GUIDE TO FIELD TRIP BETWEEN PASCO AND PULLMAN, WASHINGTON EMPHASIZING STRATIGRAPHY, VENT AREAS, AND INTRACANYON FLOWS OF YAKIMA BASALT

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Introduction

This field trip, scheduled in conjunction with the April 1976 Cordilleran Section Meeting of the Geological Society of America in Pullman, Washington, provides a southwest to northeast transect across the Columbia Plateau from the Pasco Basin to the Uniontown Plateau (fig. 1). The Yakima Basalt, the uppermost formation in the Columbia River Basalt Group, forms the bedrock throughout this area, and the field trip is designed to show some of the principal aspects of its stratigraphy as exposed along the canyons of the Snake River and its tributaries. Within this large area, many outcrops and roadcuts reveal evidence for nearby venting, and we will look at some of this evidence. The ancestral Snake River occupied roughly the same canyon during late Yakima time as today, and basalt flows occasionally poured down this canyon and spread from its mouth. Some of these intracanyon flows, whose structural relations to the older flows provide evidence concerning the timing of subsidence of the Columbia Plateau, will be seen on the trip.

The field trip lasts two days, with an overnight stop in Dayton, Washington. An informal discussion session is planned after dinner in Dayton. It is doubtful that all of the stops described in the accompanying road log can be seen in only two days; consequently, we have designated certain stops -- of secondary importance, time-consuming access, or confusing complexity -- as optional. Both days of the trip involve long bus rides, although we have tried to keep them as short as possible while still maintaining what we hope is a logical

