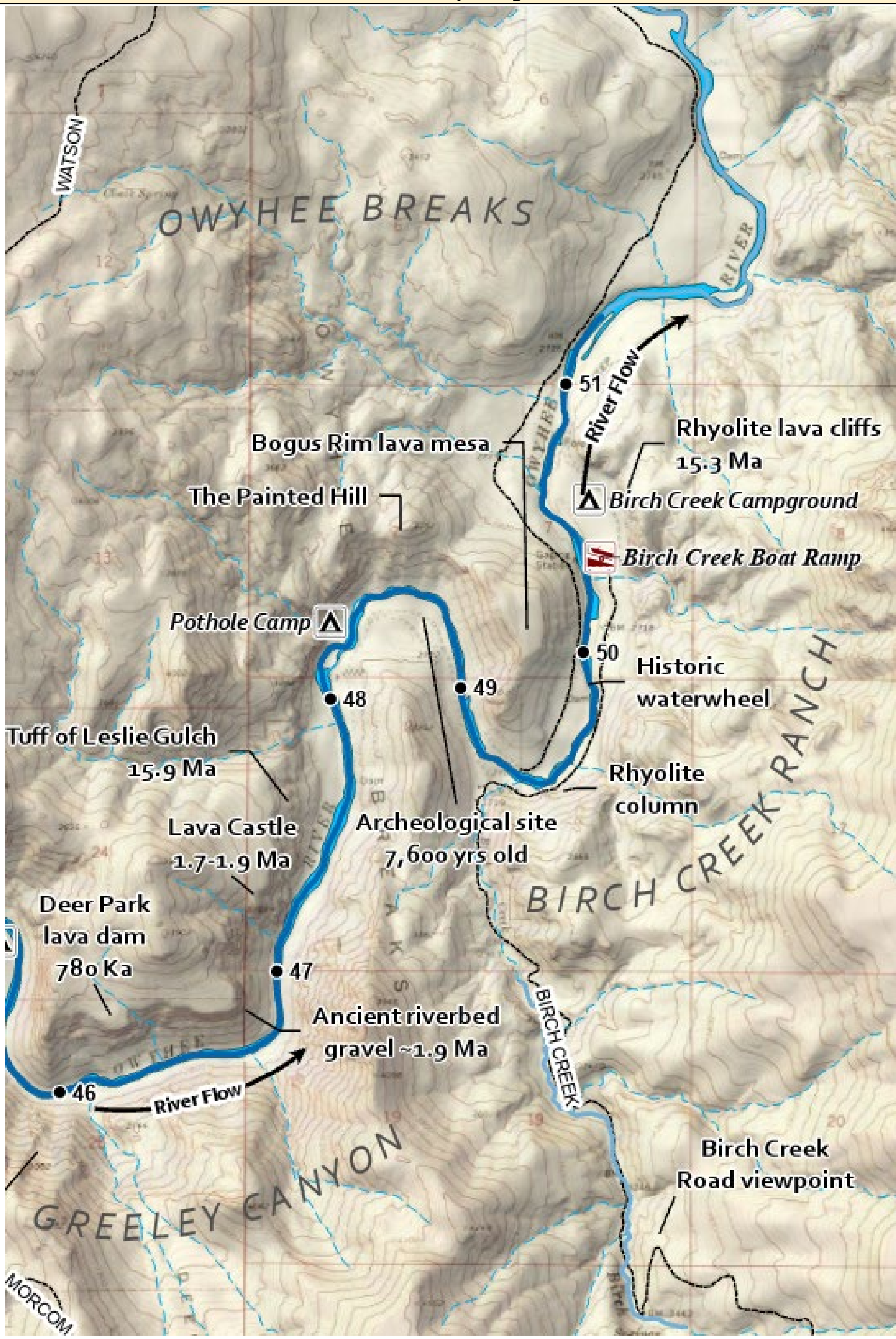
Mile 48.5: A large vertical fault. The strata on the right are down-dropped 100s of feet relative to the rhyolite cliff on the left. (About ¼ mile upstream of Pothole Camp.)

SOURCES:
(Swenton, et al., 2022), (Black, 2021), (Benson & Mahood, 2016), (Ely, et al., 2012), (Cummings, et al., 2000), (Ferns, et al., 1993), (Vander Meulen, et al., 1990), (Vander Meulen, 1989), (Plumley, 1986)

.

Birch Creek Ranch *(mile 47-51)*

Vicinity map



Birch Creek Ranch map

Prehistoric site *(mile 48)*

On the river terrace about 1.5 miles upstream of the rafters' takeout at Birch Creek ranch, Washington State University archeologists uncovered artifacts that show prehistoric people lived here more than 7,600 years ago. They conducted two excavations over seven field seasons, 1998-2006, resulting in at least six published thesis papers. The site was selected because a scatter of chipped stone was visible in the alfalfa field and charcoal stains were exposed in a cutbank. Today nothing of interest is visible, the archeological excavations were filled in and the surface returned to its present-day condition.

Mile 48: Prehistoric people occupied this river terrace at Birch Creek for thousands of years. After it was homesteaded in the 1890s it became an irrigated field. View downstream.

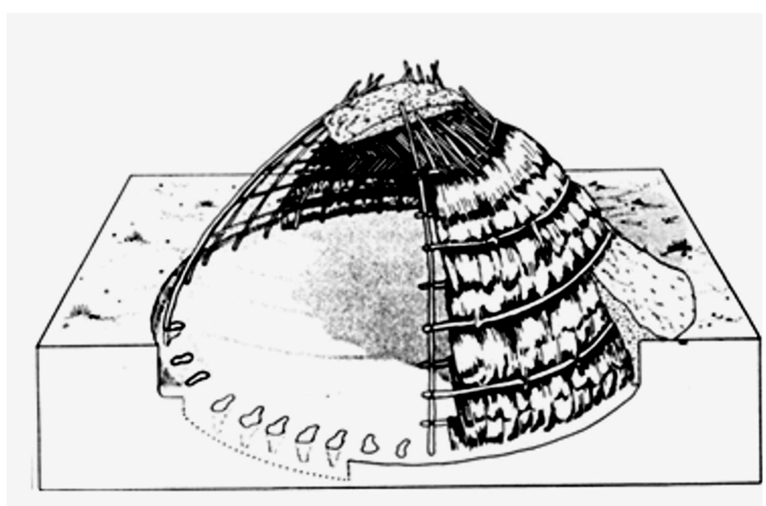
At the first excavation site, archeologists dug down to a layer of 7,600-year-old Mount Mazama ashfall (a well-known age-marker). Beneath the layer of ash were a few broken artifacts and domesticated dog remains, evidence of brief visits earlier than 7,600 years ago. Above the layer of ash, they found evidence of an open-camp occupation, and above that they found evidence of a hamlet composed of at least three house pit earth floors. Radiocarbon dates show the site was occupied for at least 5,300 years, from 2,200 to 7,500 years ago, with several gaps in occupation. Analysis of obsidian fragments shows that at least three different groups of people inhabited the site during those 5,300 years, each group had to rediscover where the nearest source of obsidian was located, all which are miles away.

Analysis of the chipped stone artifacts, and fragments of bones and shells indicates this was a place of extended occupation – a home. People probably lived here in a small family group in a permanent late fall/winter residence and moved within a 20-to-30-mile radius seasonally to collect seeds, roots, and game, rarely congregating in larger groups. Samples of bone show the occupants consumed large and small mammals, as well as fish and birds. Fragments of pestles and mortars indicate they also collected and processed seeds for consumption throughout the 5,300-year occupation period. Mussels and fish supplied large portions of their diet, along with big horn sheep, deer, bison, coyote, rabbits, marmots, and squirrels.

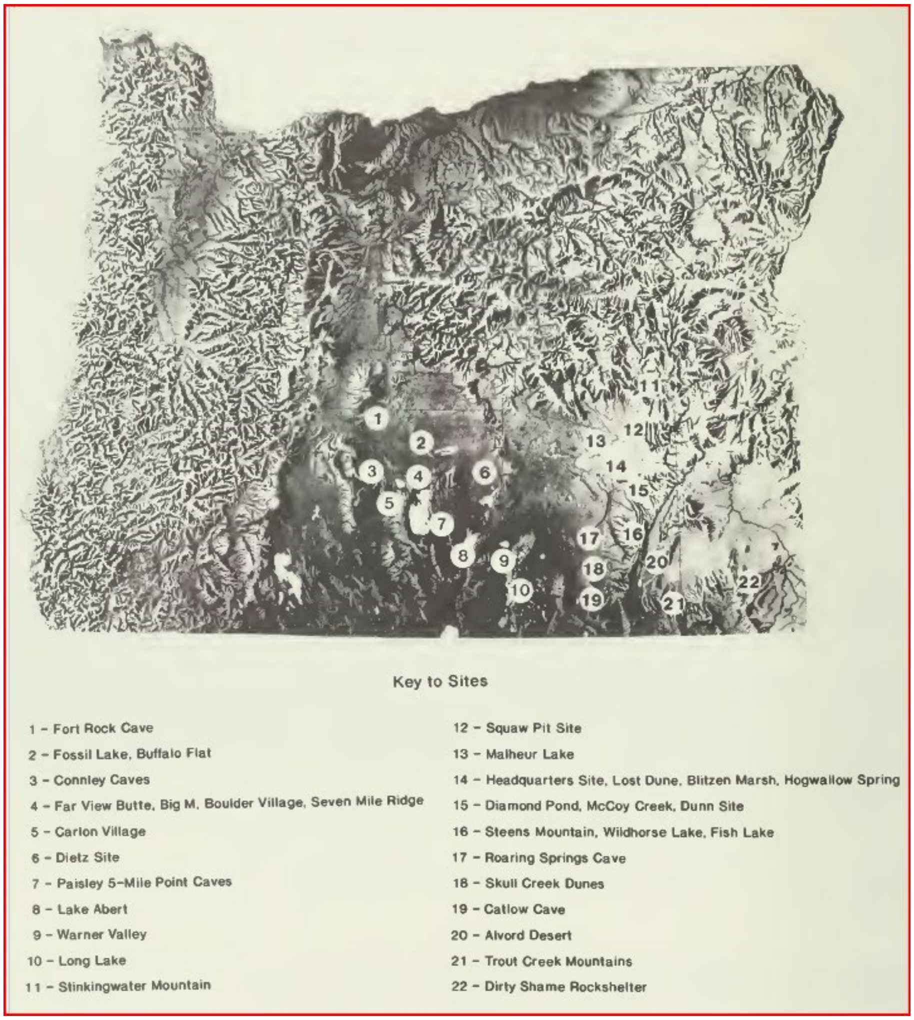
No bow-and-arrow projectile points were found, indicating these people hunted with the atlatl dart-thrower that had earlier replaced spears, and in turn would be replaced by the bow-and-arrow.

