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Field Trip Guide to the Geology of the Umatilla River Basin October 14 and 15, 2004

Prepared for the Umatilla River Geology Workshop held at the Tamaskslikt Cultural Center, Confederated Tribes of the Umatilla Reservation

By

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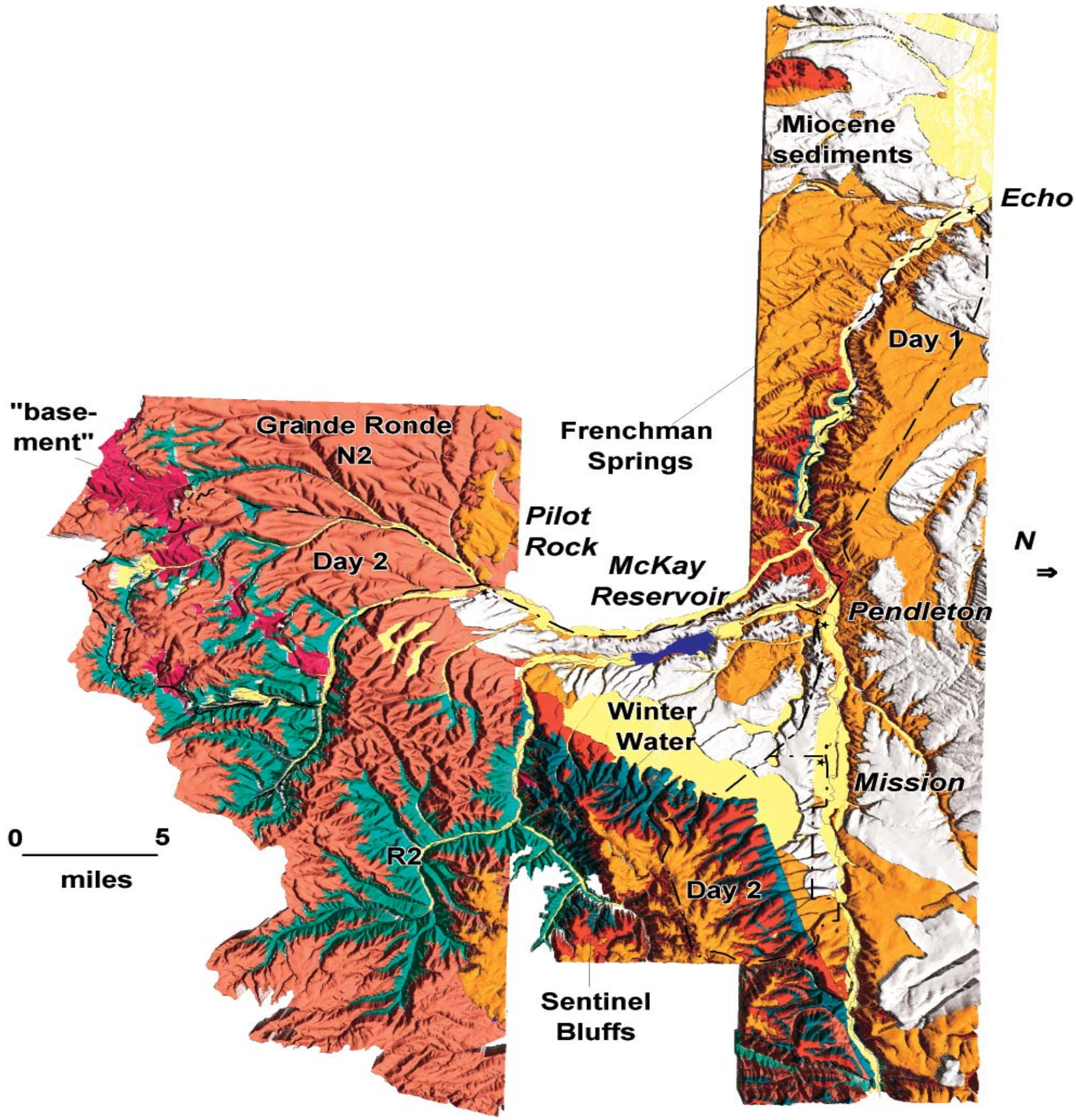
SHADED RELIEF MAP OF THE FIELD TRIP AREA SHOWING THE GENERALIZED GEOLOGY



WEST UMATILLA RIVER FIELD TRIP

DAY 1

The Day 1 field tip will look at Columbia River Basin lava flows and their distinctive physical characteristics. The trip will focus on 3 packages of lava flows: the Frenchman Springs Basalt, Sentinel Bluffs member, and Winter Water Basalt (Figure 1). They form important stratigraphic markers whose lava flows can usually be recognized in the field and always recognized when chemically analyzed. They can also be geochemically correlated with flows encountered in water wells. Our correlations show that wells which produce from the Wanapum Basalt's lower member (Frenchman Springs Basalt) or the Grande Ronde Basalt's uppermost unit (Sentinel Bluffs member) generally yield lesser amounts of water than wells drilled into/through the underlying Winter Water member of the Grande Ronde Basalt.

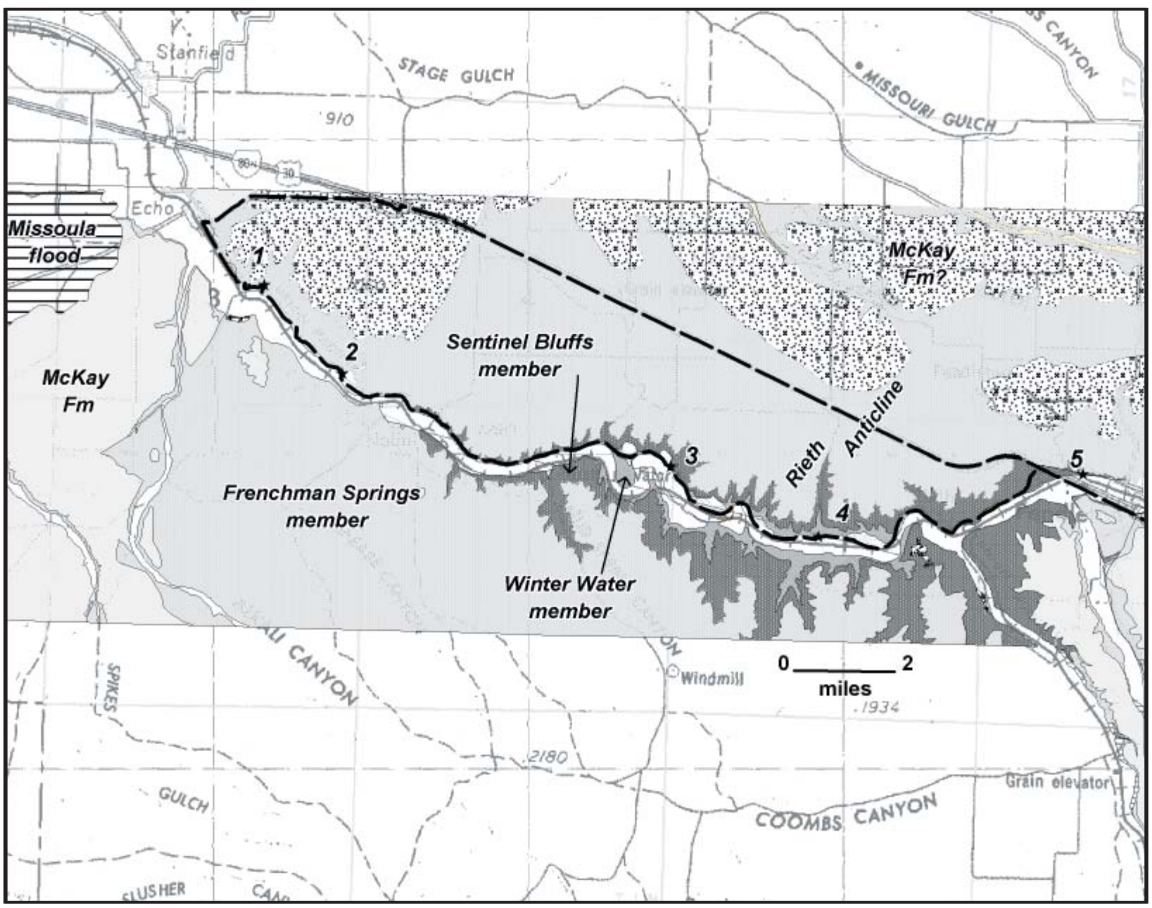


Figure 1. Simplified Geologic Map for Day 1. Oldest strata are exposed at Stops 3 and 4, in the core of the Rieth Anticline.

Columbia River Basalt Stratigraphy in the Umatilla River Basin

The Columbia River Plateau is one of world's best known flood basalt provinces. Flood-basalts are unique in that a single eruption can last over a period of years to centuries and produce an almost unbelievably large volume of lava. Massive eruptions, which began about 17 million years ago, produced more than 170,00 km^3 of mafic lava flows. Some of the larger eruptions generated more than 1,000 km3 of lava. Flowing from vents located near the Snake River, the lava crossed Oregon, and eventually reached the Pacific Ocean.

Various workers through the years have painstakingly taken apart monotonous-appearing layers of look-alike lava flows by using paleomagnetic measurements and geochemical analyses to match flows across great distances. Although five formally designated formations and more than 35 members have been described in the Columbia River Basalt Group (CRBG), only two formations (Grande Ronde Basalt and Wanapum Basalt) are exposed along the field trip route (Figure 2). The contact between the two formations is defined by three members (Winter Water and Sentinel Bluffs units of the Grande Ronde Formation, and Frenchman Springs member of the Wanapum Formation) that can be traced laterally through outcrops and water wells.

We follow the work of Swanson and others (1979) in defining a member as a flow or group of similar flows that can be positively identified through their unique stratigraphic position, magnetic properties, and chemical compositions. It is important to note that a "flow" means an individual cooling unit that is bounded at the top and base by vesiculated flow tops or flow breccias. It is important to realize that a long-lasting eruption may have produced more than one cooling unit.

The Grande Ronde Basalt is by far the largest formation in the Columbia River Basalt Group and, on the basis of paleomagnetic direction, has been broken into four magnetostratigraphic units (MSU's). The upper MSU's (N2, R2, and N1) are exposed in the Umatilla River Basin. Only the N2 MSU is exposed along the Day 1 Field Trip route.

The upper part of the N2 MSU has been broken into two members based on geochemical analyses and stratigraphic position. The N2 MSU is capped by a flow-on-flow sequence of relatively thin, medium- to coarse-grained, vesicular flows that make up the Sentinel Bluffs member. Sentinel Bluffs flows are relatively "primitive" (more mantle-like in its composition) high magnesium – low titanium lavas marked by >4.2 weight percent MgO and < 2.0 weight percent TiO_2.

The underlying Winter Water member varies from a single flow to a multiple flow-on-flow sequence of much thicker, fine-grained, sometimes glassy flows. Individual Winter Water flows are as much as 80 m thick. Winter Water flows are relatively less "primitive" low magnesium – low titanium flows marked by < 4.0 weight percent MgO and ~ 2.0 weight percent TiO_2.

The formation that overlies the Grande Ronde Basalt N2 MSU is the Wanapum Basalt. The Frenchman Springs member forms the base of the Wanapum Basalt throughout most of the Umatilla Basin and nearly everywhere directly overlies the Sentinel Bluffs member. The contact between the Frenchman Springs member and the Sentinel Bluffs member Grande Ronde Basalt is variously marked by a red or brown weathering soil zone, fine-grained pale-colored tuffaceous siltstone, fine pebbly gravels, pillow lavas, and hydroclastic and flow breccias. Where recognizable, the erosional break is referred to as the "Vantage Horizon". The contact is often marked by springs.