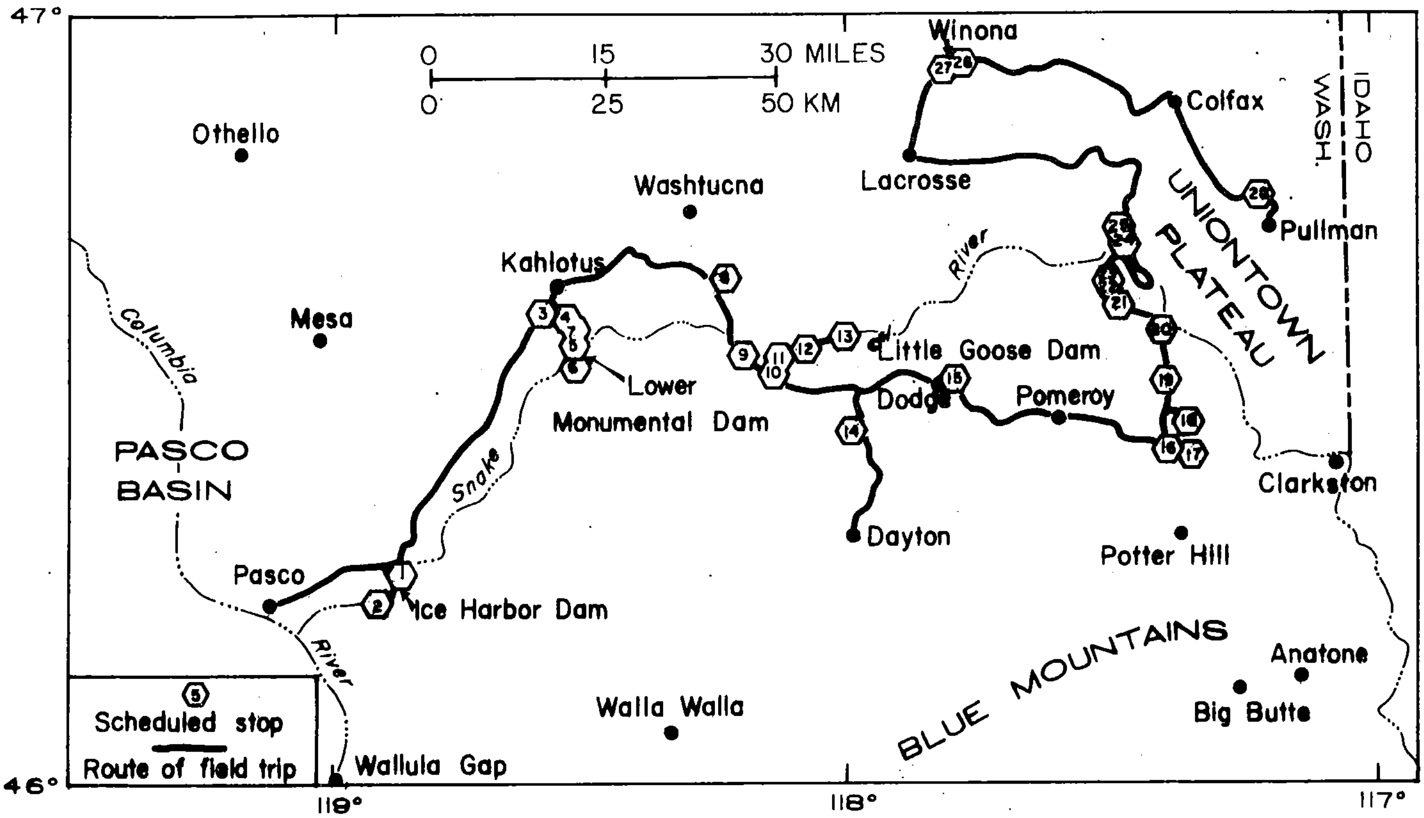

Figure 1. Index map of southeast Washington, showing route of field trip, scheduled stops, and important localities mentioned in text.

order of presentation. If nothing else, the long rides emphasize the size of the basalt field, especially when one remembers that southeast Washington is only a small part of the total area underlain by the Yakima Basalt (fig. 2).

We have been studying the Yakima Basalt since 1971, and Swanson dealt with it earlier during thesis work (Swanson, 1967). Our emphasis has been on the regional stratigraphic, chemical, and structural relations, as we are especially interested in deriving models for the origin of flood basalt provinces in general. The Columbia River basalt, particularly its most extensive formation, the Yakima Basalt, forms perhaps the best flood basalt province in the world to study from the standpoint of models, as it is the youngest such province, is reasonably well exposed, chemically fresh or at most little altered, and has been the subject of much good work. In particular, we are attempting to build on the past work of Hoover Mackin, Aaron Waters, and their students, who showed that single flows could be mapped on a regional basis, and that chemistry is a valuable aid in delineating the regional stratigraphy.

Stratigraphy of the Yakima Basalt

One of the main topics of this field trip is the examination of stratigraphic relations in the Yakima Basalt between Pasco and Pullman. This requires the usage of a consistent terminology, and the one we have chosen, from Wright, Grolier, and Swanson (1973) with changes and additions by us, is given in table 1. Some of the names are informal and for several reasons not presently acceptable for elevation to formal status, according to the Code of Stratigraphic Nomenclature. We are currently (fall 1975) attempting to devise a new classification that will employ formal stratigraphic nomenclature and still remain as consistent as possible with currently used terminology.