At a second excavation site, located about 900 feet farther upstream, archeologists uncovered evidence of 200 years of continuous surface occupation (open-camps), refuse disposal, and possibly one sweat-lodge. It was occupied with no gaps from about 1,100 to 1,300 years ago, before being abandoned. Pollen evidence indicates the 200-year-long occupation period was during an unusually dry period of low river levels; the site was abandoned when flooding occurred and deposited at least two massive layers of sediment over the river bar. Researchers don't know whether this second site was a seasonal camp or a year-round camp.

The style of projectile points recovered indicates the inhabitants now used the bow-and-arrow instead of the atlatl (dart-thrower) for hunting. The transition to bow-and-arrow occurred sometime between the two known occupation periods: 2,200 to 1,300 years ago.



Artist sketch of pit house thatched with grass. (Source: Archaeology Southwest.)



Map showing prehistoric Great Basin desert culture sites in Oregon. (Source: Aikens, 1993, "Archaeology of Oregon", a BLM pub.)

Dirty Shame Rockshelter: In 1977, University of Oregon researchers studied another prehistoric occupation site on the Owyhee River, the Dirty Shame Rockshelter, located on a small tributary named Antelope Creek about 50 miles upstream of Birch Creek. (Named for the fact that it was heavily pillaged by artifact collectors before it could be professionally excavated.) According to archeologist Melvin Aikens, the rockshelter deposits remained dry and thus preserved an exceptionally diverse and well-dated inventory of artifacts and food remains, which portray in rare detail the Great Basin desert culture (hunting-gathering) from the end of the Ice Age into historical times. The site was occupied from 10,800 to 400 years ago, but with a gap in the dates between about 6,700 and 2,900 years ago when the site saw little or no human occupation for a 3,800-year interval. The break in occupation came at a time of decreasing moisture when apparently the landscape dried and food resources in the area shrank to a level that made travel there unprofitable. Regular use resumed probably because of better environmental conditions. It's interesting that the 3,800-year break in human occupation at Dirty Shame coincides with the 5,300-year continuous occupation at Birch Creek, 50 miles downstream, a lower elevation site with year-round water.

The rockshelter contained well preserved remains of at least five and probably six conical or domed-shaped house structures that were thatched with native grass and willow lashings. There were also woven sandals, soft mats, bags, baskets and cordage, including more than one hundred more or less intact specimens of sandals of the famous Fort Rock type, as well as other sandal varieties. The Fort Rock type sandals and other artifacts indicate the prehistoric people who lived here were the same hunting-gathering culture found throughout the high desert of SE Oregon, at numerous well-studied archeological sites ranging from Fort Rock to Malheur Lake to the Owyhee River.

Aikens states "Perhaps the most arresting conclusion to come from the Dirty Shame study is that the general way of life of its occupants, and much of their technology, changed scarcely at all over the entire period." (About 10,000 years.)

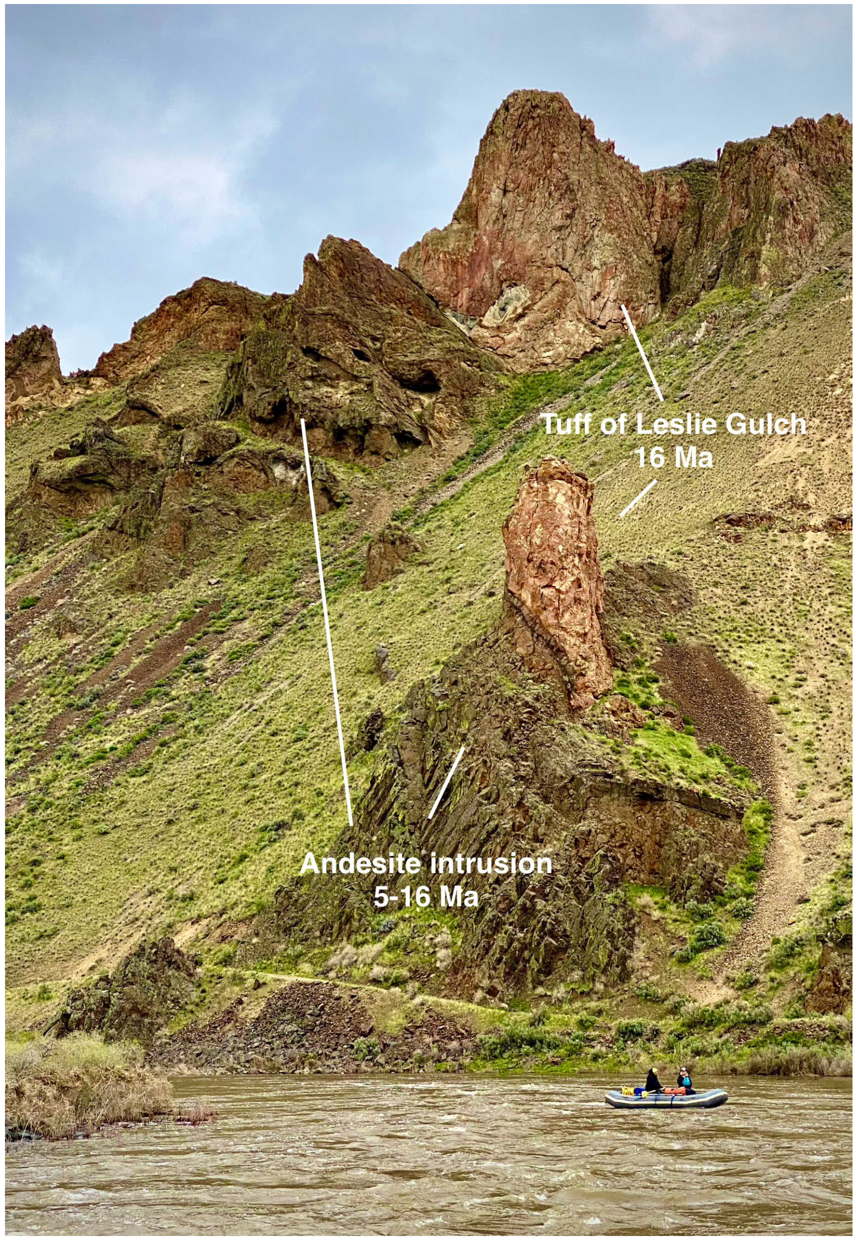
Paiute arrival: At the time of European contact (1850), this area was inhabited by a band of Northern Paiute named the Tagotoka ("tuber eaters"). The Paiute are thought to have immigrated to this region about 500 to 1,000 years ago from the southern Great Basin. The Paiutes are from the same hunting-gathering, Great Basin desert culture as the prehistoric inhabitants and carried on with the same lifestyle, occupying many of the same living sites and living in similar structures. Archaeologists don't know if the prehistoric inhabitants abandoned the area before the Paiute arrived, or were displaced, absorbed or assimilated over time.

Source: (Aikens, 2022), (Fisher, 2010), (Cole, 2001), (Noll, 2009), (Kaestle & Smith, 2001), (Davis, 2019), (BLM and Univ of Oregon, 2023), (Aikens, 1993), (Aikens, et al., 2011)

Rhyolite pinnacle (*mile 49.5)*

Just upstream of the historic waterwheel, next to the road, stands an eye-catching, orange-colored pinnacle perched on an outcrop of dark-colored rock. The orange pinnacle is 16-million-year-old Tuff of Leslie Gulch and the underlying dark rock is intrusive andesite (undated). This is a good place to see the contact zone between the intruding hot andesite magma and the cold overlying rhyolite tuff. Note that the narrow access road does not have pullouts, so during the busy rafting season it's difficult to stop and look at the formation closeup. (Similar formations can be seen in the canyon walls 2 to 3 miles upstream. See "Greeley Canyon" section for explanation of rhyolite pinnacles and intrusive andesite.)

Source: (Ferns, et al., 1993), (Plumley, 1986)



Mile 49.5: Pinnacle of 16-million-year-old Tuff of Leslie Gulch standing on base of intrusive andesite rock. Contact zone is clearly visible. View downriver/north. (Raft for scale.)

Historic waterwheel (*mile 49.8)*

The waterwheel once provided irrigation water to the Morrison Ranch. It is believed to be one of only three pioneer waterwheels still surviving in the state of Oregon as of 1997. According to local historian Bill Crowell's blog (OwyheeMarginala.com), there were more than a dozen waterwheels on the Owyhee between Rome and Leslie Gulch, almost every homestead had one, and nearly every flat place along the river was occupied by a homestead. Materials for each waterwheel were brought in by wagon and assembled onsite.

This waterwheel measures about 30 feet in diameter and is an "undershoot" design where the water hits the wheel from beneath instead of dropping from above. It's designed specifically for irrigation purposes to lift water from a stream where the water level is low and does not have a high vertical drop (head). The wheel is equipped with paddles and buckets along the circumference of the wheel that rotates when the water strikes the bottom of the wheel. The design is relatively simple and cost-effective, making it a popular solution in historical and rural irrigation systems without access to electric power. They generally fell into disuse once power became available.

(You can find another half-buried waterwheel at the abandoned pioneer Island Ranch, 3 to 4 miles downstream on river-right, before Lake Owyhee begins.)

Source: (Crowell, 2022), (National Register of Historic Places, 1997),

Mile 49.8: ca 1890s waterwheel that once supplied irrigation water to Morrison Ranch.

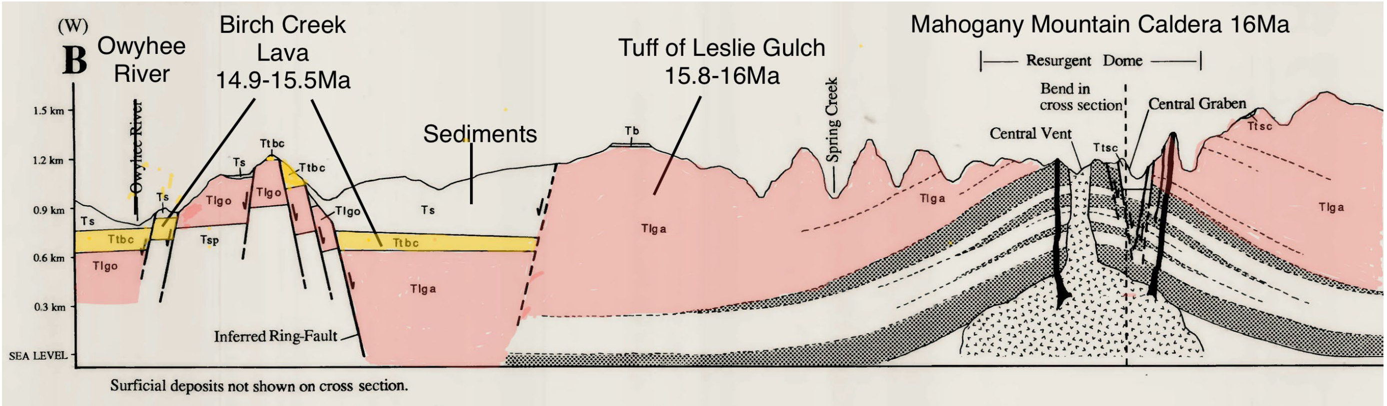
Mile: 50: The cliffs at Birch Creek are a flow of rhyolite lava dated 14.9 to 15.5 million years old, the aftermath of the Mahogany Mountain Caldera eruption. (Looking SE.)