The Frenchman Springs member is a flow-on-flow sequence of relatively thin, fine- to medium-grained vesicular lava flows that like the Sentinel Bluffs member, weather to form relatively gentle slopes. Although the various Frenchman Springs lava flows exhibit a wide variety of textures, they are uniformly high titanium flows with typically > 3.0 weight percent TiO_2.

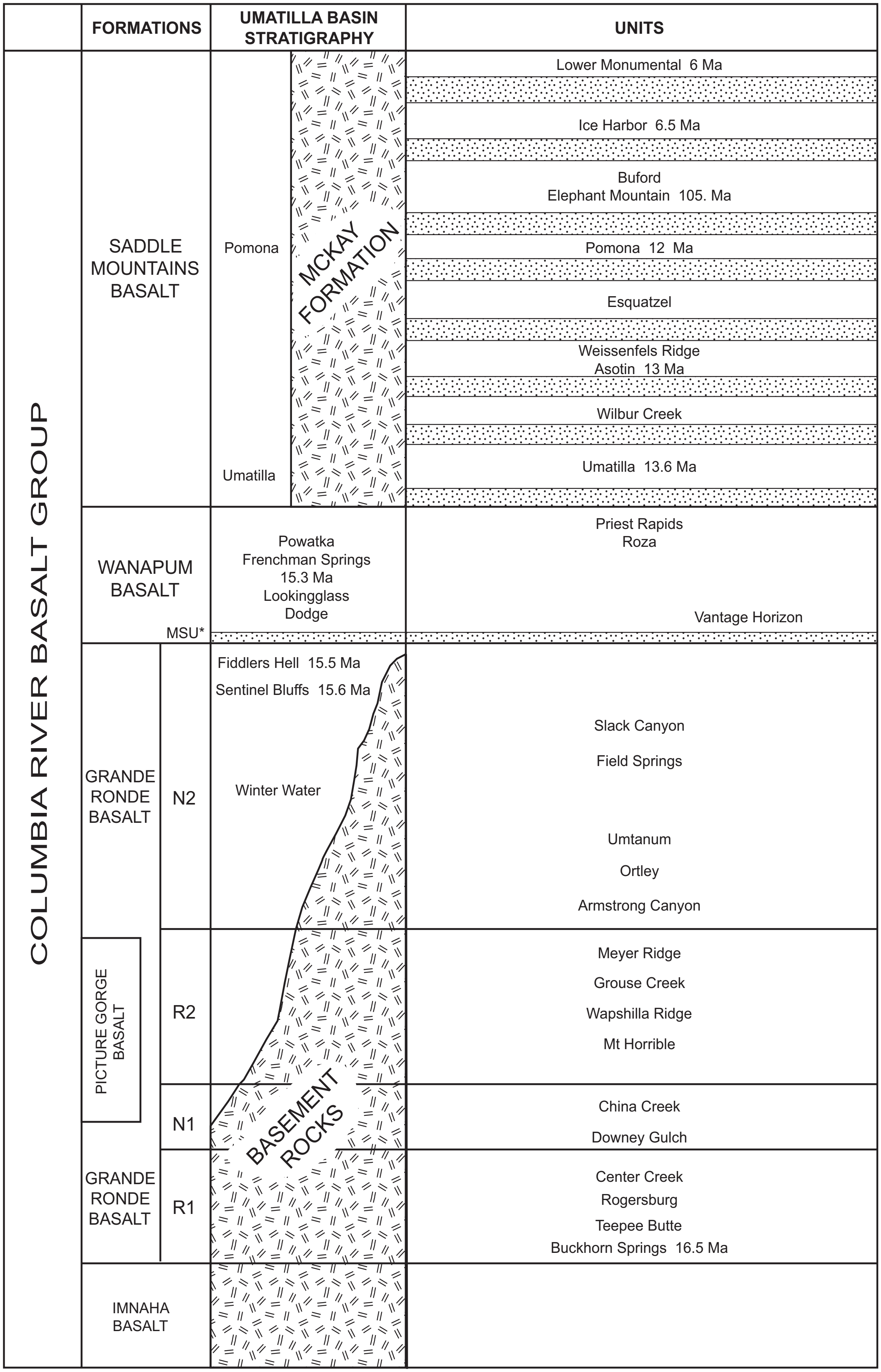


Figure 2. Stratigraphic Correlation Diagram for the Umatilla Basin. *MSU = magnetostratigraphic unit.

ROADLOG (LEG 1)

Day 1 Field Trip Guide

Miles (Mile Post)

0.0 We begin at the Tamastslikt Cultural Institute. Proceed out of the assembly area and turn left (south) on Market Road, past the Wildhorse Casino and highway toward Interstate I-84.

Market Road crosses a rolling plain eroded into a 50 m thick section of the late Miocene sedimentary McKay Formation. More than 130 m of Frenchman Springs Basalt is penetrated by wells drilled by the CTUIR in this area. Based on analyzed well cuttings, the contact between the Wanapum Basalt and the Grande Ronde Basalt dips gently to the north, being at about 930 ft elevation here and dropping to 790 ft elevation at Mission.

1.9 Turn right onto Interstate I-84 and proceed west, toward Pendleton. Fluvial gravels of the McKay Formation are exposed in roadcuts along the freeway. Here the McKay Formation overlies the Frenchman Springs Basalt member of the Wanapum Basalt. Late Miocene vertebrate fossils have been found in the McKay Formation gravels and paleosols.

2.7 Canyon of the Umatilla River comes into view to the right. Underlying Frenchman Springs lava flows are exposed in the canyon walls.

7.2 Cross over railroad bridge. Continue on Interstate I-84 through Pendleton. Interstate I-84 drops through both the McKay Formation and underlying Frenchman Springs Basalt as it descends onto the present day flood plain of the Umatilla River. A thin, red soil zone commonly referred to as the Vantage Horizon sometimes marks the contact between the Frenchman Springs Basalt and underlying Grande Ronde Basalt. The Vantage Horizon is exposed at several locations in Pendleton, including here along the south bank (to the left) of the Umatilla River.

The Vantage Horizon is an important stratigraphic marker that separates the Grande Ronde Basalt from the Wanapum Basalt. Here the uppermost Grande Ronde Basalt flows belong to the Sentinel Bluff member while the basal Wanapum Basalt flows are part of the Frenchman Springs member. Since some Frenchman Springs flows physically resemble underlying Sentinel Bluff flows, geochemical analyses are needed for positive identification in areas where the Vantage Horizon is not present. The Grande Ronde –Wanapum contact here is exposed at an elevation of about 1050 ft above sea level.

8.8 Continue west on Interstate I-84 past exit 207. Interstate I-84 begins to climb up onto the east limb of broad Rieth Anticline.

13.2 The Rieth Anticline appears to be somewhat asymmetric and plunges to the northeast. The Frenchman Springs member here is more than 200 m thick. Flows in the upper part of the Frenchman Springs weather readily to form rounded, subdued hills and generally do not form good outcrops.

15.5 The core of the Blue Mountains Uplift forms the skyline to the left. Highest point is Madison Butte, an erosional remnant made up of Eocene sandstones and early Tertiary volcanic rocks.

21.9 Interstate I-84 crosses the nose of a northeast-trending fault on the west limb of the anticline.

23.1 Turn off of Interstate I-84 at exit 193 onto Echo Road and proceed south, toward Echo.

Rounded hills here are underlain by fine-grained, semi-consolidated sands and silts. We are presently uncertain as to whether these are a fine-grained facies of the McKay Formation or a younger, eolian dominated unit. We suspect that they are a fine-grained facies of the McKay Formation made up of alluvial plain silts and paleosols that have been extensively modified by subsequent wind erosion.

26.0 The north-trending ridge visible in the foreground to the southwest is Service Buttes. Although access problems prevented our getting a close examination of the lava flow stratigraphy on the buttes, it appears they are cored by a north dipping sequence of upper Grande Ronde Basalt (Sentinel Bluffs member) flows. The buttes are flanked on both sides by down-faulted blocks made up of Frenchman Springs flows.

27.6 Turn left at Echo, onto Rieth Road, continue east on Rieth Road and proceed upstream, into the Umatilla River canyon. Frenchman Springs flows form the outcrops along both sides of the river. Geochemical analyses from city of Echo water well indicates that Frenchman Springs member here is more than 150 m thick and places the contact between the Frenchman Springs member and the underlying Sentinel Bluffs member at an elevation of about 150 ft above sea level. The Sentinel Bluffs member itself is more than 100 m thick.

The lower canyon of the Umatilla River at Echo was scoured by the Missoula floods in the Pleistocene. Glacial outburst floods flowed down the Columbia River and backed up the Umatilla River canyon a number of times in the past, forming Lake Condon. The largest flood would have covered the city of Echo with more than 80 m of water.

Stop 1: Missoula Flood Deposits

30.1 Missoula flood deposits (Figure 3) at Corral Springs: Many if not all of the terraces along the lower Umatilla River are heavily mantled by light colored silt and sand. Large granite and metamorphic boulders found at the top of mantling silt are ice-rafted glacial erratics that were left behind as Lake Condon drained. Here we will look for some of the glacial erratics on the hillsides above the old Oregon Trail campsite at Corral Springs. You might also wish to take time to look at some of the old Oregon Trail wagon ruts.

Stop 2: Frenchman Springs Basalt

32.6 Frenchman Springs Basalt: The thick flow exposed here is situated near the contact between two Frenchman Springs geochemical units. Distinction is based on subtle differences in minor elements such as phosphorus. Upper, more phosphorus-rich flows belong to the Sentinel Gap geochemical type while underlying flows belong to the Sand Hollow geochemical type. Frenchman Springs units are separated in the field on the basis of scattered, thumbnail sized, pale amber colored plagioclase phenocrysts in one of the uppermost Sand Hollow flows. Frenchman Springs flows in general are fine- to medium grained and crystalline; typically forming poor outcrops that readily weather to rounded hill slopes. Individual flows are typically thin and seldom reach 40 m in thickness. Where the flows are thickest, they form blocky outcrops with columns 0.25 m or more in width. Vesicular flow tops are common in places; rubbly basal flow breccias are less common. Interiors to the more poorly exposed Frenchman Springs flows weather to form granular soils and spheroidal core stones. This weathering pattern may be indicative of "water-affected" basalt (WAB) (Figure 4). Idea is that volcanic glasses and microcrystals are