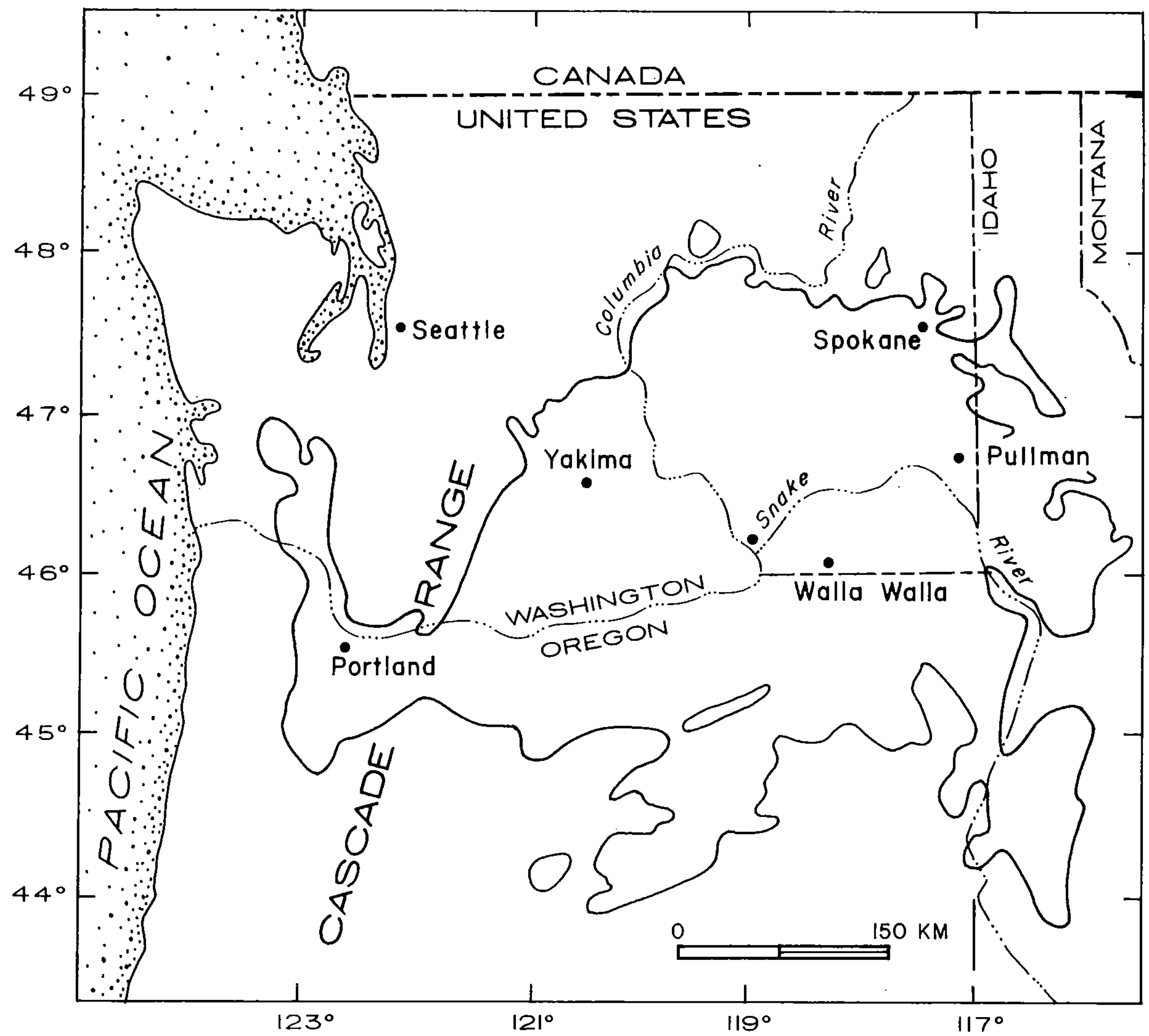

Figure 2. Area underlain by Columbia River Basalt Group in the Pacific Northwest, after Waters (1961). The Yakima Basalt comprises most of this area. The Picture Gorge Basalt is known only from central Oregon, the Imnaha basalt from northeast Oregon and adjacent parts of Washington and Idaho.

Table 1. Informal stratigraphic nomenclature for Yakima Basalt.[1] [Modified and amended from Wright, Grolier, and Swanson, 1973]

Columbia River Basalt Group	Yakima Basalt	Upper Yakima basalt	Ice Harbor flows - Lower Monumental flow[2]
			Elephant Mountain Basalt Member of Schmincke (1967b)
			Pomona Basalt Member of Schmincke (1967b)
			Mesa flow
			Unnamed intracanyon flow
			Umatilla Basalt Member of Schmincke (1967b)
		Middle Yakima basalt	Priest Rapids Member
			Roza Member
			Frenchman Springs Member (includes Dodge flows)
		Lower Yakima basalt	Includes the Pataha and other named basalt flows traceable for several tens of kilometres.

1/ Formal names are indicated by capitalizing the initial letter of all words in the name.

2/ The age relation of the Ice Harbor flows to the Lower Monumental flow is not known.

We will visit outcrops of every unit listed in table 1, except the Umatilla, which does not crop out along the Snake River. However, flows of possible comparable stratigraphic position to the Umatilla occur on the Uniontown Plateau (the Uniontown flows of Swanson and others, 1975) and in the Lewiston basin. A schematic cross section between Pasco and Pullman, showing the relation of most of the stratigraphic units, is shown in figure 3.

Few sedimentary deposits occur between the basalt flows in this area, in contrast to areas near the margins of the plateau. Those deposits that we will see are thin and of limited lateral extent (except for one tuff beneath the Pomona) and hence are not useful in regional correlation.

A zone of weathering and soil formation developed on top of the lower Yakima basalt before eruption of the Frenchman Springs Member; this zone, now preserved as a saprolite, is important in working out the stratigraphy.

Elsewhere in the section, we must depend upon recognition of the flows for determination of stratigraphic position. We will, therefore, place some emphasis on the features that are useful in recognizing certain flows. In general, features inherited from before eruption, such as chemical composition and phenocryst assemblage, size, and habits, are by far the most useful criteria. Features imposed on a flow during cooling, such as jointing habit, color, and degree of vesicularity, are important only on a local scale and even then should be used only with caution. Hand-lens identification of olivine phenocrysts and microphenocrysts is essential to the recognition of certain flows. Field identification of many flows is not secure, even with practice. In such cases, chemical composition, used in conjunction with observed stratigraphic sequence, is a powerful tool to back up field observations, as described by Wright, Grolier, and Swanson (1973).