Rhyolite Lava Cliffs *(mile 50)*

At Birch Creek ranch, the downcutting Owyhee River encountered a thick layer of ancient rhyolite lava and created the spectacular, orange-colored cliffs lining the bank on river-right. Just a short walk from the boat ramp, this is an excellent place to see flow-banded rhyolite lava, where viscous lava piled up on itself, forming flow patterns visible as curls or swirls. The cliffs start at the mouth of Birch Creek and run downstream (north) for about two miles. Scattered eroded outcrops of the rhyolite lava also line the east side of the Birch Creek road from the bottom of the canyon up to the canyon rimrock. This seldom-studied flow is aptly named "Birch Creek Lava". In 2022, researchers obtained high-precision ages of 14.94 and 15.52 million years from two rock samples.

The lava is thought to be a post-caldera lava flow from the nearby Mahogany Mountain Caldera, a well-studied rhyolite eruption whose explosive phase lasted for about 250,000 years, from 15.75 to 16.0 million years ago. It created a now-buried 15-mile-wide caldera whose rim is estimated to be about four miles away.

Mile 50: Boat ramp at Birch Creek Historic Ranch.



Mahogany Mountain Caldera cross-section near Birch Creek. (Adapted from Vander Meulen, 1989, a USGS report.)

During the explosive phase of rhyolite volcanic eruptions, caldera floors collapse, and fracture rings (faults) occur in the earth's crust that provide pathways for molten rhyolite to reach the surface. The subsequent post-caldera lava flows often continue for hundreds of thousands of years (or longer) after the main eruption.

Unlike the other rhyolite lava canyons upstream (Sleeping Dragon Gorge and First Rhyolite Gorge), the cliffs here have eroded into crumbly, hoodoo-like shapes and developed a substantial scree slope of angular rhyolite rock. This may be evidence of stress fracturing related to regional tectonic stress that occurred after the lava flow formed. The lava flow is cut by numerous faults and the fault-blocks on the lava rimrock have been uplifted as much as 2,000 vertical feet relative to those on the canyon floor. The enormous forces required to accomplish this amount uplift may have caused stress fracturing throughout the lava flow.

Source: (Benson & Mahood, 2016), (Cummings, et al., 2000), (Black, 2021), (Swenton, et al., 2022), (Plumley, 1986), (Ferns, et al., 1993), (Vander Meulen, 1989)

Birch Creek Historic Ranch site is made up of two pioneer homesteads established in the 1890s originally known as the Birch Creek Ranch and the Morrison Ranch.

Birch Creek Historic Ranch *(Mile 50)*

According to their field notes, surveyors from the General Land Office reached Birch Creek in 1912 and found three well-established homesteads located in this 6-mile reach of the river, each with irrigated fields, gardens, orchards and cabins. Two of the ranches had waterwheels with flumes and irrigation ditches to distribute water from the river, the other obtained its irrigation water from Birch Creek. These ranches were probably first settled sometime in the mid-1890s as the first wave of homesteaders arrived in the lower Owyhee Canyon.

General Land Office survey maps show that access was by two wagon roads: one is today's Birch Creek Road leading up and out of the canyon to Jordan Valley; the other wagon road was located on the opposite bank of the river and went about 6-miles downstream to the small pioneer community of Watson (now abandoned). The Watson wagon road forded the river several times and would have been unusable during spring high-water season. Watson's population was 37 in 1911; it's post office opened in 1898 and closed in 1936.

The buildings at the mouth of Birch Creek mark the site of the Birch Creek Ranck homestead. (Photo from BLM brochure.)

The present-day BLM "Birch Creek Historic Ranch" site contains two of the three 1890s homesteads. These two homesteads were originally known as the "Birch Creek Ranch" (located at the mouth of Birch Creek and running upstream), and the "Morrison Ranch" (from the waterwheel to the boat ramp and campground). The two ranches were combined under one owner and sold to the BLM in the 1980s. The third homestead was on the opposite side of the river, downstream from the Morrison Ranch, and was abandoned after being purchased by the government when construction of the Owyhee dam began in 1928.

The water wheel and stone walls date back to the original homesteads and are considered historic. The wooden structures have a hazy history and are probably mid-to-late 1900s vintage, after it was possible to economically transport lumber to this remote site. Trees suitable for milled lumber do not grow in the canyon and it was a long drive by wagon and team on rough roads to the nearest sawmill. Early homesteaders along the river usually built their homes out of local sandstone or volcanic tuff. Even fenceposts were in short supply once the local juniper trees had been harvested, hence the rock walls.

Source: (Crowell, 2022), (National Register of Historic Places, 1997), (BLM General Land Office Records Search, 2024)

This dirt road went to the Morrison Ranch homesite. It now leads to the BLM boat ramp and campground. (Photo from BLM brochure.)

Owyhee Breaks from Birch Creek Road viewpoint looking NW. The road climbs 1,700 vertical feet through orange-colored rhyolite tuff and lava that erupted between 15 and 16 million years ago.

Birch Creek Road Viewpoint

The Birch Creek Road climbs 1,700 vertical feet out of the Owyhee Canyon on a narrow winding, rocky road before exiting at an elevation of 4,600 feet onto a basalt lava plain approximately 5 million years old. In comparison, this is about the same elevation as most highways that pass across Oregon's Cascade Mountain range. The road pullouts offer excellent views of the Owyhee Breaks, a faulted and eroded volcanic landscape created by the eruptions and collapse of ancient volcanoes in the Lake Owyhee Volcanic Field.

Rock outcrops: The eroded, orange-colored rhyolite rock outcrops look the same on both sides of the road but are not. The west side is generally tuff (Tuff of Leslie Gulch) and the east side is generally lava (Birch Creek Lava). The road and creek bed roughly follow the seam between the two different rock formations. The tuff and lava were formed between 15 and 16 million years ago when nearby Mahogany Mountain Caldera erupted. The tuff deposits came first, followed several hundred thousand years later by the lava flow(s).

Birch Creek Road warning sign on plateau.

Source: (Vander Meulen, 1989), (Ferns, et al., 1993)

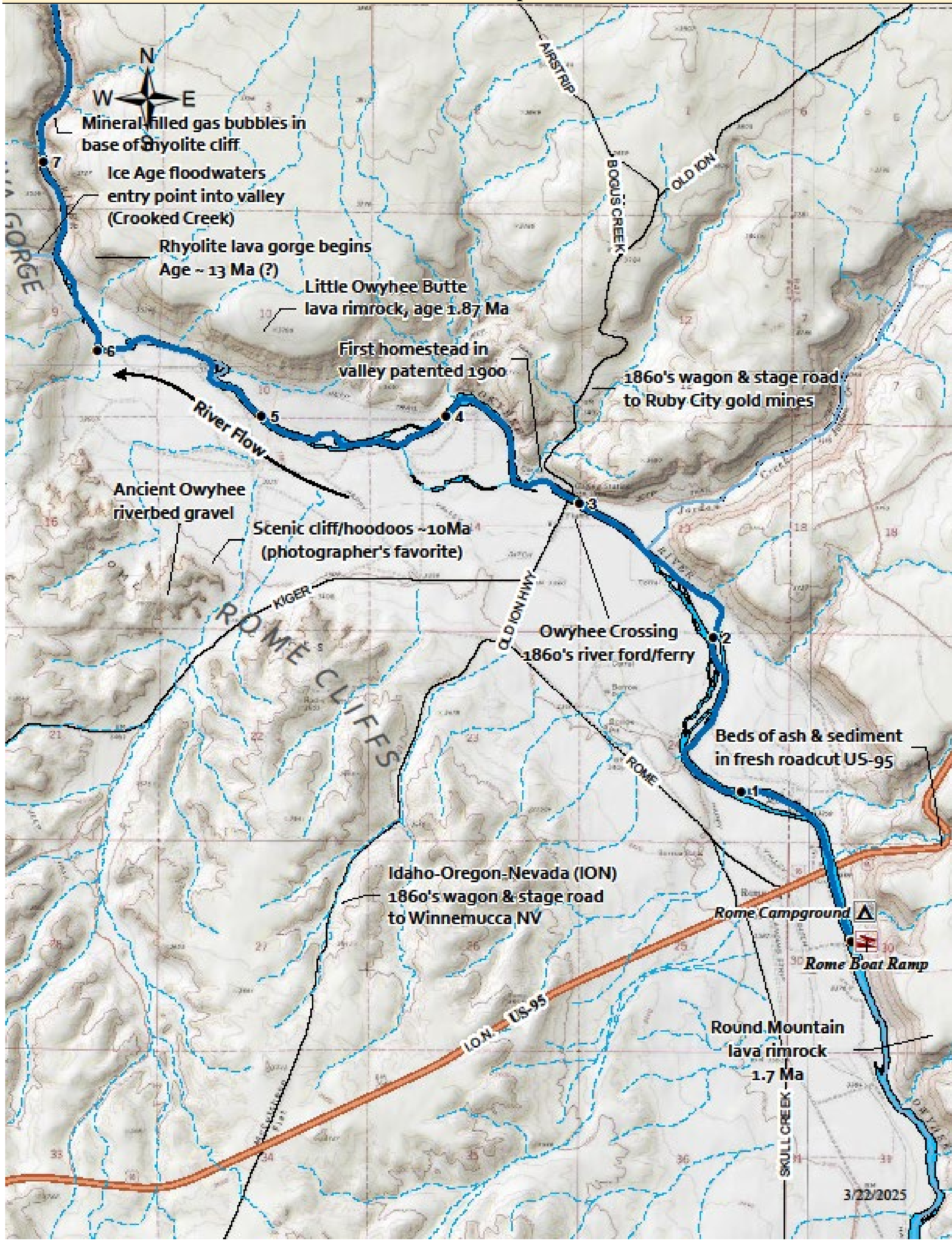
Maps of the Lower Owyhee River

The only practical way to see the geology described in this guide is by raft so locations are given in terms of river-miles starting from the BLM boat launch at Rome, Oregon and increasing as you travel downriver (north). The BLM boat ramp at Birch Creek Ranch is river-mile 50.5, the usual rafters takeout. The official names and locations of campsites and rapids were downloaded from the national geospatial database. Distance is calculated along the official river channel centerline using ArcGIS Pro software.