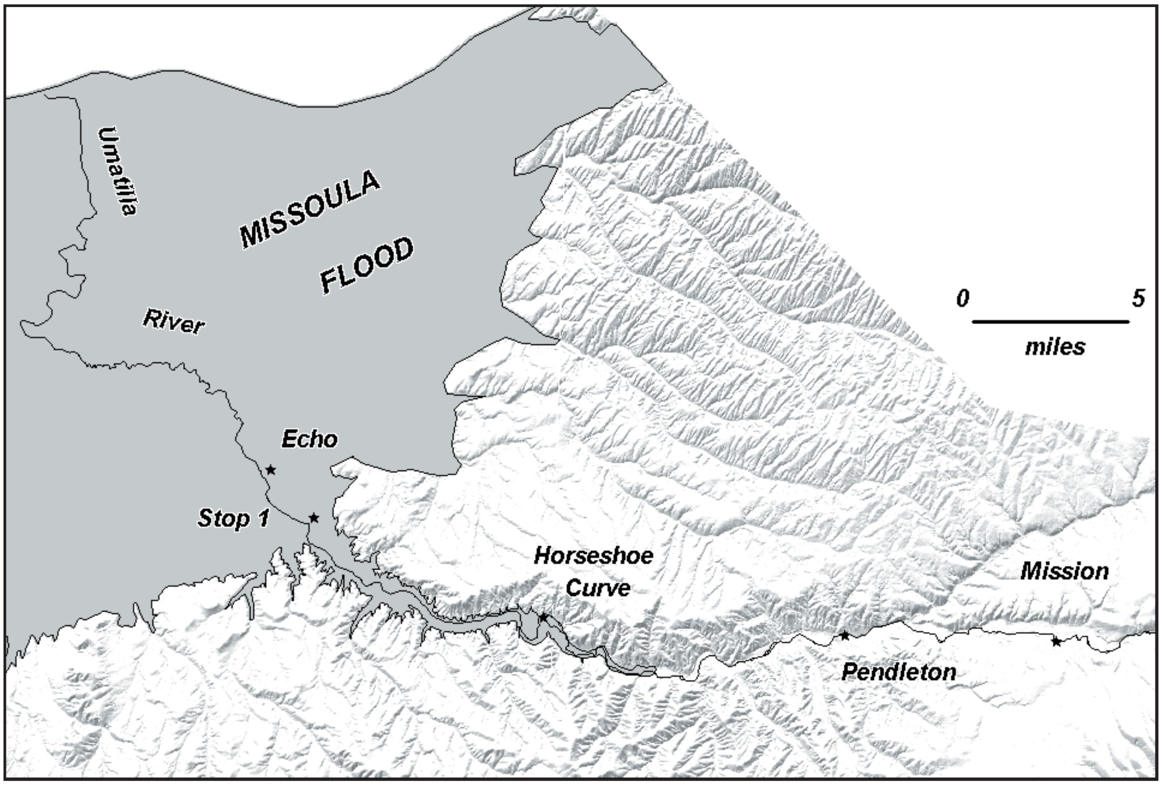


Figure 3. Shaded relief map showing extent of the Missoula flood.

Figure 4. Photograph of two Frenchman Springs member flows near Pendleton. Palagonitic breccia between the flows is evidence of interaction with water.

altered to clay as surface or ground water interacts with the cooling lava flow. Other evidence for water includes glassy rinds – which indicate rapid quenching, and yellow, palagonite breccias – which indicate fragmentation due to steam explosions.

Terraces along the river contain cemented gravels that contain exotic clasts such as vein quartz. In outcrop, the younger terrace gravels are indistinguishable from older McKay Formation gravels.

38.0 Rieth Road leaves the Umatilla River at Horseshoe Curve and crosses onto another terrace deposit. Floodplain deposits visible along the river on the east side of Horseshoe Curve are Holocene silts that were deposited in a small dam that once blocked the river here.

Stop 3: Sentinel Bluffs Member

39.7 Base of the Sentinel Bluffs member, the uppermost Grande Ronde Basalt unit in the Umatilla Basin (Figure 5). The Sentinel Bluffs flows are typically medium grained crystalline lavas that, unlike the Frenchman Springs, seldom contain phenocrysts. Although most Sentinel Bluff flows appear to be coarser grained than Frenchman Springs flows, appearances can be deceiving. Finer-grained flows are sufficiently similar enough in appearance to require geochemical analyses for positive identification (Figure 6). Titanium is an especially useful element for distinguishing Sentinel Bluffs flows (≤ 2.00 weight percent TiO_2) from Frenchman Springs flows (≥3.00 weight percent TiO_2). It should be noted that both the Frenchman Springs and Sentinel Bluffs members can be character-

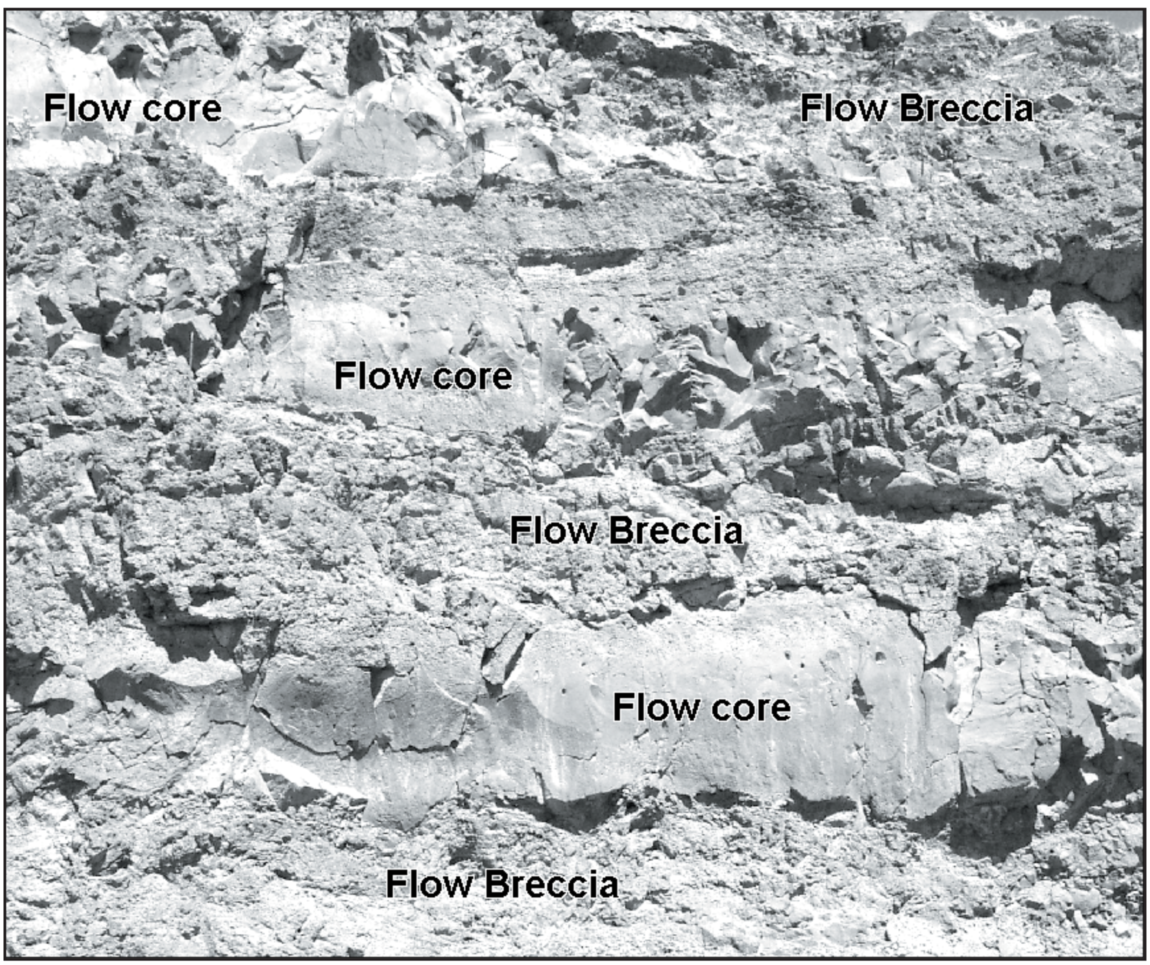


Figure 5. Sentinel Bluffs flow with multiple flow lobes and intraflow breccias.

ized as “high magnesium” flows, generally having more than 4.0 weight percent MgO. The comparatively high magnesium levels is related to presence of microscopic olivine crystals that typically occur in what are euphemistically termed “more primitive” magmas. Although the last of the Grande Ronde Basalt flows to erupt, Sentinel Bluffs flows are one of the most primitive of the Grande Ronde Basalt units. This is atypical of the formation that in general becomes more silica-rich (evolves) over time. Weathered surfaces of the coarsest grained flows have a “salt-and-pepper” appearance due to randomly-oriented, white-weathering feldspar crystals.

Like the Frenchman Springs flows, individual Sentinel Bluffs flows are generally thin, seldom exceeding 30 m in thickness. Individual flow boundaries may be marked by rubbly flow breccias. Thicker flows tend to form blocky outcrops cut by widely spaced vertical joints and marked by subhorizontal partings that together form blocky “biscuits”. Some Sentinel Bluffs flows exhibit WAB textures.

40.0 The top of the Winter Water member begins to appear beneath the Sentinel Bluffs member along this stretch of the Umatilla River. The Winter Water member forms distinctive, hackly jointed outcrops throughout the map area and is made up of individual lava flows are as much as 80 m thick (Figure 7). In contrast to the overlying Sentinel Bluffs flows, Winter Water flows display closely spaced joints, narrow columns (< 10 cm) and thick outcrops (Figure 8). Natural Winter Water outcrops tend to weather to form steep bluffs mantled by fist-sized, angular blocks. Note the westward dips that mark the west limb of the Rieth Anticline.

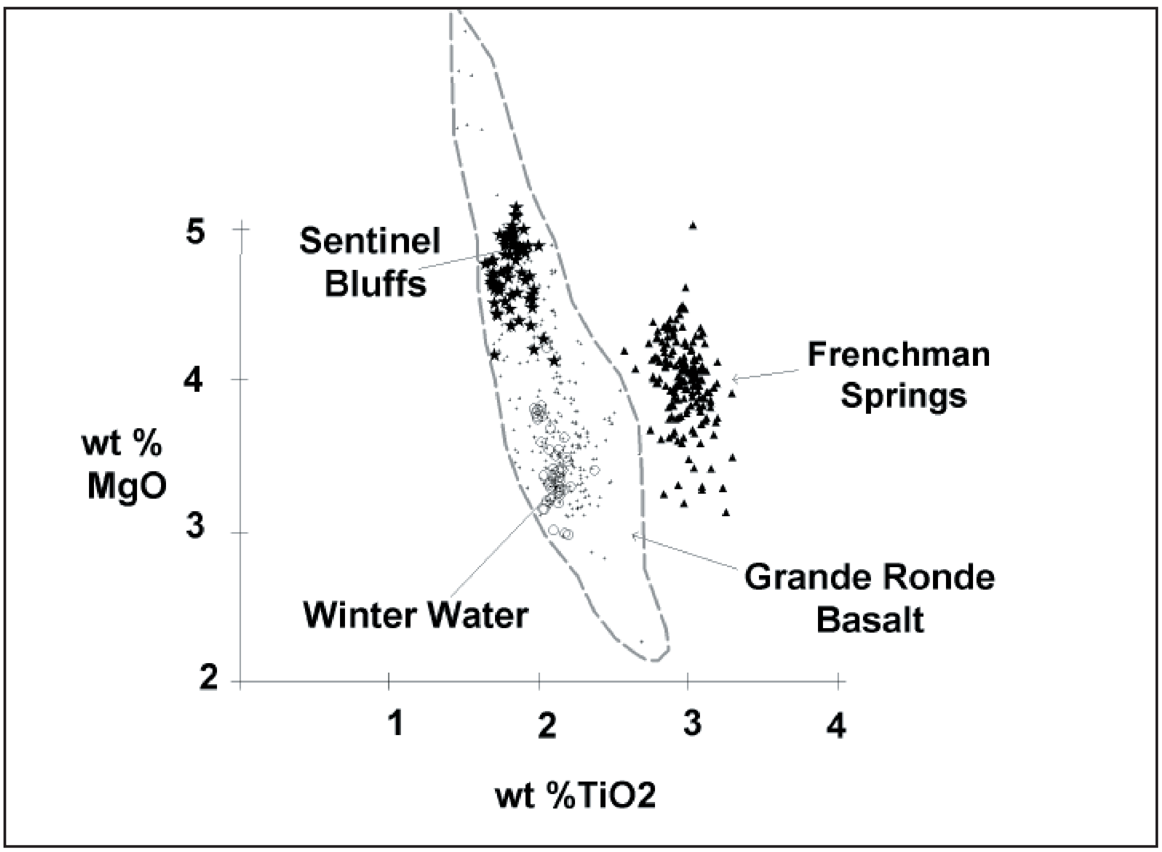


Figure 6. Geochemical diagram of samples from the Umatilla Basin. Note that Winter Water and Sentinel Bluffs cannot be identified solely through geochemical analyses.