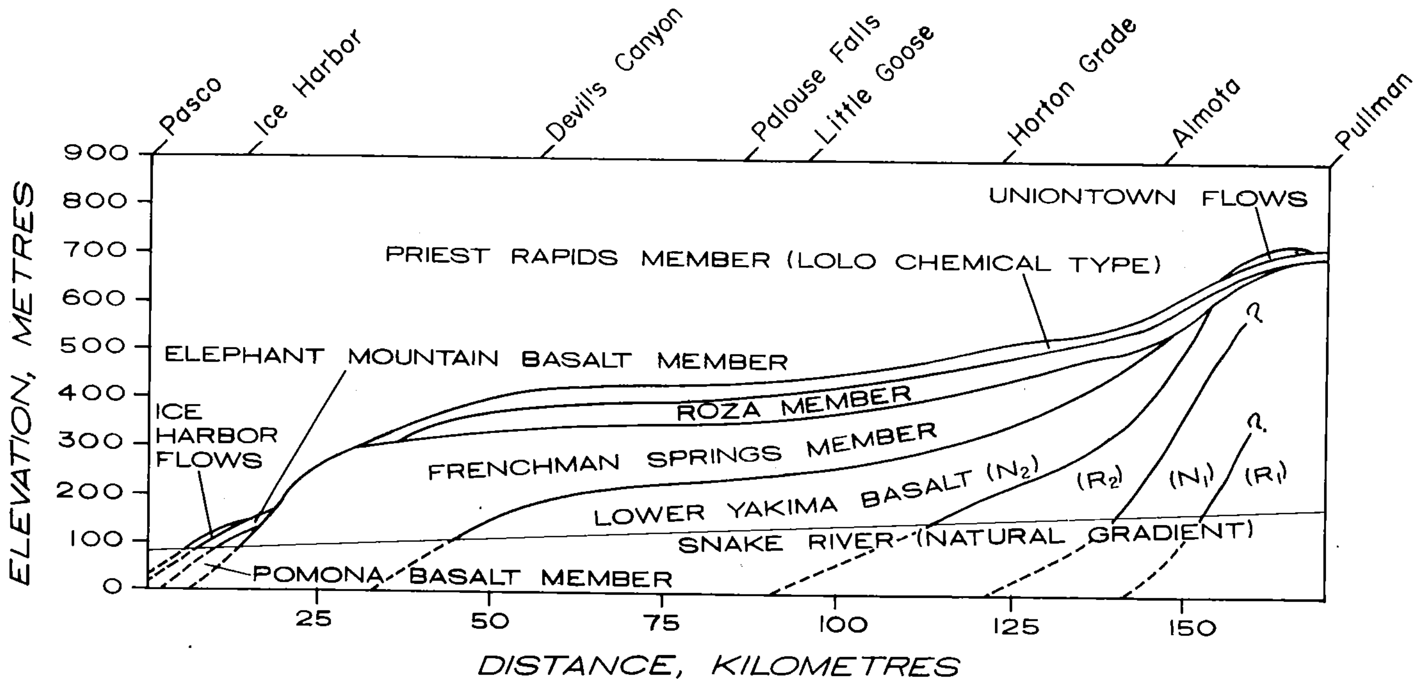

Figure 3. Schematic cross section across Columbia Plateau from Pasco to Pullman. The lower Yakima basalt is subdivided into four units on the basis of paleomagnetic polarity, two normal (N) and two reversed (R). The Uniontown flows may in part be stratigraphically equivalent to the Umatilla Basalt Member of Schmincke (1967b). Note the constructional high in the Frenchman Springs Member between Devils Canyon and Ice Harbor, and the steeper dips in older units as compared with younger units. The Frenchman Springs pinches out eastward against lower Yakima N_2, but the Roza is in contact with both lower Yakima N_2 and R_2.

A "black-box" method, field determination of paleomagnetic polarity with a portable fluxgate magnetometer, has proven very useful throughout the section. We have been able to subdivide the lower Yakima basalt into four units on the basis of paleomagnetic polarity (fig. 3) and have found them to be mappable over wide areas of southeast Washington. This is important, because we have found few field criteria permitting delineation of mappable units in the lower Yakima section. Of the Yakima units in table 1, the following have reversed paleomagnetic polarity: some Ice Harbor, Pomona, Priest Rapids, and some lower Yakima. The Roza and some Elephant Mountain have transitional polarities; all others have normal polarities.