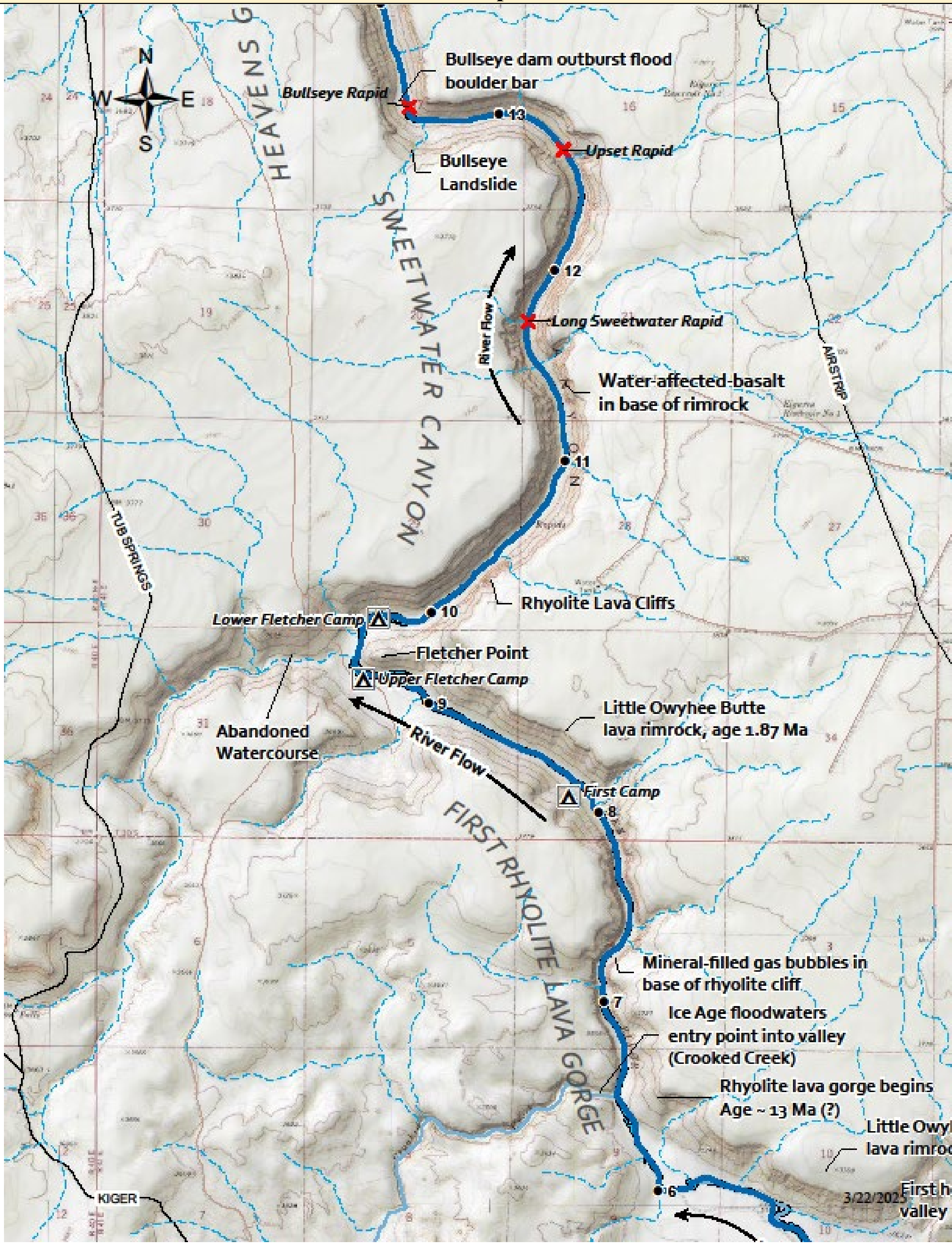
Map symbols:

- Campsites and boat ramps have standard BLM symbols.
- Rapids are a red X symbol.
- River-miles are a black solid circle (dot) symbol with a number.
- Geological features are labeled with a leader line pointing to the location.
- Basalt volcanic vents and shield volcanos are a red triangle symbol.
- North is always up.
- River flow direction is shown with a black arrow, generally from south to north.

River Map 1

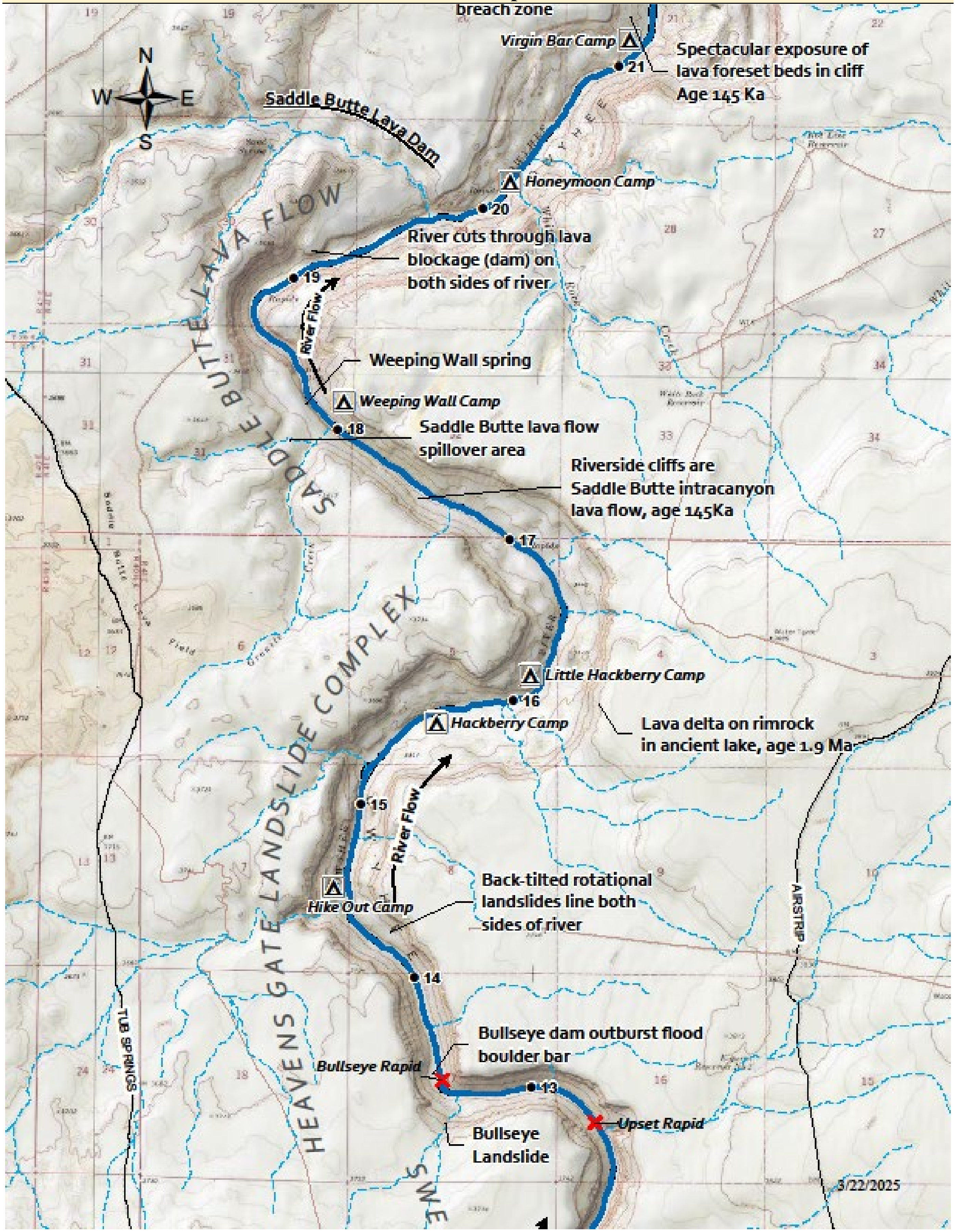

N
W
E
S
Mineral-filled gas bubbles in base of rhyolite cliff
Ice Age floodwaters entry point into valley (Crooked Creek)
Rhyolite lava gorge begins Age ~ 13 Ma (?)
GORGE
Little Owyhee Butte lava rimrock, age 1.87 Ma
First homestead in valley patented 1900
1860's wagon & stage road to Ruby City gold mines
AIRSTRIP
BOGUS CREEK
OLD ION
River Flow
Ancient Owyhee riverbed gravel
Scenic cliff/hoodoos ~10Ma (photographer's favorite)
KIGER
ROME CLIFFS
OLD ION HWY
Owyhee Crossing 1860's river ford/ferry
Beds of ash & sediment in fresh roadcut US-95
ROME
Idaho-Oregon-Nevada (ION) 1860's wagon & stage road to Winnemucca NV
Rome Campground
Rome Boat Ramp
I.O.N.
US-95
Round Mountain lava rimrock 1.7 Ma
SKULL CREEK
3/22/2025