Figure 7. Breccia zone at the top of the Winter Water member. Breccia is made up of scoria and bombs and is intruded by a tongue of massive lava. Note geologist at base of outcrop for scale.

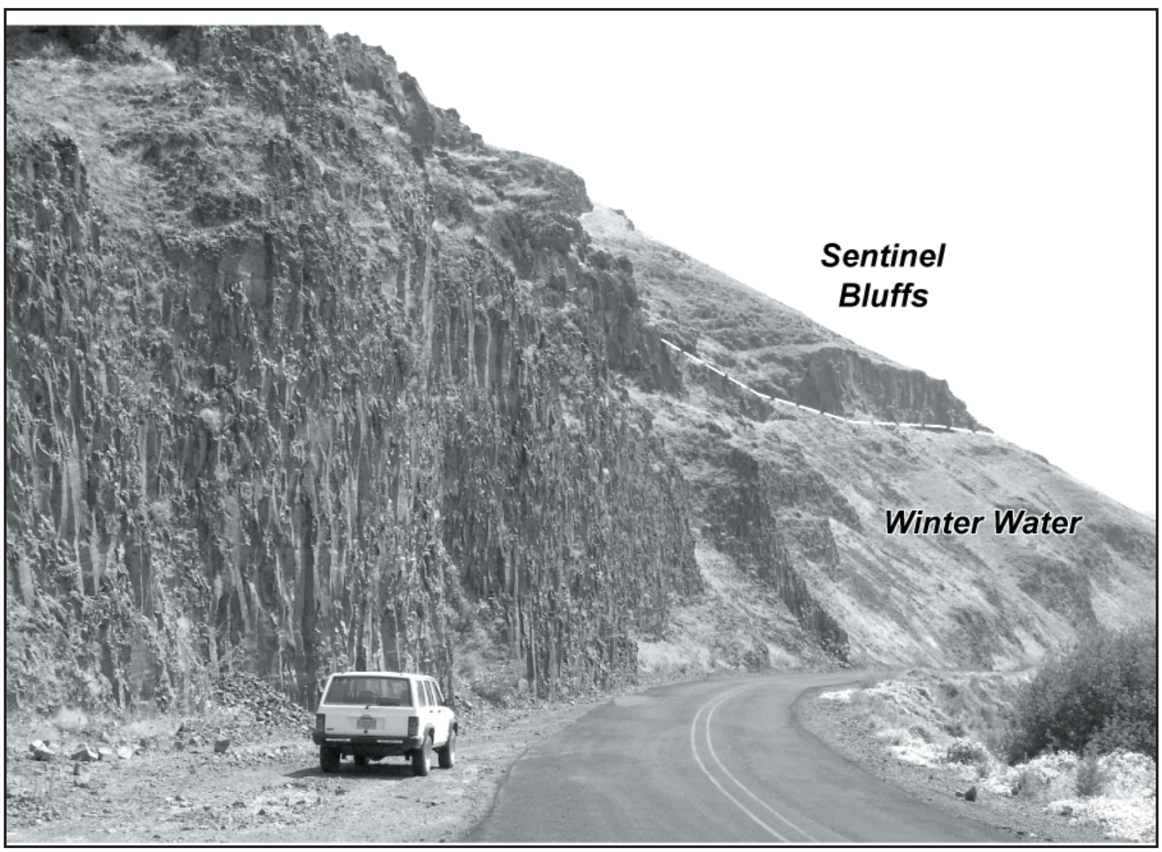


Figure 8. Typical road cut exposure of Winter Water. Note how the Winter Water displays narrow columnar jointing while the overlying Sentinel Bluffs tends to form thicker, more massive columns.

40.5 Railroad tunnel on south side of river goes under another terrace. Glacial erratics on the lower part of this terrace mark the 900 ft elevation high stand of the Missoula Flood on the Umatilla River. In this area glacial erratics often occur as large granite or greenstone boulders. Local lore has it that many of the distinctive boulders were used for gravestones.

41.0 Rieth Road crosses another terrace gravel. Note bench and bluff topography along river to south. In comparison to other geologic features, contacts between successive CRBG unit packages are imprecisely located. It is difficult to determine just where the upper vesiculated flow breccia of the uppermost Winter Water flow ends and the basal flow breccia of the overlying Sentinel Bluffs flow begin. Since the interior of the uppermost Winter Water member is comparatively resistant to erosion and tends to form bluffs, we consider the break in slope in the benches above the bluffs to mark the contact between the Winter Water and Sentinel Bluffs members. Where the Vantage Horizon is missing, the contact between the Sentinel Bluffs member and the Frenchman Springs Basalt can be located only with difficulty, as both units weather to form similar topography.

42.0 A high magnesium (> 5 weight percent MgO) flow is exposed beneath the Winter Water member along the south side of the Umatilla River here at the core of the Rieth Anticline. Elevation of the contact (a.k.a., Vantage Horizon) between the Sentinel Bluffs member and Frenchman Springs Basalt is at about 1,300 ft elevation on the north side of the river. Point to consider. The City of Echo, City of Pendleton, and CTUIR 3, 4, and 5 wells had to penetrate the Winter Water member before reaching production zones. It has been suggested that core of the Rieth Anticline is the recharge area for City of Pendleton well.

44.9 Winter Water flows have much finer textures and sometimes appear glassy in hand samples. Narrow columnar joints are readily apparent in quarry and road cut exposures. The Winter Water is a preferred aggregate source because the closely spaced jointing produces small sized material that requires less crushing.

Flow tops are in place marked by thick, scoraceous breccias. The flow top breccia here contains blocks and volcanic bombs and is invaded by a dike-like tongue of massive lava. Bombs and scoria are usually associated with vent complexes and considered to be evidence for being at or near the point from where the lava flow erupted. At this local, a dike-like feature of massive lava intrudes the red breccia at the top of the quarry wall. Possible explanations: 1) The Winter Water vent was located near here. 2) The Winter Water vent was located somewhere to the east with the breccias being part of the original vent complex that has been rafted away from the vent and transported atop a flood-like flow. 3) The scoria and bombs are part of a littoral cone resulting from steam eruptions along the face of the flow as it entered water, many miles from where it originally erupted.

Stop 4: Winter Water Flow

Road cut here offers a good look at the interior of a typical Winter Water flow. Note the thin, undulating columns. Chemical differences between the Winter Water and Sentinel Bluffs members is much more subtle than the differences between the Sentinel Bluffs and Frenchman Springs members. Winter Water flows are more "evolved", containing mor silica, potassium, and phosphorus than Sentinel Bluffs flows. Magnesium and titanium show the most notable differences; with Winter Water flows containing < 4.0 weight percent MgO and > 2.0 weight percent TiO_2 and Sentinel Bluffs flows containing > 4.2 weight percent MgO and < 2.0 weight percent TiO_2.generally more titanium (>

2.0 weight percent TiO_2) than do the overlying Sentinel Bluff flows.

45.6 East limb of the Rieth Anticline is defined by the descending Sentinel Bluff – Winter Water contact.

47.0 Proceed on Rieth Road through the town of Rieth, continuing toward Pendleton.

47.6 Note red breccia below Sentinel Bluffs flow in road cut. This is an example of a red zone that does not correlate with the Vantage Horizon. Basal flow breccia apparently developed as the Sentinel Bluff flow interacted with water. Pillow features have been identified at the base of Sentinel Bluff flows near here.

48.6 Cross under Interstate I-84, following Rieth Road (U.S. Highway 30) toward Pendleton. Here we are near the Vantage Horizon, which marks the contact between the Frenchman Springs and Sentinel Bluffs members.

Stop 5: Vantage Horizon

48.8 In most places in the Umatilla Basin, the Vantage Horizon (Figure 9), when present, is less than 0.5 m thick and marked by red-weathering, possibly saprolitic soils that may contain root and other organic material. The Vantage Horizon apparently formed over a period of time of not more than 200,000 years, during the hiatus between the last Sentinel Bluffs eruption and the first eruption of the Frenchman Springs Basalt.

Turn right on U.S. Highway 30 (Westgate) and proceed west toward Interstate I-84.

49.0 Turn left onto Interstate I-84 and proceed east toward Tamastslikt.

55.6 Turn left onto Market Road and proceed north, past the Wildhorse Casino to the assembly area at the Tamastslikt Cultural Institute.

57.4 **End of first leg of field trip.**

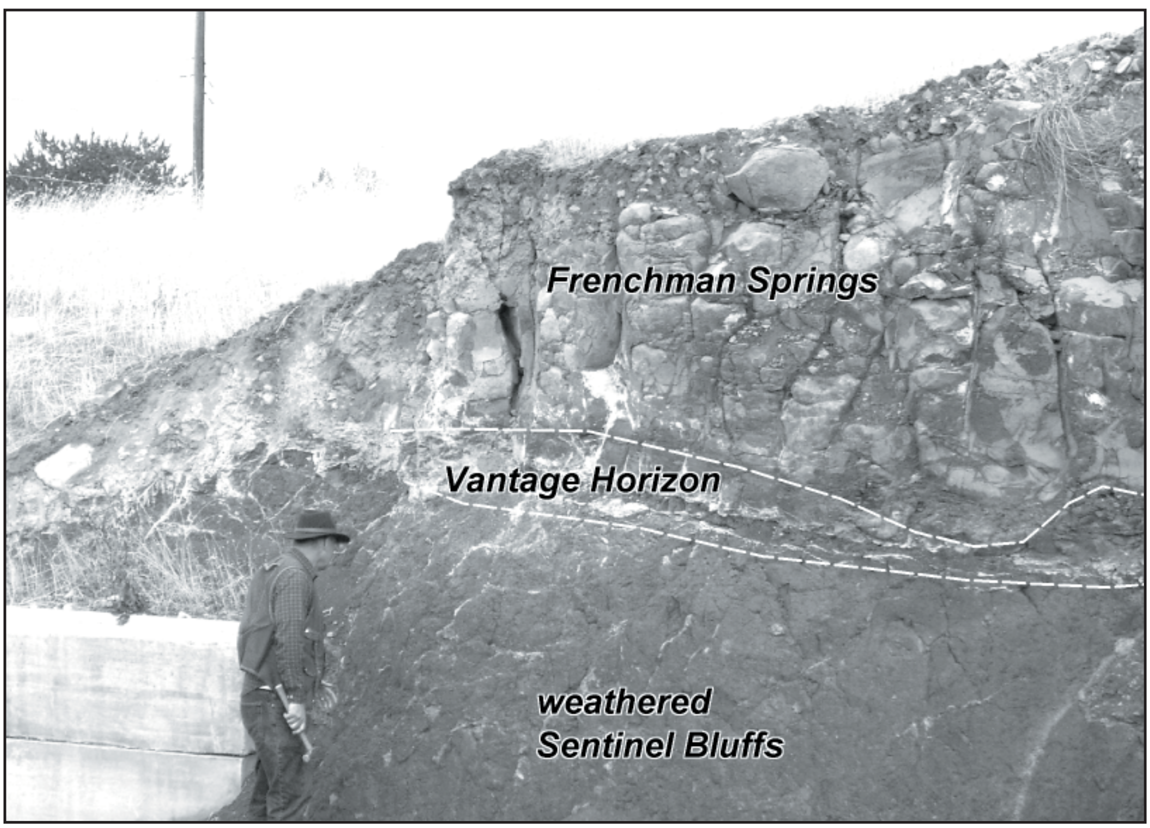


Figure 9. Excavation exposure of Vantage Horizon at Pendleton. Here a clay-rich soil zone has developed at the top of a heavily weathered Sentinel Bluffs flow.