River Map 2



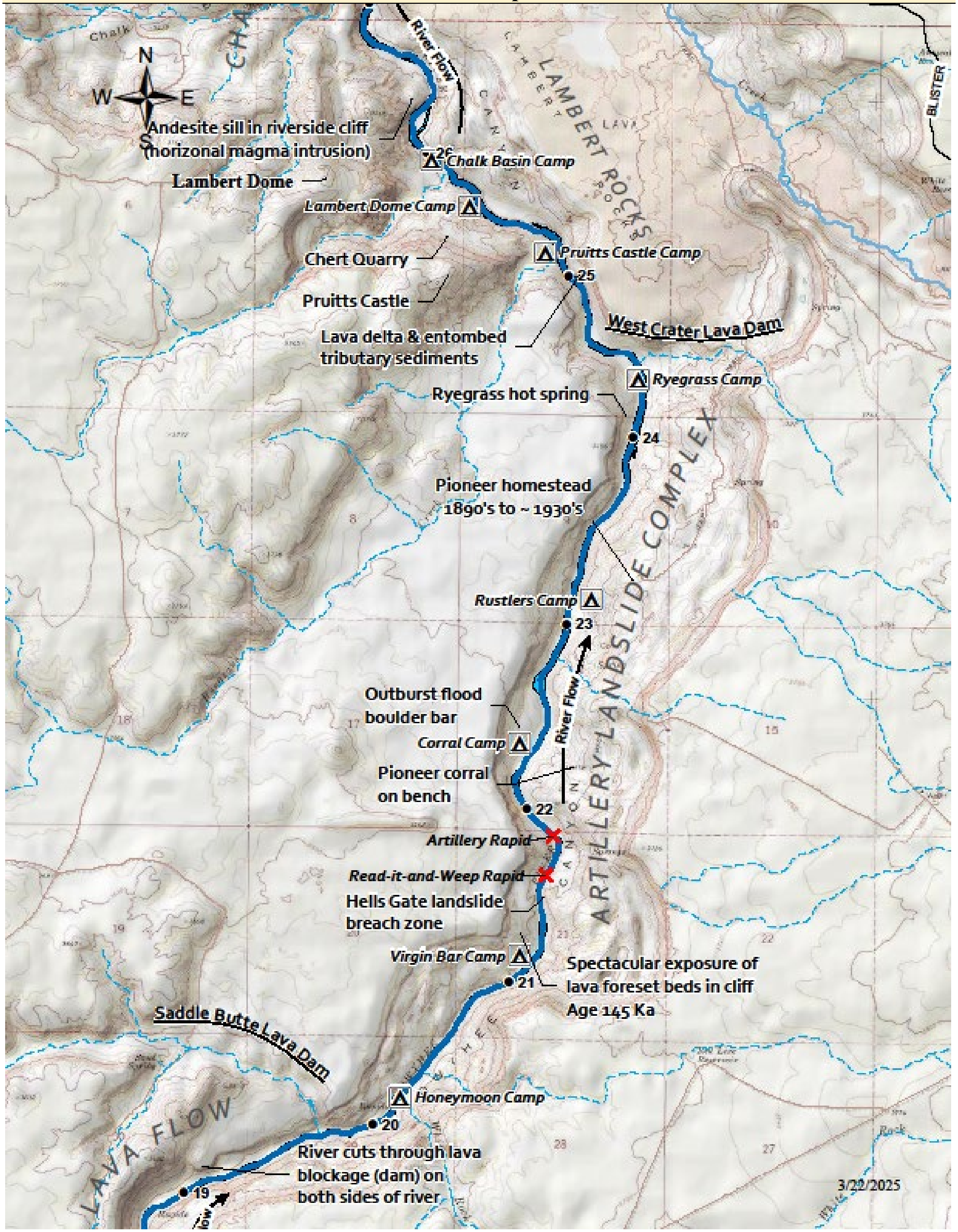
N
W
E
S
HEAVENS G
Bullseye dam outburst flood boulder bar
Bullseye Rapid
13
Upset Rapid
Bullseye Landslide
SWEETWATER CANYON
12
River Flow
Long Sweetwater Rapid
AIRSTRIP
Water-affected-basalt in base of rimrock
11
TUB SPRINGS
Rhyolite Lava Cliffs
Lower Fletcher Camp
10
Fletcher Point
Upper Fletcher Camp
9
Little Owyhee Butte lava rimrock, age 1.87 Ma
Abandoned Watercourse
River Flow
First Camp
8
FIRST RHYOLITE LAVA GORGE
Mineral-filled gas bubbles in base of rhyolite cliff
7
Ice Age floodwaters entry point into valley (Crooked Creek)
Rhyolite lava gorge begins Age ~ 13 Ma (?)
Little Owyh
lava rimrocl
6
KIGER
3/22/2025
First ho
valley p

River Map 3

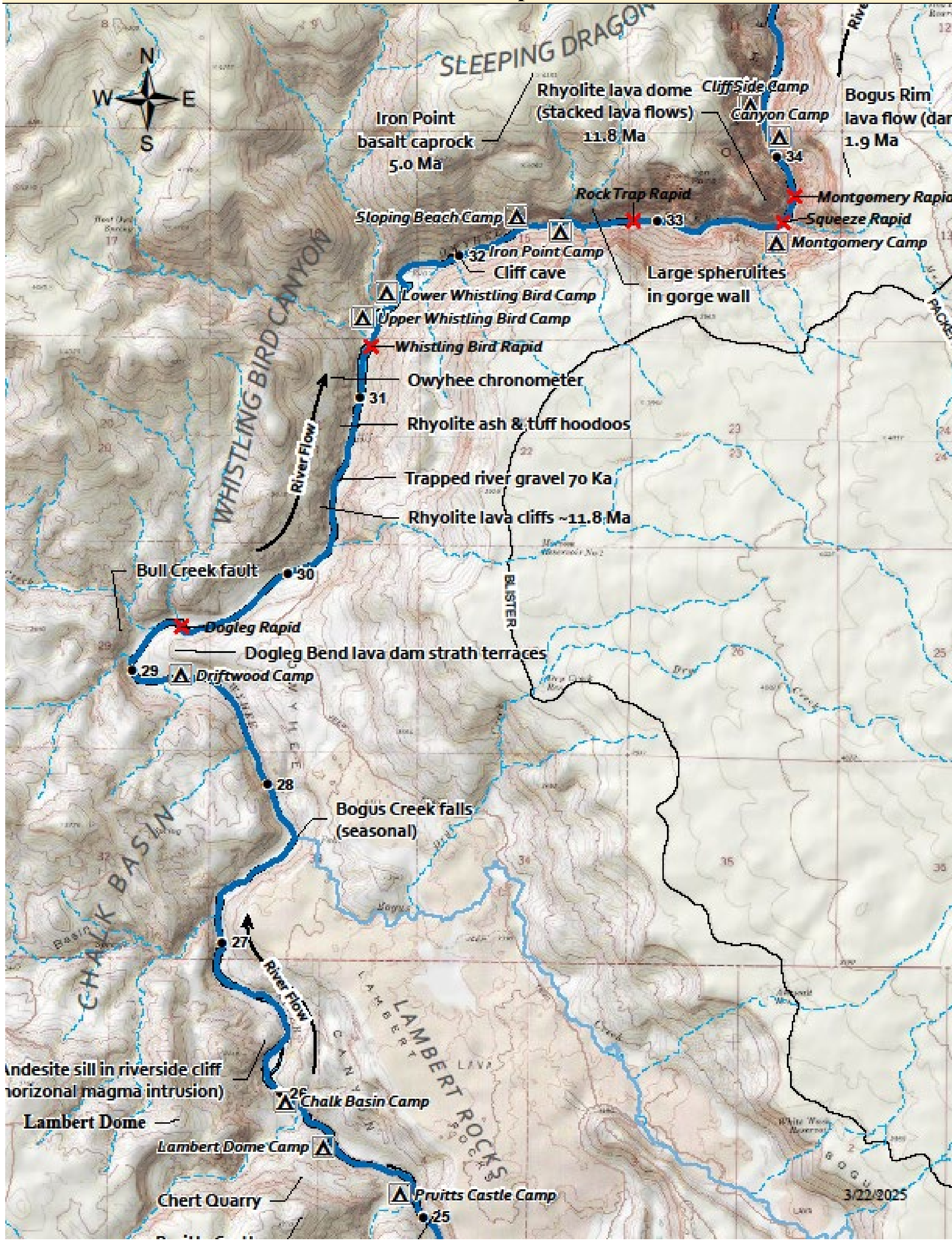


breach zone
Virgin Bar Camp
21
Spectacular exposure of
lava foreset beds in cliff
Age 145 Ka
N
W
E
S
Saddle Butte Lava Dam
Honeymoon Camp
20
SADDLE BUTTE LAVA FLOW
River cuts through lava
blockage (dam) on
both sides of river
19
River Flow
Weeping Wall spring
Weeping Wall Camp
18
Saddle Butte lava flow
spillover area
Riverside cliffs are
Saddle Butte intracanyon
lava flow, age 145Ka
17
HEAVENS GATE LANDSLIDE COMPLEX
Little Hackberry Camp
16
Hackberry Camp
Lava delta on rimrock
in ancient lake, age 1.9 Ma
15
River Flow
Back-tilted rotational
landslides line both
sides of river
Hike Out Camp
14
AIRSTRIP
TUB SPRINGS
Bullseye dam outburst flood
boulder bar
Bullseye Rapid
13
Upset Rapid
Bullseye
Landslide
3/22/2025

River Map 4

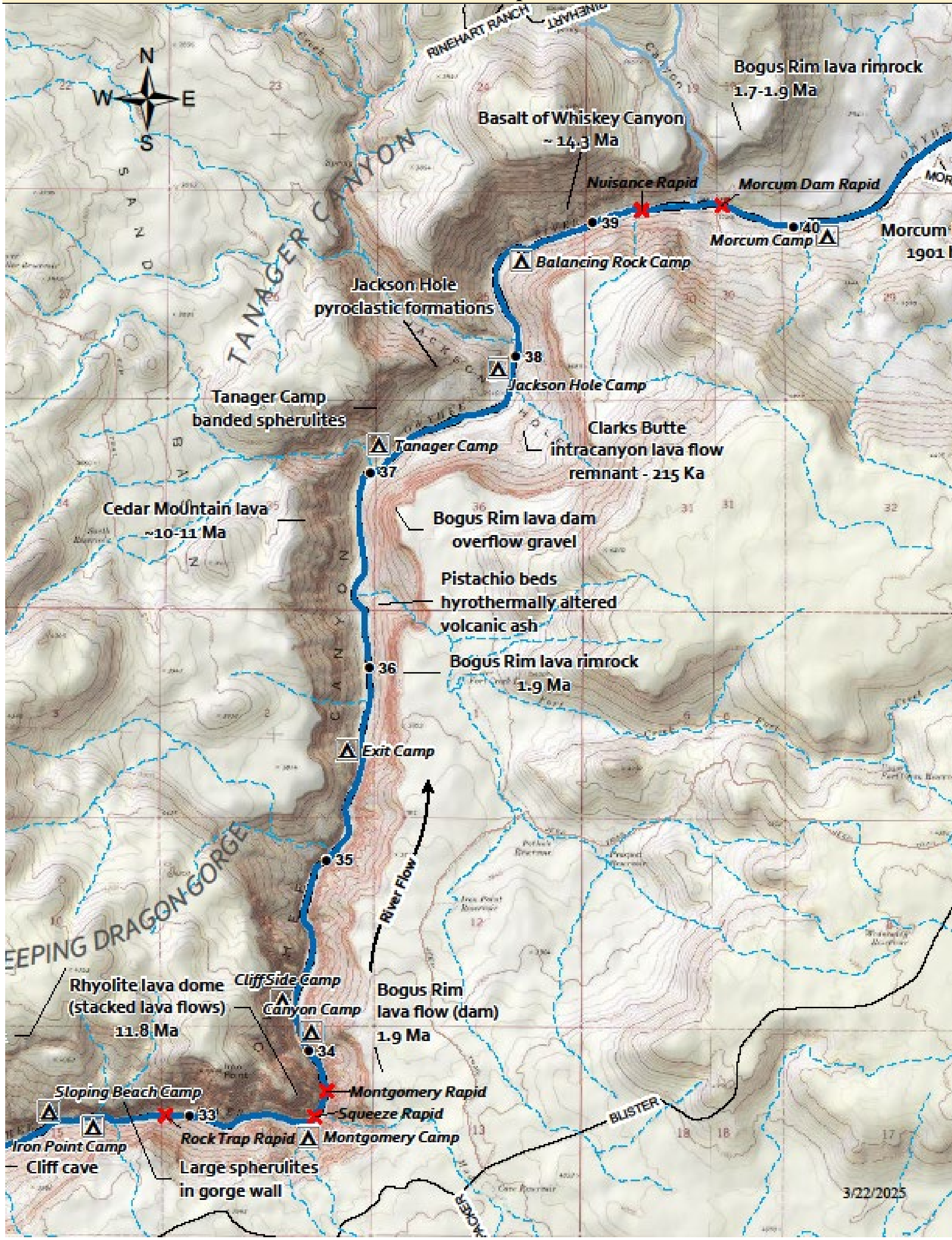

River Flow
LAMBERT ROCKS
N
W
E
S
Andesite sill in riverside cliff
(horizonal magma intrusion)
26
Chalk Basin Camp
Lambert Dome
Lambert Dome Camp
Chert Quarry
Pruitts Castle Camp
25
Pruitts Castle
West Crater Lava Dam
Lava delta & entombed
tributary sediments
Ryegrass Camp
Ryegrass hot spring
24
ARTILLERY LANDSLIDE COMPLEX
Pioneer homestead
1890's to ~ 1930's
Rustlers Camp
23
River Flow
Outburst flood
boulder bar
Corral Camp
Pioneer corral
on bench
22
Artillery Rapid
Read-it-and-Weep Rapid
Hells Gate landslide
breach zone
Virgin Bar Camp
21
Spectacular exposure of
lava foreset beds in cliff
Age 145 Ka
Saddle Butte Lava Dam
LAVA FLOW
Honeymoon Camp
20
River cuts through lava
blockage (dam) on
both sides of river
19
3/22/2025

River Map 5

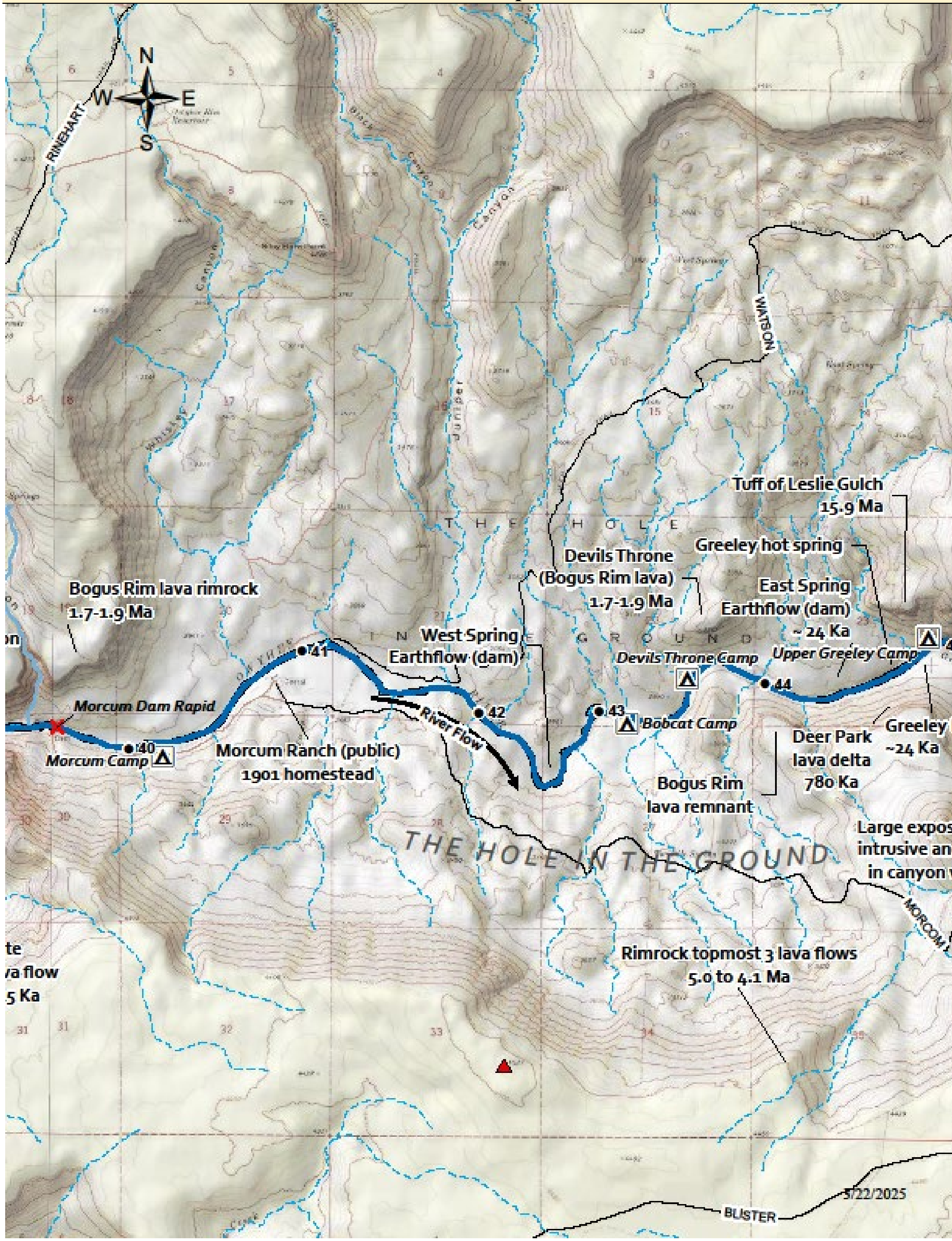


N
W
E
S
SLEEPING DRAGON
Rhyolite lava dome
(stacked lava flows)
11.8 Ma
CliffSide Camp
Canyon Camp
Bogus Rim
lava flow (dam
1.9 Ma
Iron Point
basalt caprock
5.0 Ma
34
Rock Trap Rapid
Montgomery Rapid
Sloping Beach Camp
33
Squeeze Rapid
Montgomery Camp
32
Iron Point Camp
Cliff cave
Large spherulites
in gorge wall
WHISTLING BIRD CANYON
Lower Whistling Bird Camp
Upper Whistling Bird Camp
Whistling Bird Rapid
PACKER
Owyhee chronometer
31
Rhyolite ash & tuff hoodoos
River Flow
Trapped river gravel 70 Ka
Rhyolite lava cliffs ~11.8 Ma
Bull Creek fault
30
BLISTER
Dogleg Rapid
Dogleg Bend lava dam strath terraces
29
Driftwood Camp
28
Bogus Creek falls
(seasonal)
CHALK BASIN
27
River Flow
LAMBERT ROCKS
Andesite sill in riverside cliff
horizonal magma intrusion)
26
Chalk Basin Camp
Lambert Dome
Lambert Dome Camp
Chert Quarry
Pruitts Castle Camp
25
3/22/2025

River Map 6



N
W
E
S
RINEHART RANCH
RINEHART
TANAGER CANYON
SLEEPING DRAGON GORGE
Bogus Rim lava rimrock
1.7-1.9 Ma
Basalt of Whiskey Canyon
~ 14.3 Ma
Nuisance Rapid
Morcum Dam Rapid
39
40
Morcum Camp
Morcum
1901
Balancing Rock Camp
Jackson Hole
pyroclastic formations
38
Jackson Hole Camp
Tanager Camp
banded spherulites
Clarks Butte
intracanyon lava flow
remnant - 215 Ka
Tanager Camp
37
Cedar Mountain lava
~10-11 Ma
Bogus Rim lava dam
overflow gravel
Pistachio beds
hyrothermally altered
volcanic ash
36
Bogus Rim lava rimrock
1.9 Ma
Exit Camp
35
River Flow
Rhyolite lava dome
(stacked lava flows)
11.8 Ma
CliffSide Camp
Canyon Camp
Bogus Rim
lava flow (dam)
1.9 Ma
34
Sloping Beach Camp
Montgomery Rapid
33
Squeeze Rapid
Rock Trap Rapid
Montgomery Camp
Iron Point Camp
Cliff cave
Large spherulites
in gorge wall
BLISTER
3/22/2025


N
W
E
S
RINEHART
WATSON
Juniper
Tuff of Leslie Gulch
15.9 Ma
Greeley hot spring
Devils Throne
(Bogus Rim lava)
1.7-1.9 Ma
East Spring
Earthflow (dam)
~ 24 Ka
Bogus Rim lava rimrock
1.7-1.9 Ma
West Spring
Earthflow (dam)
41
Devils Throne Camp
Upper Greeley Camp
44
Morcum Dam Rapid
42
River Flow
43
Bobcat Camp
Greeley E
~24 Ka
Deer Park
lava delta
780 Ka
40
Morcum Camp
Morcum Ranch (public)
1901 homestead
Bogus Rim
lava remnant
Large expos
intrusive and
in canyon w
THE HOLE IN THE GROUND
MORCOM
Rimrock topmost 3 lava flows
5.0 to 4.1 Ma
5/22/2025
BLISTER