UMATILLA BASIN FIELD TRIP

DAY 2

Day 2's field trip also begins at the Tamastslikt Cultural Institute (Figure 10). The first part of the trip will focus on tilting, folding, and faulting in the Blue Mountain Uplift, the major recharge area for the Umatilla River Basin. Regional structures are interpreted by determining the position of the Wanapum – Grande Ronde Basalt contact and the distribution of the Frenchman Springs, Sentinel Bluffs, and Winter Water members. The latter part of the trip will continue into the Uplift for a look at pre-Columbia River Basalt "basement" rocks.

Structure Overview

The Umatilla Basin presents somewhat of a descriptive challenge. At first glance, the Umatilla Basin appears to be defined by two fault-bounded blocks that are clearly separated from one another (Figure 11). The eastern upland block is a deeply dissected, highlands that forms part of what is commonly referred to as the Blue Mountain Uplift. The upland block is marked by east-west trending fold axis and is cut by northeast- and northwest-trending faults. The Umatilla River and many of its major tributaries, including East Birch Creek and McKay Creek begin in the upland block.

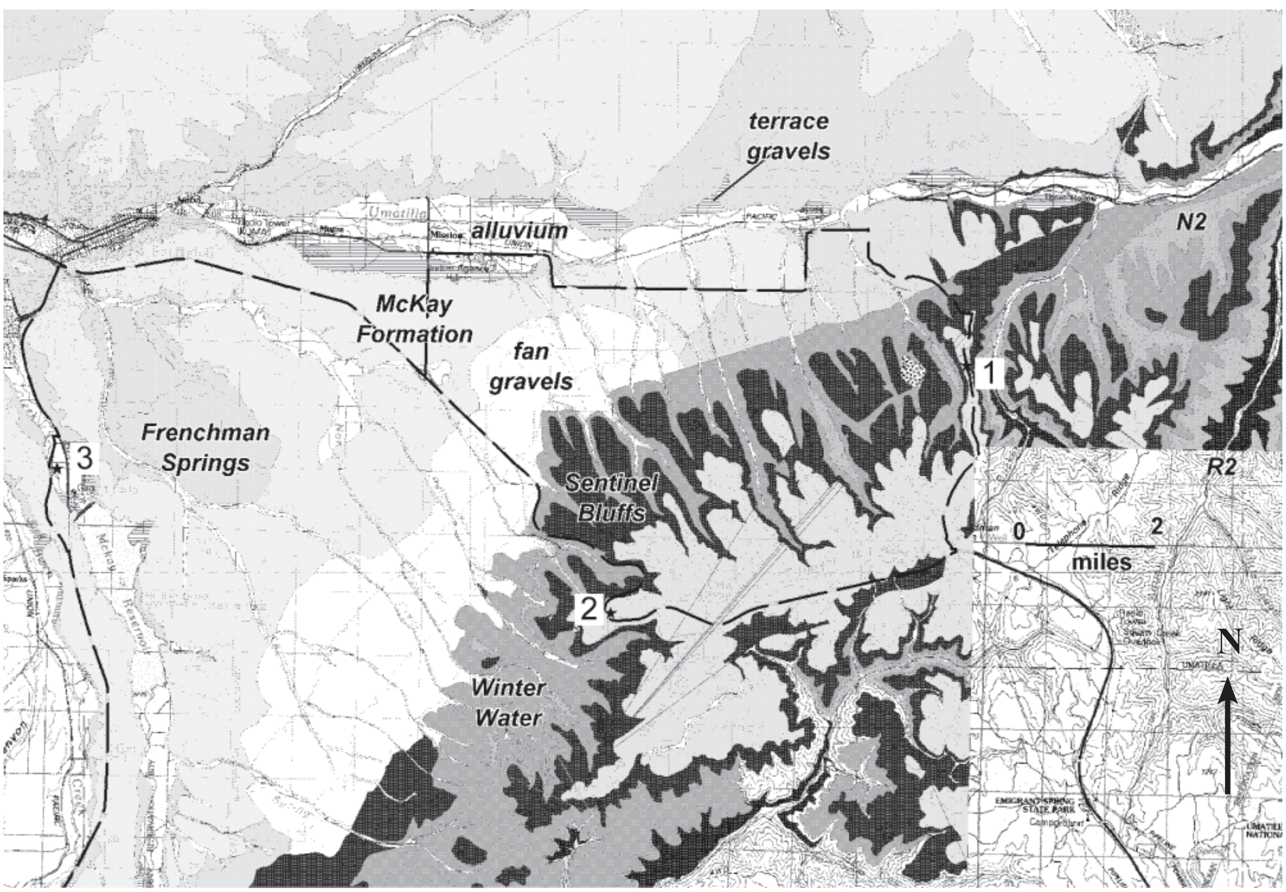


Figure 10. Simplified Geologic Map of the Day 2 the field trip.

The western lowland block is a broad “depression” that flanks the northern and western margins to the Blue Mountain Uplift. The lowland block is a depression only in the sense that the central part of the block is a somewhat sediment-filled, topographic low that is flanked on all sides by bedrock cored uplands. Western part of the lowland block is marked by the northeast trending, north plunging Rieth anticline. The Rieth Anticline is one of a series of poorly defined folds that mark the transition from the lowland block into the larger Columbia Basin.

In plan view, the eastern uplands block is a rhombohedron whose complex northwest corner is marked by the intersection of two major fault zones, the northeast-trending Wilahatya (Weel-a-hut-tee-ya) fault zone and the north-trending Hawtmi (How’t-mee) fault zone. These two fault zones form a clear boundary between the eastern uplands and western lowlands. The Wilahatya fault zone juxtaposes north-northwest dipping Grande Ronde Basalt flows (Winter Water and Sentinel Bluffs) in the upland block against more gently west-northwest dipping Frenchman Springs flows in the lowland block. The Grande Ronde Basalt flows form the north limb of an east-west trending, west-plunging anticline.

Water well logs indicate that the west end of the Wilahatya fault zone is truncated by the north-trending Hawtmi fault zone. Western lowlands water well logs show a marked increase in the depth of sediments from east to west, across the projected trend of the Hawtmi fault zone. The Hawtmi fault zone is marked by en echelon, down-to the west faults that bring the Winter Water member and underlying Grande Ronde Basalt flows into contact with Sentinel Bluffs and Frenchman Springs flows. Amount of displacement decreases to the south, where the Hawtmi fault zone swings sharply to the west to where the fault zone merges with the of east-west trending faults and anticlinal folds that mark the crest of the Blue Mountain Uplift. Here the boundary between the western lowlands block and the eastern uplands block is obscure and is best described as the north-dipping limb of a broad anticlinal fold.

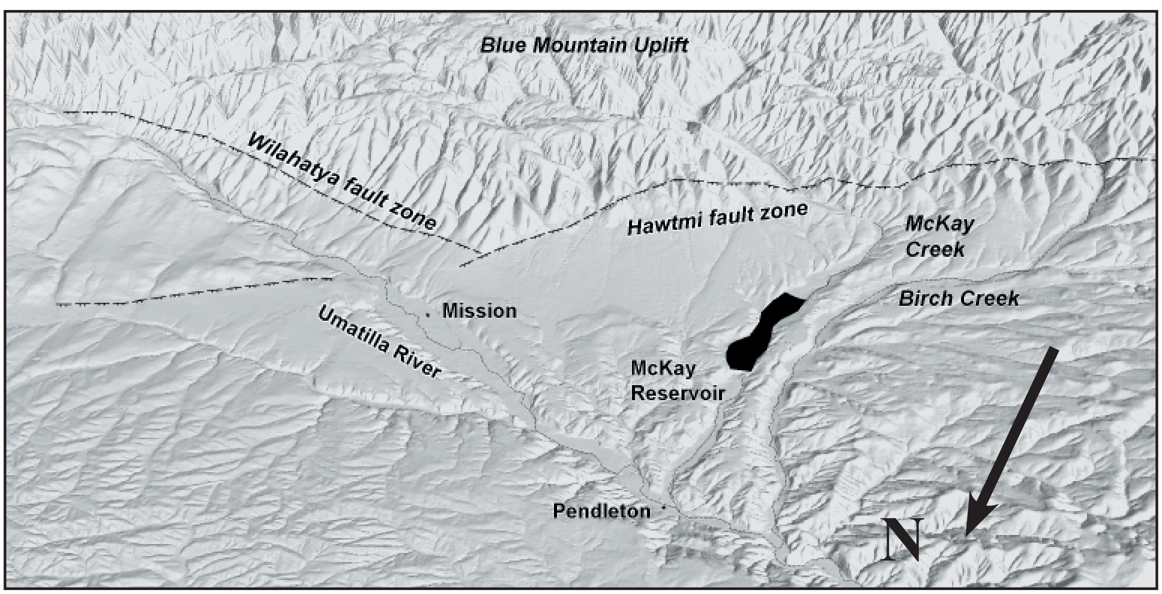


Figure 11. Shaded relief diagram showing upland and lowland blocks. Viewers perspective is looking down and to the southeast.

ROADLOG (LEG 2 AND 3)

Day 2 Field Trip Guide

Miles (Mile Post)

0.0 Turn right (north) on Market Road and proceed north to Mission Highway (U.S. Highway 30). Fluvial gravels of the late Miocene McKay Formation are intermittently exposed along the sides of Market Road. Water well logs indicate that the McKay Formation is locally more than 50 m thick.

0.5 Market Road drops down onto a terrace on the south flank of the Umatilla River. The terrace is made up of weakly cemented gravel deposits and overlain by loess and silt. Market Road continues north onto the floodplain of the Umatilla River. Here the Umatilla River floodplain is underlain at very shallow depths by lava flows belonging to the upper part of the Frenchman Springs member. Flow tops are exposed in the river bed over a 3 km long reach, centered on the Market Road bridge.

0.7 Turn right onto U.S. Highway 30 and proceed east, into Mission. Mission is home to the tribal headquarters for the Confederated Tribes of the Umatilla Indian Reservation.

1.9 Continue on U.S. Highway 30 through Mission and turn left onto Cayuse Road. McKay Formation gravels overlie Frenchman Springs Basalt at the intersection.

2.2 Continue east on Cayuse Road. Note north dip of Grande Ronde Basalt flows exposed along the deep canyons that emerge from the Blue Mountains Uplift to the southeast (right). Upper, rounded hill forms are underlain by more easily eroded Sentinel Bluffs flows. The more resistant Winter Water unit forms stone striped fingers.