River Map 8

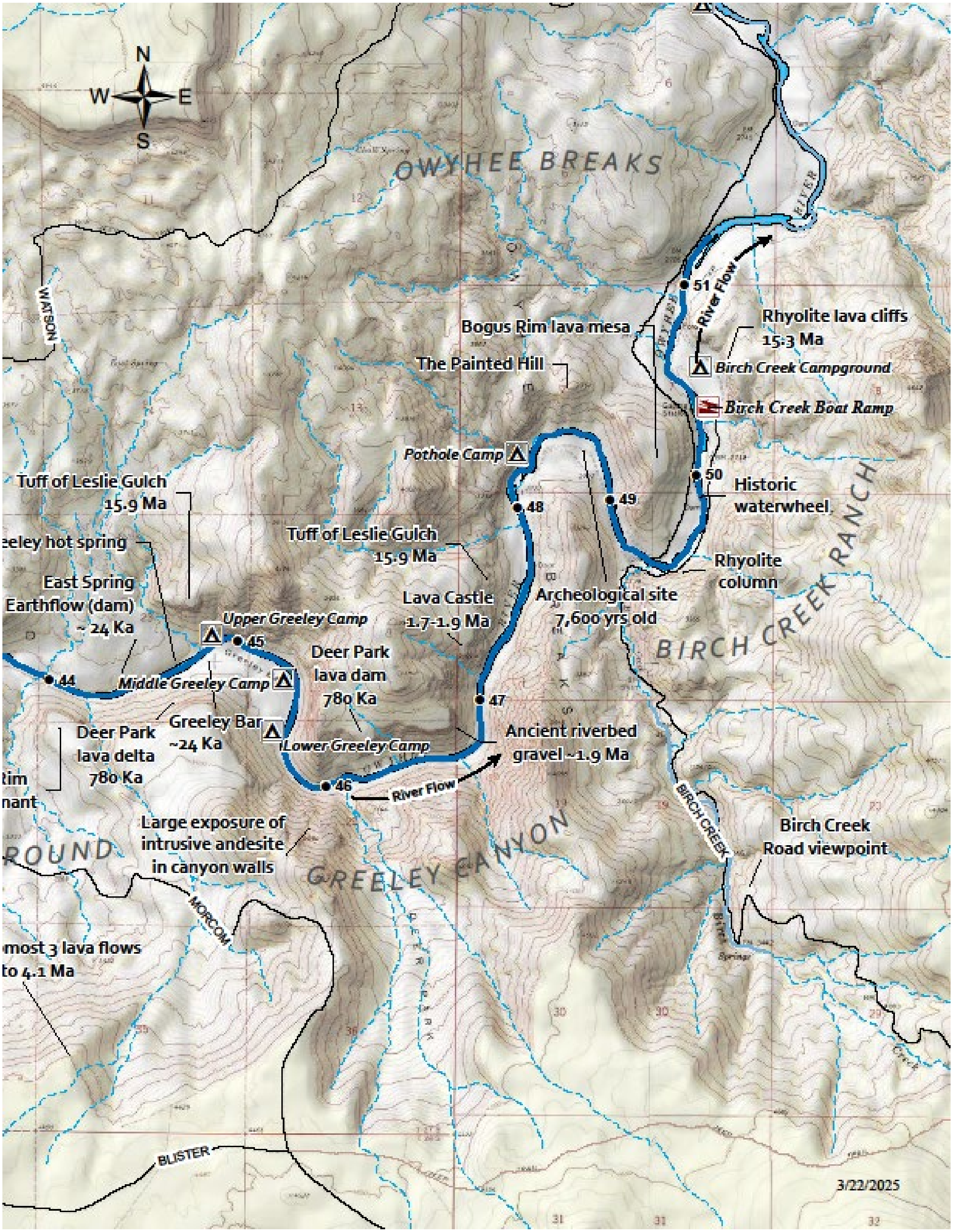

N
W
E
S
OWYHEE BREAKS
WATSON
Bogus Rim lava mesa
The Painted Hill
51
River Flow
Rhyolite lava cliffs
15.3 Ma
Birch Creek Campground
Birch Creek Boat Ramp
Pothole Camp
50
Historic
waterwheel
48
49
Tuff of Leslie Gulch
15.9 Ma
eeley hot spring
Tuff of Leslie Gulch
15.9 Ma
Rhyolite
column
BIRCH CREEK RANCH
East Spring
Earthflow (dam)
~ 24 Ka
Upper Greeley Camp
Lava Castle
1.7-1.9 Ma
Archeological site
7,600 yrs old
BIRCH CREEK
45
44
Middle Greeley Camp
Deer Park
lava dam
780 Ka
47
Greeley Bar
~24 Ka
Deer Park
lava delta
780 Ka
Lower Greeley Camp
Ancient riverbed
gravel ~1.9 Ma
Rim
nant
46
River Flow
BIRCH CREEK
Large exposure of
intrusive andesite
in canyon walls
ROUND
GREELEY CANYON
Birch Creek
Road viewpoint
MORCOM
most 3 lava flows
to 4.1 Ma
BLISTER
3/22/2025

Table of Rock Ages

Name	Age	Source
Bogus Rim Lavas	1.7 to 1.9 Ma	Ely et al (2012) Table 2
Deer Park	780 Ka	Ely et al (2012) Table 2
Clarks Butte	215 Ka	Ely et al (2012) Table 2
Saddle Butte	145 Ka	Ely et al (2012) Table 2
West Crater	70 Ka	Ely et al (2012) Table 2
Bogus Bench Vent	1.92 Ma	Bondre (2006)
Owyhee Butte	1.86 Ma	Bondre (2006)
Little Owyhee Butte	1.87 Ma	Bondre (2006)
Round Mountain vent	1.7 Ma	Unpublished
Iron Point basalt mesa	4.99 Ma	Unpublished
Hole in the Ground rimrock flow 1	4.49 Ma	Hart & Mertzman (1983)
Hole in the Ground rimrock flow 2	4.09 Ma	Hart & Mertzman (1983)
Hole in the Ground rimrock flow 3	4.06 Ma	Hart & Mertzman (1983)
Dry tributary caprock near Fletcher Point	650 Ka	Shoemaker (2004)
Sacramento Butte	11.85 Ma	Swenton (2022)
Iron Point (Sleeping Dragon Gorge)	11.84 Ma	Swenton (2022)
Saddle Butte	10.94 Ma	Swenton (2022)
Dome N of Iron Point	10.57 Ma	Swenton (2022)
Cedar Mountain Basalt	~11 Ma	Ferns and Evans, 1993
Owyhee Basalt (avg)	14.3 Ma	Ferns and Evans, 1993
Basalt of Whiskey Canyon	~14.3 Ma	Ferns and Evans, 1993
Andesite intrusions (Dikes/sills/etc)	10.8 to 14.3 Ma	Ferns and Evans, 1993
Tuff of Leslie Gulch (avg)	15.9 Ma	Black (2021)/Ferns et al (2017)
Birch Creek lava (avg)	15.3 Ma	Swenton (2022)
Mt Mazama tephra	7.7 Ka	Ely et al (2012) Table 2
Devine Canyon Tuff	9.68 Ma	Jenda Johnson Thesis (1995)

Glossary

Abraded boulders– rocks, typically large ones, worn down by friction with wind, water or ice.

Andesite intrusion– a body of andesite magma that did not reach the surface and solidified within existing rock layers.

Basalt lava– molten rock (lava), rich in iron, low in silica, resulting in highly fluid dark lava

Basaltic tephra– basalt volcanic debris, including ash and rock fragments, ejected during an eruption.

Chert-a hard, fine-grained rock often used by ancient people to make tools.

Fluvial deposits- deposits of sediments moved and deposited by a river or stream.

Foreset beds-inclined layers of sediment or lava deposited at the leading edge of a lava flow or a river where it enters a body of water.

Graben-a block of land that has dropped between two parallel faults, often forming a basin.

Hoodoos-tall, thin spires of rock shaped by erosion, typically topped by harder stone.

Interbedded basalt-basalt lava flows alternating with layers of other rock types in a stratified sequence.

Intrusion- magma that did not reach the surface and solidified within existing rock layers.

Ka- Abbreviation for "kilo-annum", meaning one thousand years.

Lithified- sedimentary rock or other material hardened into stone through compaction and cementation.

Ma- Abbreviation for "mega-annum", meaning one million years.

Magma-liquid or molten rock found beneath Earth's surface.

Mazama Volcano- the eruption that created Oregon's Crater Lake, depositing widespread ash.

Pillow lava-hot lava that solidifies as rounded masses when it enters water and cools rapidly.

Pyroclastic-ash, rock fragments and gases ejected explosively from a volcano.

Rhyolite lava- high-silica viscous lava that forms thick, slow-moving flows, domes, or steep-sided structures.

Rotational landslides-earth slumps that rotate as they slide downhill.

Scoria-gas-filled basaltic lava that cools rapidly, trapping the gas bubbles.

Sedimentary-rock formed when sand, mud or rock fragments or minerals in water turn to rock.

Shield volcano-a broad, gently sloping volcano built by runny lava flowing from a central vent.

Spherulites- circular mineral growths that sometimes occur in silica-rich glassy igneous rock.

Stratigraphy-the study of rock layers (strata) and their order, relative dating and position.

Strath (river)-a flat-bottomed river channel mainly carved in bedrock with thin sediment deposits.

Talus-a pile of angular rock fragments that accumulate at the base of steep rock slopes or cliffs.

Tectonic- the movement and interactions of the Earth's crust (lithospheric plates).

Bibliography

Aikens, C. M., 1993. *Archaeology of Oregon.* s.l.:BLM.

Aikens, C. M., Connolly, T. & Jenkins, D., 2011. *Oregon Archaeology.* s.l.:Oregon State University Press.

Aikens, M., 2022. *Dirty Shame Rockshelter.* [Online]
Available at: https://www.oregonencyclopedia.org/articles/dirty_shame_rockshelter/#.Y5aoIHbMKUk
[Accessed 11 12 2022].

Andreae, M. & Andreae, T., 2022. Archaeometric studies on rock art at four sites in the northeastern Great Basin of North America.

Barlock, et al., 1990. *Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon,* s.l.: USGS Survey Bulletin 1741-G.

Benson, L., Hattori, E., Southon, J. & Aleck, B., 2013. Dating North America's oldest petroglyphs, Winnemucca Lake subbasin, Nevada. 40(4466-4476).

Benson & Mahood, 2016. *Geology of The Mid-Miocene Rooster Comb Caldera and Lake Owhyee Volcanic Field, Eastern Oregon,* s.l.: Elesevier open-access.

Black, C. C., 2021. *Rhyolite Stratigraphy Along Succor Creek: Insights into the Eruptive History of the Three Fingers and Mahogany Mountain Volcanic Field,* s.l.: Portland State University, Thesis.

BLM and Univ of Oregon, 2023. *Testing Yields New Evidence of Human Occupation 18,000 years ago in Oregon,* s.l.: Bureau of Land Management.

BLM General Land Office Records Search, 2024. *Search Documents.* [Online]
Available at: https://glorecords.blm.gov
[Accessed Nov-Dec 2024].

Bondre, N., 2006. *Field and Geochemical Investigation of Basaltic Magmatism From the Western United States and Western India,* Oxford, OH: Miami University Dissertation.

Breitkreuz, C., 2013. Spherulites and lithophysae - 200 years of investigation on high-temperature crystallization domains in silica-rich volcanic rocks. *Springer,* 3 April, Volume Bull Volcano (2013) 75:705, p. 16.

Breitkreuz, C., Gotze, J. & Weibmantel, A., 2021. Mineralogical and geochemical investigation of megasphurlites from Argentina, Germany, and the USA. *Bulletin of Volcanology (2021) 83:14,* 19 February.p. 15.

Brossy, C., 2006. *Fluvial Response to Intra-Canyon Lava Flows, Owhyee River, SouthEastern Oregon,* s.l.: Central Washington University, Thesis.

Campion, K., 1979. *PhD Dissertation "Diagenetic Alteration and Formation of Authigenic Minerals in the Miocene "Rome Beds" SE Oregon".,* s.l.: Ohio State Univ.