4.5 More canyons come into view along the face of the Blue Mountains Uplift to the right. A major fault zone separates the incised highlands – largely made up of N2 MSU Grande Ronde Basalt flows – from the lowlands through which the Umatilla River flows.

6.7 Cayuse Road makes a sharp turn to the left (north), heading toward the Umatilla River. Over 70 m of overlying Frenchman Springs Basalt flows are exposed along the Umatilla River canyon.

7.7 Cayuse Road makes a sharp turn back to the right (east). Frenchman Springs flows are exposed along the side of the road.

8.7 Spheroidal weathered outcrops of Frenchman Springs Basalt exposed on both sides of Cayuse Road.

8.8 Turn right at corner onto Kanine (Kaa-nigh-nee) Ridge Road. Road is gravel and unimproved. The road will cross the bounding Wilahatya fault zone and ascend onto the north flank of the Blue Mountain Uplift. Road crosses onto Frenchman Springs Basalt at Mile Post 9.7.

10.4 Bear left at intersection and cross the Wilahatya fault zone which here juxtaposes Frenchman Springs Basalt against Winter Water. Although no fault surfaces are exposed along the zone, a series of springs and topographic slope breaks form a linear zone that separates the Winter Water from the Frenchman Springs. We cannot determine which way the fault plane dips, this may be a high angle reverse fault.

10.6 Kanine Ridge Road crosses the Wilahatya fault zone fault zone onto the Winter Water unit. Road is somewhat rough.

10.7 Road steepens and climbs up onto overlying Sentinel Bluffs unit. These are relatively thin, crystalline (sugary textured) lavas that lack visible phenocrysts. Coarser grained flows have weathered surfaces that display an interlocking network of white plagioclase feldspar crystals.

11.4 Kanine Ridge Road crosses onto overlying Frenchman Springs Basalt unit. Contact in places is marked by a thin soil zone (Vantage Horizon) that is manifested by springs and seeps.

Stop 1: Buckaroo Canyon Overlook (Figure 12)

12.1 Park along road and walk east, to where we can look down into Buckaroo Creek. Top of the R2 MSU Grande Ronde Basalt unit is exposed at the base of the canyon wall along the upstream reach of Buckaroo Creek. Here N2 MSU Grande Ronde Basalt flows separate R2 from the overlying, hackly jointed Winter Water flow. The Grande Ronde section here has a north dip steeper than the stream gradient of Buckaroo Creek; which flows northward onto successively younger Grande Ronde Basalt units.

13.1 Kanine Ridge Road continues to climb atop Frenchman Springs flows as it proceeds south. Note the small displacement along the fault that cuts the Sentinel Bluff – Winter Water flows on the west side of Coonskin Canyon to the right (west). Fault trend is north- to northwest. Although the Kanine Ridge Road stays on Frenchman Springs flows and gains more than 500 ft in elevation between here and the summit, the Frenchman Springs Basalt is no more than 70 m thick. Kanine Ridge Road is actually climbing the north flank of an anticline.

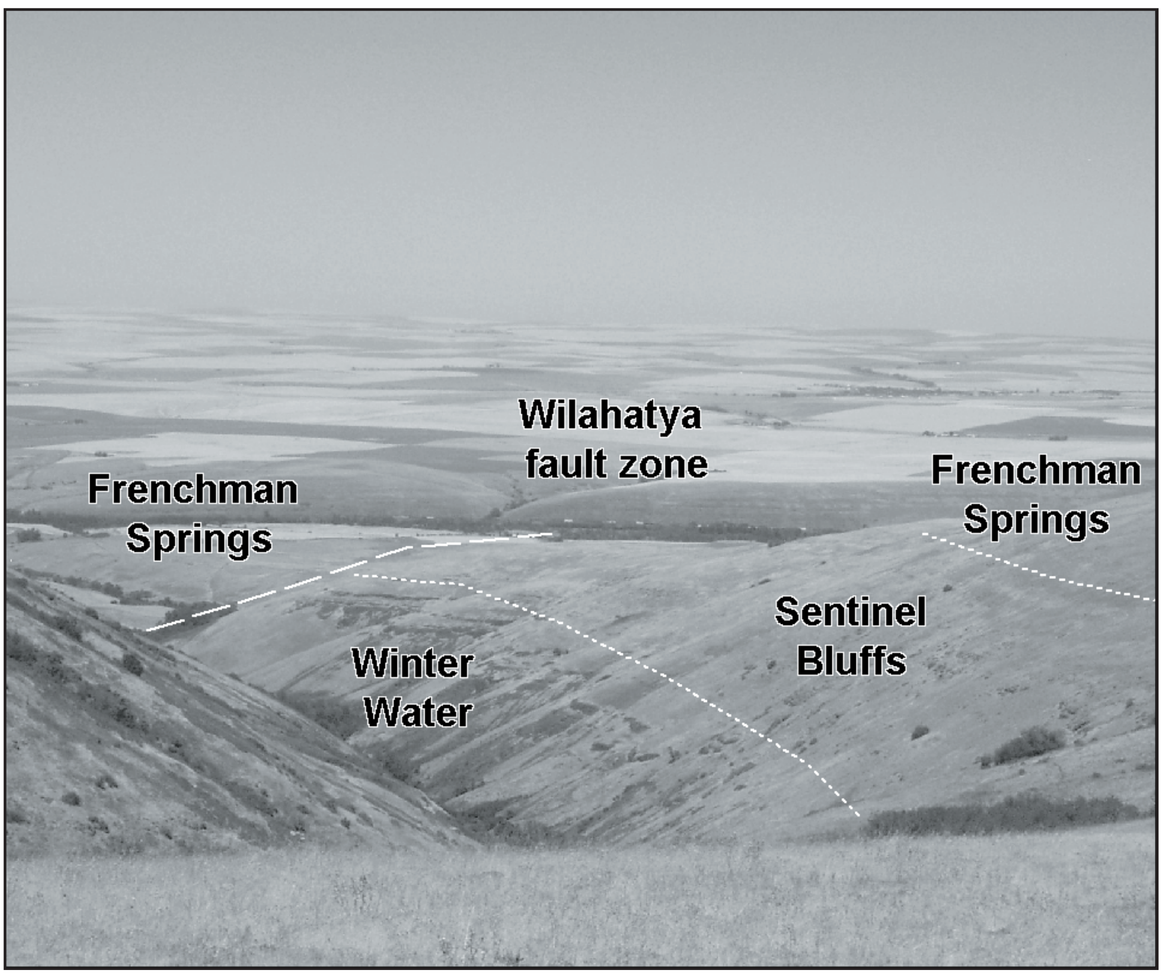


Figure 12. Vista looking northwest, toward the Umatilla River from Stop 1.

13.9 True thickness of the Frenchman Springs and underlying units was determined by a reference geochemical traverse that was collected between here and Buckaroo Creek.

14.3 The road reaches the crest of the anticline at the summit of Kanine Ridge, where the capping Frenchman Springs flows form a flat lying surface.

15.1 Kanine Ridge Road descends off of Frenchman Springs flows onto underlying Sentinel Bluffs flows. The contact is often marked by springs.

15.5 Turn left at the stop sign, then left into the Interstate I-84 rest area. We will stop here and take advantage of the facilities. Field trip participants are encouraged to use the restroom here and not wait until our lunch stop.

15.8 Turn right onto Interstate I-84 and proceed along the Interstate toward Pendleton. Traffic hazards prevent stopping at enticing outcrops. Drivers are encouraged to be careful and watch truck traffic. Freeway exposures of Sentinel Bluffs flows from mile post 15.8 to 17.0.

17.0 Fault that is exposed on near side of road cut to right brings the Frenchman Springs down to road level. Prominent red zone at contact is the Vantage Horizon. Note the thick blocky columns in the basal Frenchman Spring flow.

18.0 As Interstate I-84 descends, it “climbs” onto Frenchman Springs flows that here make up the top of the Columbia River Basalt Group. Interstate I-84 follows a west plunging, east-west trending anticline that here marks the top of the Blue Mountain Uplift.

Figure 13. Spheroidal weathering Frenchman Springs flow on Interstate I-84.

19.0 Flat bench to the left (south) is Poverty Flat, a down-dropped block capped by Frenchman Springs flows. Through this region, the Blue Mountain Uplift is marked by wide, deep canyons that have been cut into, and in some place through, a thick stack of nearly flat-lying Columbia River Basalt flows.

20.0 McKay Reservoir, Pendleton, and the middle reach of the Umatilla River come into view to the west. Frenchman Springs Basalt flows are exposed along the freeway here.

21.0 Spheroidal weathering zone at top of Frenchman Springs flow to right (Figure 13). Note widely-spaced blocky jointing pattern that appears to be typical of thin basalt flows in both the Frenchman Springs and Sentinel Bluffs.

STOP 2: Blue Mountain Uplift Overlook

21.3 Turn off of Interstate I-84 at scenic viewpoint. Proceed to parking lot. From here we can see a stacked sequence of northwest-dipping Columbia River Basalt flows. To the northwest, Interstate I-84, drops down off the uplift through Frenchman Springs, Sentinel Bluffs and Winter Water flows. Note the subtle differences in geomorphology formed by the different units and see if you can pick out the Sentinel Bluff – Winter Water contact.

Also note the geomorphology to the south. A thicker, and more resistant Sentinel Bluff flow forms Table Rock in the middle ground. Table Rock lies along the crest of an east-west trending anticline. The prominent break in the slope below Table Rock marks the Sentinel Bluff – Winter Water contact at 3,400 ft elevation. The same contact is exposed in Red Hawk Canyon, the canyon nearest to Interstate I-84, at 2,800 ft elevation. Same contact on Interstate I-84 to the north is at 2,400 ft elevation.

The Winter Water unit thickens rapidly to the south, where it is made up of 4 individual flows that form a stack more than 180 m thick. As presently mapped, our southern Winter Water unit very likely includes flows mapped elsewhere as Umtanum or Ortley. In places, a thin high MgO flow crops out at the base of the upper Winter Water flow.

22.0 Return to the Interstate I-84 and continue west toward Pendleton.

22.4 Springs mark the contact between Frenchman Springs and Sentinel Bluff. Here the Frenchman Springs readily weathers back to form subdued landforms. Contact is marked by a thin, organic-rich soil zone (Vantage Horizon).

22.8 Truck escape. Stacked Sentinel Bluff flows are exposed on both sides of Interstate I-84. These artificial exposures provide a good look at the morphology of a typical Sentinel Bluffs flow. Note the prominent vesicular flow tops and characteristic thick, blocky jointing pattern in the interiors of the flows.

23.1 Chaotic, red-weathering, scoracious flow breccia at the top of the Winter Water unit is exposed in road cuts along the interstate. The Winter Water flow top apparently formed an uneven surface onto which the Sentinel Bluffs lavas flowed. The basal Sentinel Bluffs flow appears to thicken, forming more resistant outcrops, where it covered the low points in the Winter Water suface.

23.7 Thicker Sentinel Bluffs flow immediately overlying Winter Water.

24.2 Interstate I-84 drops down into the Winter Water unit. Note typical thin, undulating columns in road cut (Figure 14). Also note the rounded, stone-striped “fingers” formed by the Winter Water to the north.

Figure 14. Interstate I-84 exposure of columnar jointed Winter Water flow.

24.8 Interstate I-84 crosses the Hawtmi fault zone onto a dissected alluvial fan.

27.5 Continue west on Interstate I-84 toward Pendleton. The Interstate leaves the fan surface and crosses onto McKay Formation gravels. Considerable uncertainty exists regarding the relationship (if any) between the McKay Formation and the fans along the front of the Blue Mountain Uplift.

One school of thought considers the McKay Formation to be fan gravels that record late Miocene uplift. A second hypothesis considers the McKay Formation to be fluvial deposits that record lava flow-induced disruption of stream drainages in the late Miocene. Regardless of whichever hypothesis is more correct, the Hawtmi fault zone appears to be relatively old/quiescent, displaying no evidence of Quaternary offset.

One additional point to puzzle over. A considerable amount of material has to have been removed by erosion in order to form the deep canyons cut into the Blue Mountain Uplift. Where did that material go?

29.7 Continue west on Interstate I-84 past exit 213. Note Frenchman Springs flows exposed along the Umatilla River to the northeast. Roadcuts in the foreground are McKay Formation gravels.

34.1 Leave Interstate I-84 at exit 209; proceeding right (south) onto U.S. Highway 395, toward Pilot Rock and John Day. Frenchman Springs, Vantage Horizon, and Sentinel Bluffs units are exposed along river to the east and west.

34.7 Remain in left lane and continue south on U.S. Highway 395. Frenchman Springs Basalt flows intermittently exposed in roadcuts and hill sides to left (east).

34.7 Get in left lane and continue south on U.S. Highway 395. Frenchman Springs Basalt flows intermittently exposed in roadcuts and hill sides to left (east).

37.5 Frenchman Springs rests on Sentinel Bluffs to left. Note reddish color to flow top. Vantage Horizon is not readily apparent here. U.S. Highway 395 is following along the floodplain to McKay Creek. McKay Reservoir comes into view to the south. Frenchman Springs – McKay Formation contact is considerably higher on the east side of the dam than the west side of the dam. Funny how faults tend to follow dams around.

38.2 U.S. Highway 395 crosses McKay Creek onto McKay Formation gravels, well exposed on both sides of the highway.

38.8 Turn right onto Coombs Canyon Road, then turn again onto Schroeder Road and proceed north.

Stop 3

40.0 McKay Formation: Park at wide spot at base of road and proceed back up along road to look at McKay Formation gravels (Figure 15). Here they are predominantly medium gravels with well define channels. Note sedimentary rip-ups, volcanic composition of clasts, and tuffaceous interbeds. A number of late Miocene mammal fossils have been recovered from this unit. Return to U.S. Highway 395 via Schroeder Road to begin the 3rd leg of the field trip.

The 2nd leg of the Umatilla River Basin field trip ends at this point. After this stop, we will proceed south on the 3rd leg (Figure 16).

41.2 Turn right onto U.S. Highway 395 and proceed south toward Pilot Rock.

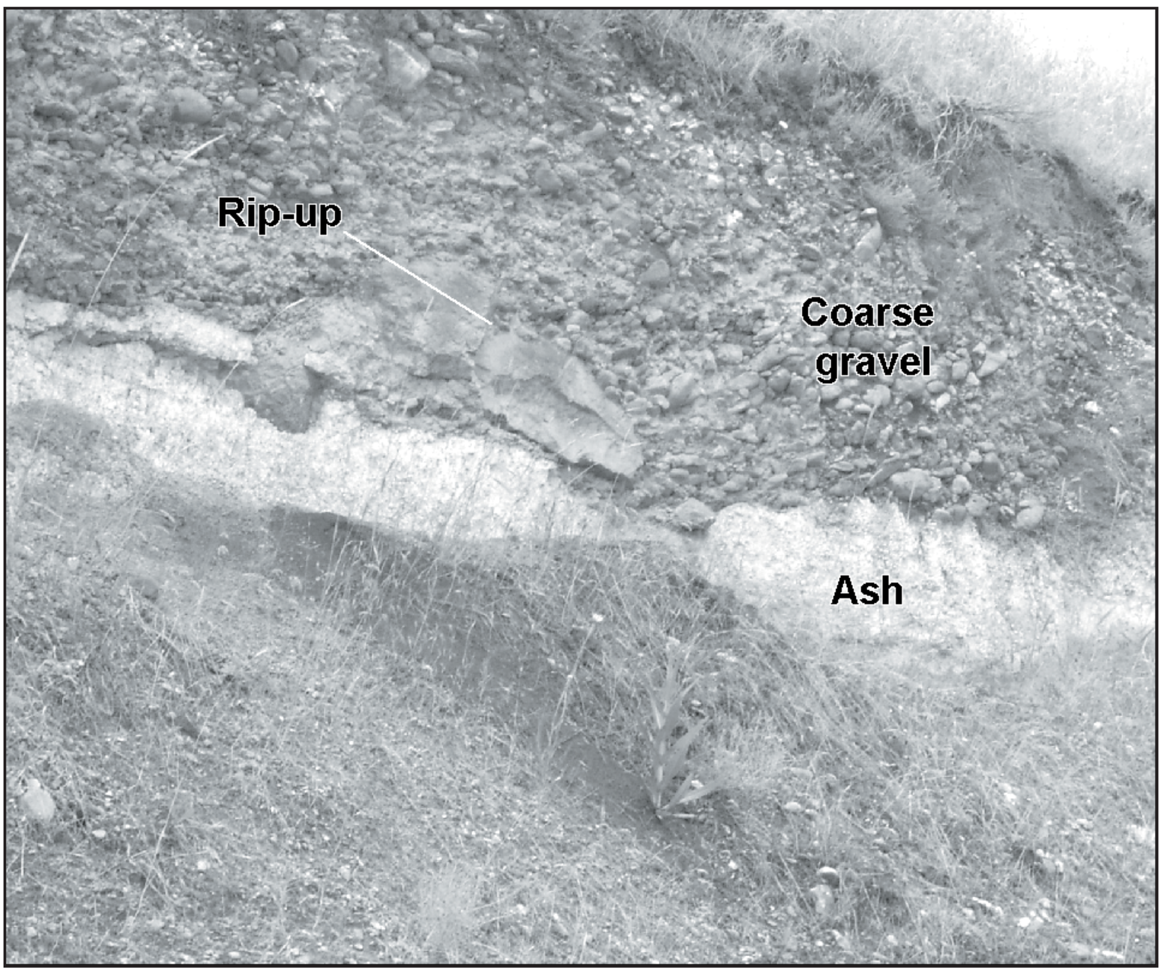


Figure 15. Coarse McKay Formation – fluvial gravels with ash interbeds.

42.5 Blue Mountain Uplift to left. Hawtmi fault zone separates the north dipping flows in the uplift from west dipping flows in the foothills.

44.5 Frenchman Springs flows and overlying McKay Formation gravels are exposed along U.S. Highway 395 between here and Pilot Rock. Terrace gravels are preserved in places on elevated benches along McKay Creek.

48.4 The small bluff forming the west bank of McKay Creek is Pilot Rock. Capping flow is Frenchman Springs Basalt, underlying flows are Sentinel Bluffs.

LUNCH STOP

50.0 Turn left into the Pilot Rock city park for bathroom break. We can have lunch here at the park or at the next stop. The park has grass and shade, but no view. The next stop has a view but no shade or grass. Note, this is about as far south as any of the Frenchman Springs flows have been identified.

Turn left onto U.S. Highway 395 and proceed south toward John Day. The latter part of the field trip will focus on the basement rocks of the southern Umatilla Basin.

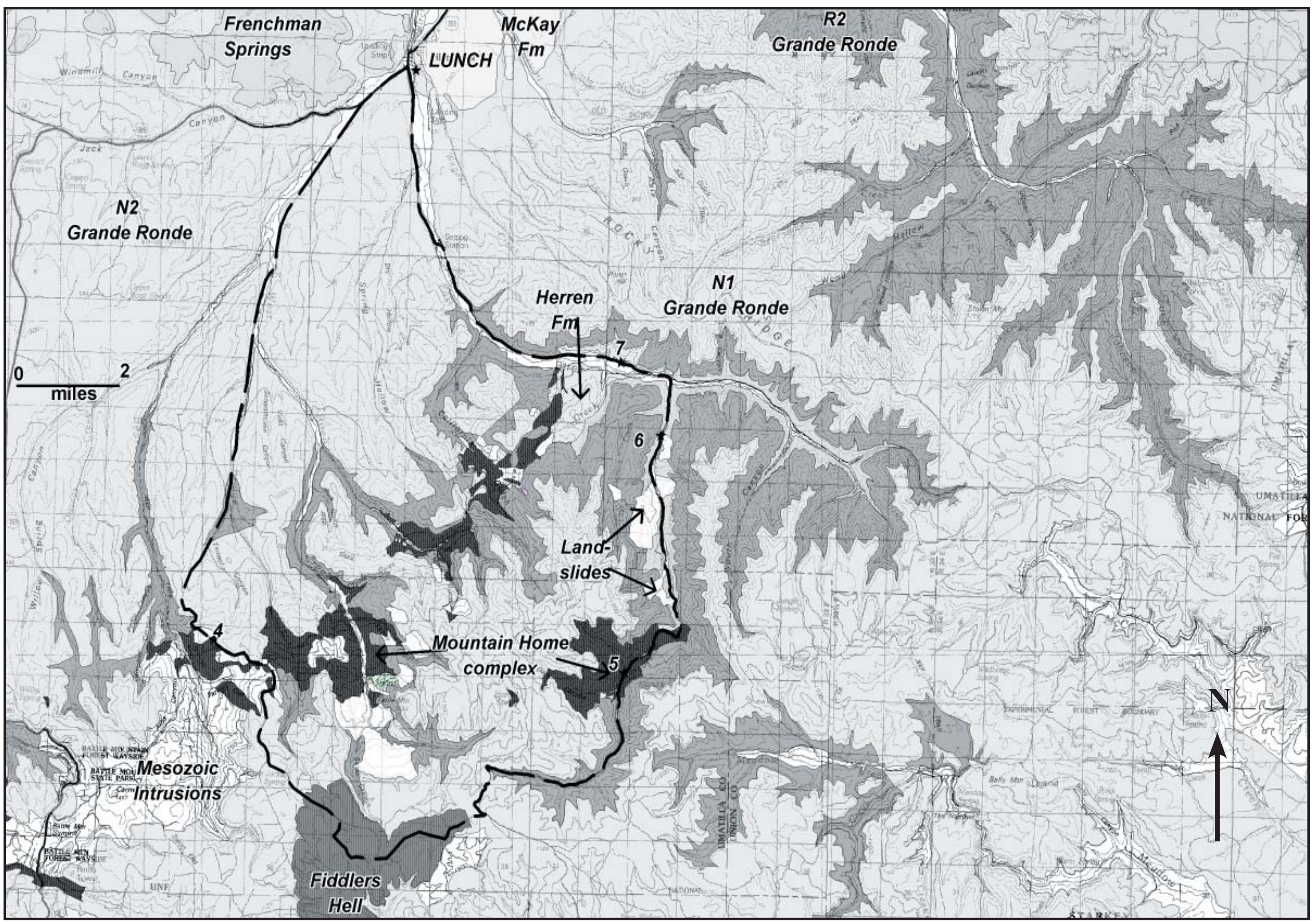


Figure 16. Leg 3 Field Trip Map.