Camp, V. & Wells, R., 2021. The Case for a Long-Lived and Robust Yellowstone Hotspot. v. 31(No. 1 January 2021).

Carter, D., Ely, L., O'Connor, J. & Fenton, C., 2005. Late Pleistonce outburst flooding from pluvial Lake Alvord into the Owyhee River, Oregon. Geomorphology 75 (2006) 346-367(doi:10.1016/j.geomorph.2005.07.023).

Cas, R. & Wright, J., 1992. *Volcanic Successions Modern and Ancient.* London: Chapman & Hall.

Cole, C. R., 2001. *Raw Material Sources and the Prehistoric Chipped-Stone Assemblage of the Birch Creek Site (35ML181) Southeastern Oregon,* s.l.: Washington State University, Thesis.

Cressman, L. S., 1937. *Petroglyphs of Oregon.* s.l.:University of Oregon.

Crowell, B., 2022. *Davis Ranch At Hole In The Ground.* [Online]
Available at: https://www.zhuangzismuddytail.com/owyheemarginalia/ranch-at-hole-in-the-ground.html
[Accessed 10 12 2022].

Cummings, Evans, Ferns & Lees, 2000. Stratigraphic and Structural Evolution of the Middle Miocene Synvolcanic Oregon-Idaho Graben. Bulletin Vol 112(No 5, p 668-682).

Davis, e. a., 2019. Late Upper Paleolithic occupation at Cooper's Ferry, Idaho, USA, 16,000 years ago. 365(891).

Ellison, B., 1968. *Thesis. "Stratigraphy of the Burns Junction - Rome Area, Malheur County, Oregon.",* s.l.: Oregon State Univ.

Ely, et al., 2012. Owhyee River intracanyon lava flows: Does the river give a dam?. Bulletin Published Online(doi: 10.1130/B30274.1).

Evans, C. S., 1986. *The Geology, Geochemistry, and Alteration of Red Butte, Oregon: A Precious Metal-Bearing Paleo Hot Spring System,* Portland, OR: Portland State University.

Evans, J., 1991. Geologic Map of the Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon. Volume Misc Field Studies Map MF-2167.

Evans, Turner, Griscom & Sawatzky, 1990. Mineral Resources of the Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon. Volume USGS Survey Bulletin 1741-F.

Ferns, Evans & Cummings, 1993. *Geologic Map of the Mahogany Mountain 30x60 Quadrangle, Malheur Co, Oregon, and Owhyee Co, Idaho,* s.l.: Oregon Dept of Geology and Mineral Industries, Map Series 78.

Ferns, M. & Evans, J., 1993. *Preliminary Geologic Map of the Rinehart Quadrangle Malheur County Oregon,* s.l.: ODGMI.

Ferns, M., Streck, M. & McClaughry, J., 2017. Field-Trip Guide to Columbia Flood Basalts, Associated Rhyolites, and Diverse Post-Plume Volcanism in Eastern Oregon.

Fisher, P. R., 2010. *Points In Time: Stone Tool Analysis As An Indication of Group Movement At the Birch Creek Site (35ML181), Southeastern Oregon,* s.l.: Washington State University Thesis.

Fretwell-Johnson, H., 1990. *In Times Past, A History of the Lower Jordan Creek Communities.* s.l.:s.n.

Godchaux, M. & Bonnichsen, B., 2002. Syneruptive Magma-Water and Posteruptive Lava-Water Interactions in the Western Snake River Plain, Idaho, During the Past 12 Million Years. *Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province: Idaho,* Volume Bulletin 30.

Hart & Mertzman, 1983. "Late Cenozoic volcanic stratigraphy of the Jordan Valley area, southeastern Oregon.". Vol 45(No 2 Feb 1983).

Highland, L., 2004. *Landslide Types and Processes (Fact Sheet 2004-3072),* s.l.: USGS.

Kaestle, F. & Smith, G., 2001. Ancient Mitchondrial DNA Evidence for Prehistoric Population Movement: The Numic Expansion. Volume 115:1-12.

Kittleman, L., 1973. *Guide to the Geology of the Owyhee Region of Oregon,* Eugene, OR: University of Oregon.

Loring, J. M. & Loring, L., 1996. *Pictographs & Petroglyphs of the Oregon Country.* s.l.:Institute of Archaeology, University of California, Los Angles.

Lyons, Glascock & Mehringer, 2003. *Silica from sources to site: ultraviolet fluorescence and trace elements identify cherts from Lost Dune, southeastern Oregon, USA,* s.l.: Journal of Archaeological Science, 30 (2003) 1139-1159.

Markley, C., 2013. *Characterization Mass Wasting Through The Spectral Analysis of LiDAR Imagery: Owhyee River, Southeastern Oregon,* s.l.: Central Washington University, Graduate Thesis MS Geology.

National Register of Historic Places, 1997. *Birch Creek Ranch Historic Rural Landscape,* s.l.: National Park Service Online Database.

Nevada Rock Art Foundation, 2015. *Exploring Great Basin Archaeology,* s.l.: Nevada Rock Art Foundation.

Noll, C. D., 2009. *Last Holocene Occupation of the Birch Creek Site (35ML181), Southeastern Oregon,* s.l.: Washington State University, Thesis.

Oregon Museum of Nat History, U. o. O., 2022. *Dirty Shame Rockshelter.* [Online]
Available at: https://uoregonnaturalhistory.pastperfectonline.com/bysitenumber?keyword=35ML65
[Accessed 11 12 2022].

Orem, C., 2010. *Lacustrin Sediment Record of Multiple Quaternary Lava Dams on The Owhyee River, Southeastern Oregon,* s.l.: Central Washington University, Thesis.

Orr, 1985. *Rivers of the West.* s.l.:Self Published.

Othus, S., 2008. *Comparison of Landslides and Their Related Outburst Flood Deposits, Owyhee River, Southeastern Oregon,* s.l.: Central Washington University, Thesis.

Personius, S. et al., 2007. Late Quaternary Paleoseismology of the Southern Steens Fault Zone, Northern Nevada. 97(No. 5, PP. 1662-1678, October 2007).

Plumley, P. S., 1986. *Volcanic Stratigraphy and Geochemistry of The Hole In The Ground Area, Owhyee Plateau, Southeastern Oregon,* s.l.: University of Idaho, Thesis.

Sheppard & Gude, 1987. "Field trip guide to the Sheaville and Rome zeolite deposits, southeastern Oregon".. 49(No 1 Jan 1987).

Shervais, J., Schmitt, D. & et al, 2013. First Results from HOTSPOT: The Snake River Plain Scientific Drilling Project, Idaho, U.S.A.. Issue March 2013.

Shock, M., 2002. *Rock art and settlement in the Owyhee uplands of southeastern Oregon.,* s.l.: University of Pittsburg, Thesis.

Shoemaker, K. A., 2004. *The Tectonomagmatic Evolution of the Late Cenozic Owyhee Plateau, Northwestern United States,* s.l.: Miami University, Oxford Ohio.

Skilling, I. P., White, J. D. & McPhie, J., 2002. Peperite: a review of magma-sediment mingling. *Journal of volcanology and geothermal research,* Issue 114 (2002) 1-17.

Skinner, 2025. *Skinner Family Northwest (Blog).* [Online]
Available at: http://www.skinnerfamilynw.org/
[Accessed 20 Feb 2025].

Staisch, L. et al., 2022. Major reorganization of the Snake River modulated by passage of the Yellowstone Hotspot. *GSA,* July/Aug.134(no. 7/8).

Swenton, V. M., Streck, M., Miggins, D. & McIntosh, W., 2022. Filling critical gaps in the space-time record of High Lava Plains and co-Columbia River Basalt Group rhyolite volcanism. Volume GSA Bulletin.

Vander Meulen, D., 1989. *Intracaldera Tuffs and Central-Vent Intrusion of the Mahogany Mountain Caldera, Eastern Oregon,* s.l.: USGS.

Vander Meulen, D. B. et al., 1990. *Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Areas, Malheur County, Oregon,* s.l.: US Geological Survey Open-File Report 90-0517.

Walker & Repenning, 1966. Reconnaissance Geologic Map of The West Half of the Jordan Valley Quadrangle, Malheur Co., Oregon. Issue Misc Geological Investigations: Map I-457.

Willsey, S., 2017. *Geology Underfoot in Southern Idaho.* Missoula, MT: Mountain Press Publishing Company.

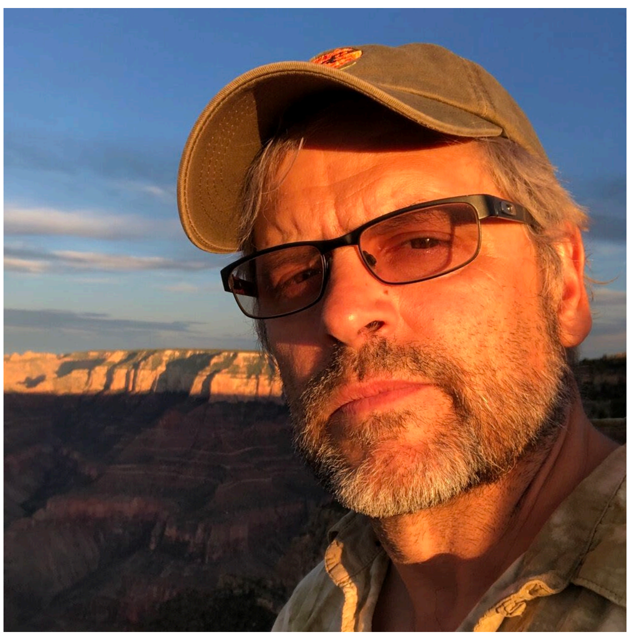
Wilson, J. K., 2007. *Curation and Lithic Technological Organizational Studies on the Owyhee River: A Case Study of the Chalk Basin Site (35ML143), Malheur County, Oregon,* s.l.: Washington State University, Department of Anthropology.

Wolf, K. & Ellison, B., 1971. Sedimentary Geology of the Zeolitic Volcanic Lacustrine Pliocene Rome Beds, Oregon. *Sedimentary Geology,* pp. 271-302.

Wood, S. & Clemens, D., 2002. Geologic and Tectonic History of the Western Snake River Plain, Idaho and Oregon. Volume 30.

The Authors

Kyle House is a professional geologist who has conducted research in the Owyhee Canyon since the 2000s and leads geology raft trips down the river. Ken Giles (retired) is an enthusiastic amateur geologist who has been rafting the Owyhee River and studying its geology since the 1970s. The authors fell in love with the Owyhee River years ago and have long wanted to write a guide explaining its unique geology. They teamed up in 2021 and spent three field seasons researching and writing this guide book.



Kyle House

Ken Giles