ROADLOG (CONTINUED)

Basement Overview

Columbia River Basalt Group lavas flowed out over an irregular surface of older stratum that, in groundwater studies, is considered as basement to CRBG aquifers. The wide variety of metamorphic, igneous, and sedimentary rocks exposed at different elevations along the Blue Mountains Uplift provide some clues as to how the basement was formed. They also provide some clues as to how much topographic relief was present when the Columbia River Basalt Group lavas erupted.

Oldest basement rocks form the Mountain Home metamorphic complex (MHMC). The MHMC contains garnet- and staurolite-bearing schists as well as amphibolites that are among the "best" metamorphic rocks in eastern Oregon. The MHMC has been intruded by coarse grained plutonic rocks – including gabbro, diorite, and granite. Similar plutonic rocks exposed elsewhere in the Blue Mountains were emplaced over a period of time between 160 and 120 million years ago. Crude pressure estimates based on metamorphic mineralogy indicate that the MHMC formed at depths of as much as 15 km.

Which means that the region must have experienced some 15 km's worth of uplift and erosion over the next 100 million years or so, before the overlying strata were laid down. The overlying strata, which forms part of the Herren Formation, is a 700+ m thick sequence of sandstone and siltstone. As both Paleocene and Eocene plant fossils have been found, it is generally felt that the Herren Formation is part of a large delta that marked the western coastal margin between 60 and 40 Ma. Gravel-choked channels exposed to the east mark what is left of the extensive stream system that must have fed the Herren Formation.

Regional uplift, this time accompanied by volcanism, began in the late Eocene, some 40 million years ago, forming the landscape across which the Columbia River Basalt Group lavas later flowed. Over the next 20 million years, silicic and intermediate composition magmas erupted to the surface, forming dome fields and caldera complexes that stood above the surrounding countryside. Some, such as the Tower Mountain caldera, formed broad volcanoes flanked by aprons of pyroclastic and debris flows.

So, just what did the basement surface look like immediately preceding the first CRBG eruptions? At this point, all we can say is that, in the south, it was highly irregular. N1 and some R2 Grande Ronde Basalt flows are exposed only on the east side of the basement highs on East Birch Creek and McKay Creek. The McKay Creek basement high (one of the Tertiary dome complexes) was not completely buried until the Winter Water erupted. Our mapping in the La Grande 30' x 60' quadrangle indicates that there was at least 300 m of local relief in places.

Miles (Mile Post)

51.2 Turn left on Yellowjacket Road. Prominent flow on nose of ridge may be Winter Water. The flow is hackly jointed, is a favored aggregate source, and is chemically similar to samples from known Winter Water flows elsewhere. We are now in the La Grande 30' x 60' quadrangle, where we in previous mapping did not attempt to separate the Sentinel Bluffs and Winter Water from the rest of the Grande Ronde Basalt N2 MSU.

56.5 Bear to the right and continue up Yellowjacket Road, which is beginning to climb the north dipping limb of an anticline. The faults that defined the west edge of the Blue Mountain Uplift further north are swinging around to merge with a series of east-west trending folds and faults at the crest of the uplift. Yellowjacket Road and Kanine Ridge Road both ascend along north-dipping fold limbs. Note the northerly dip of the N2 basalt flows to the right.

61.5 The canyon to Bent Creek comes into view to the southwest. Note the sharp flexures in the Grande Ronde Basalt flows across the canyon to the southwest. We are approaching the crest of the Blue Mountain Uplift, which here is marked by east- to northeast- trending folds and faults. Timbered ground to the south is underlain by pre-Tertiary metamorphic and intrusive rocks.

62.3 Pre-Columbia River Basalt Group basement is made up of metamorphic and intrusive rocks. N2 Grande Ronde Basalt flows directly overlie the basement here, while older R2 flows bank up against basement rock to the southwest. Here Yellowjacket Road crosses a small landslide. Landslides are fairly common where CRBG/basement contact is exposed.

Stop 4: Mountain Home Metamorphic Complex

63.0 Mica schists here are part of what we have named the Mountain Home metamorphic complex (Figure 17). Arguably these are the "best" metamorphic rocks in northeast Oregon. The MHMC is made up of biotite-garnet schists, chlorite schists, amphibolite, and metamorphosed intrusive rocks. The white blotches in the mica schist are coarse pegmatites that contain quartz, feldspar, and muscovite. Garnet and tourmaline crystals have been found in some of the pegmatites.

64.8 Yellowjacket Road passes through MHMC and climbs back onto N2 Grande Ronde Basalt flows. Note the contrast in vegetation between the basement rocks and the Grande Ronde Basalt. Springs and landslides are common features along the contact.

66.3 Bear to the right at the intersection and continue to the National Forest Service boundary. Yellowjacket Road enters the Umatilla National Forest, whereupon it becomes Forest Service Road 5415.

Figure 17. Exposure of garnet mica schists on Yellowjacket Road.

69.0 Turn left at the "T" intersection on Forest Service Road 5412. We are now at the top of the Grande Ronde Basalt section. Here the top of the Grande Ronde Basalt is marked by the Fiddlers Hell unit, which is made up of unusually highly "evolved" lavas, with relatively high amounts of silica, phosphorus, and titanium, and low amounts of magnesium.

70.0 Tower Mountain comes into view to the southeast. The forested upland is part of the resurgent core to a large caldera complex that formed about 25 million years ago. We are not sure how much of a topographic feature the Tower Mountain caldera would have made. Both N2 and R2 MSU Grande Ronde Basalt flows lap onto the flanks of the caldera.

72.0 Turn left at intersection with Forest Service Road 54. The road turns sharply to the northwest and descends into Pearson Creek, which has cut deeply into the core of the Blue Mountains Uplift. N2 and R2 flows are exposed along the upper reach of Pearson Creek.

Stop 5: More Mountain Home Metamorphic Complex

77.7 Time permitting, we will stop to look at more outcrops of metamorphic rocks. These are foliated chlorite schists. The schists are unconformably overlain by Eocene sandstones.

79.5 N1 MSU Grande Ronde Basalt flows begin to crop out along the road. Here. In this area, N1 flows form conspicuous columnar jointed outcrops. Thin organic-rich interbeds occur locally between Grande Ronde Basalt flows in this area. are parts of the N1 MSU exposed along the road here

81.0 Paleocene leaf fossils have been found in Herren Formation sandstones near here (Figure 18). The leaf locality is not open for collectors.

Stop 6: Landslide Complex

83.0 Sparsely vegetated area to the right is the toe of an active landslide. Large slides such as this one commonly occur where the contact between the Grande Ronde Basalt and underlying units have been exposed by erosion. Headscarp to this slide

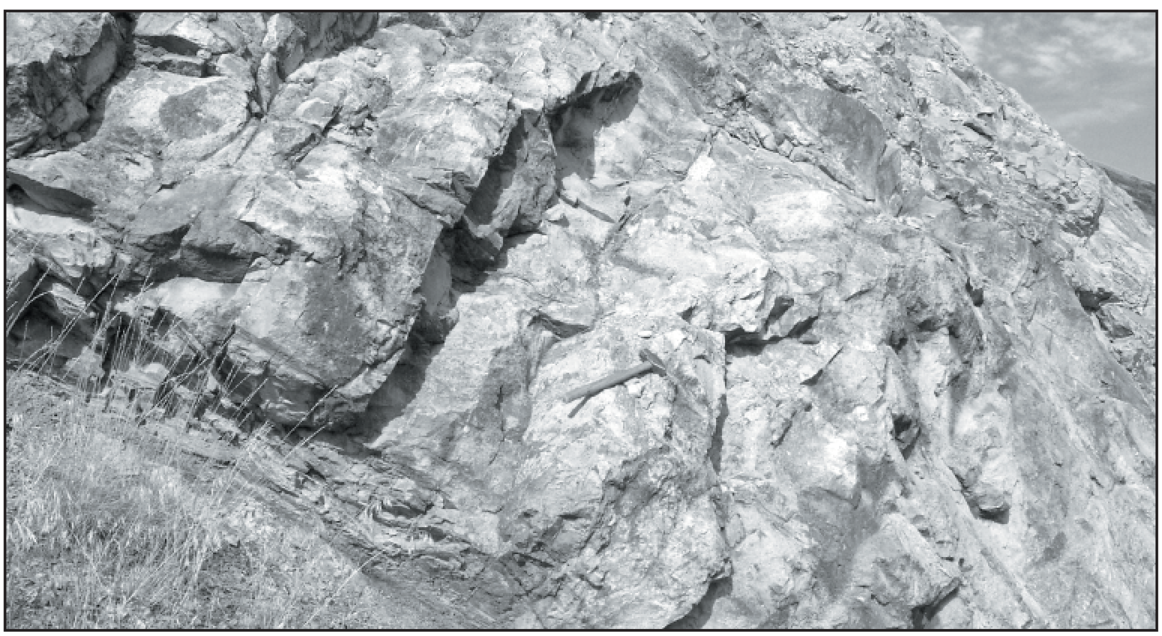


Figure 18. Quartzose sandstones and shales of the Herren Formation. Well preserved fossil leaves occur in the shales at the base of a massive sandstone bed.

is located180 m above Pearson Creek. Some of the landslide complexes can be quite large and extend over hundreds of acres.

84.2 Turn left at intersection and proceed west, down East Birch Creek. N1 Grande Ronde Basalt flows here are older than what crops out on the west side of the pre-CRBG outcrops. Distribution of CRBG flows is curious. Here on East Birch Creek and at McKay Creek to the north, we find the thickest section of Grande Ronde Basalt on the east flank of a basement high.

Stop 7: Herren Formation – Eocene Sandstone

85.2 Brown outcrops on the hillside to the north form part of the older basement to the Columbia River Basalt Group. Here the basement is made up of Eocene and Paleocene sandstone and shale. The sedimentary rocks are part of large delta system that apparently formed where a large river system emptied into the ancestral Pacific Ocean. Yes, 50 million years ago this would have been coastal view property, with palm trees.

86.1 Thick accumulation of white ash visible at the toe of another alluvial fan on the south side of Birch Creek to the south.

87.1 The road cuts through a white ash (Mazama?) in the toe of an alluvial fan. Volcanic ash deposits are best preserved where they are armored by vegetation or by younger alluvial fan gravels.

87.5 Hackly-jointed flows exposed along the East Birch Creek Road here are part of the R2 MSU of the Grande Ronde Basalt. Top of the ridges are capped by northwest-dipping N2 MSU flows.

88.5 N2 MSU flows are down dropped to the west along the Hawtmi fault zone. Since the Sentinel Bluffs and the Winter Water members were not separately mapped in the La Grande 30' x 60' quadrangle, we cannot tell for certain whether either member extends this far south. Based on limited geochemical analyses, it appears that the top of the N2 MSU here is marked by a thin sequence of high MgO flows that may be Sentinel Bluffs.

91.0 East Birch Creek turns to the north, following the regional dip of the Columbia River Basalt Group flows. Hackly jointed flow is probably Winter Water, overlain here by Sentinel Bluffs flows.

92.5 East Birch Creek Road enters the town of Pilot Rock. West flank of the uplift here is marked by both folds and faults. Here the Grande Ronde Basalt dips steeply to the west. Base of the N2 ms unit here is marked by a hackly jointed flow.

93.5 Turn right at stop sign and proceed north on U.S. Highway 395, to Pendleton.

106.3 Turn right at stoplight onto Interstate 84 and proceed east toward the assembly area at the Tamastslikt Cultural Institute.

111.6 Leave Interstate I-84 and turn left onto Market Road. Proceed north and return to Tamastslikt.

113.2 **End of Trip**