The age of lower and middle Yakima basalt is between about 16.5 and 13.5 m.y., on the basis of published and unpublished K/Ar dates by several different workers. Preliminary whole-rock K/Ar dates by E. H. McKee suggest ages of about 12 m.y. for the Pomona, 10 m.y. for the Elephant Mountain, and 8.5 m.y. for the Ice Harbor.

Of those units we will visit, the Roza and Dodge are the easiest to recognize. The Roza Member is highly porphyritic, carrying small but abundant phenocrysts of plagioclase. The Dodge flows are unusually coarse grained and contain scattered large plagioclase phenocrysts. The Roza is far more extensive than the Dodge and serves as a datum over much of the Columbia Plateau, providing that the approximate stratigraphic position is known. We will concentrate on the Roza Member on the second day of the trip.

Vent areas

Unless Abraham Gottlob Werner was correct, every basalt flow must have a source vent. Proving Werner wrong regarding the Yakima Basalt has, however, been difficult. Until recently, no clear-cut vent areas had been described, and it was simply an article of faith that the Yakima flows were fed from fissures now filled by dikes such as those in the Chief Joseph dike swarm.

We think that one of the reasons vent areas have been so rarely discovered is that the criteria for their recognition have not been well known. Our experience at Kilauea Volcano has been very educational for us in this regard, for as soon as we began working on the plateau, we started recognizing vent and near-vent features in the Yakima Basalt that were similar to those we had seen at Kilauea. This field trip will show several of these vent and near-vent areas, some obvious, some obscure, and our goals are to learn to recognize such features as collapsed pahoehoe (Swanson, 1973), to distinguish pumice and spatter from flow-top scoria, to discuss the significance if any of localized thin flows, and to emphasize the necessity of locating several vent areas before one can be certain that they are not rootless vents.

Our views concerning the geometry of the vent systems are given in a recent paper (Swanson and others, 1975). Several of the localities mentioned in that paper are on the field trip route. We find that vent areas for single flows are confined to linear systems along the trend of the dike swarm, rather than scattered randomly throughout the area covered by a flow.

Intracanyon flows

The third general topic of the field trip deals with intracanyon flows of Yakima Basalt along the ancestral Snake River canyon. Remnants of intracanyon flows along the Snake were recognized nearly 40 years ago, but most workers felt that the flows were of late Pliocene or Pleistocene age. Aaron Waters (1961) first suggested that one of these flows near Clarkston was of Yakima age. The late Richard Clem (1966) correlated all of the flows with the Yakima Basalt on the basis of the morphology of the opaque mineral fraction. Clem's work was all the more remarkable, as he was a paleontologist not trained in petrography!

Our work suggests the presence of at least five intracanyon flows, remnants of which occur close to the Snake River between Devils Canyon and the Clarkston area. Three of the flows (Mesa, Pomona, and Elephant Mountain) occur in section west of Devils Canyon, overlain by Ice Harbor flows. Thus, only the Lower Monumental flow could be younger than Yakima, but we feel that it most likely represents a late event of Yakima volcanism, perhaps close in time to the Ice Harbor flows.

Each eruption partly filled the ancestral Snake Canyon with a flow several tens of metres thick, in places 100 or more metres. The river began downcutting soon thereafter, and narrow, steep-walled gorges were eroded before the next eruption. The Elephant Mountain intracanyon flow apparently dislodged the Snake from its previous westward course west of Devils Canyon, and a canyon along the present course of the Snake at Lower Monumental Dam was established before eruption of the Lower Monumental flow.

Sources of the intracanyon flows are unknown, though several lines of evidence, to be discussed during the trip, suggest that the flows were erupted east or south of Clarkston and poured down the canyon as far as the central part of the Columbia Plateau.

The gradient of the ancestral Snake River, as reconstructed from elevations of intracanyon flows, was similar to that of the present-day Snake. The remnants rest on progressively older flows toward the east, indicating that most of the subsidence of the Columbia Plateau had been completed before canyon-filling flows were erupted, at least as early as about 12 m.y. ago.

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Road log, Pasco to Pullman, with one night's stopover in Dayton

First day, Pasco to Dayton

Mileage		
Cumulative	Difference	
0		Pasco Post Office, on W. Lewis St. at 3rd St. Drive east on Lewis beneath railroad and through traffic signal.
2.2	2.2	Intersection of Lewis and Highway 395. Continue across 395, toward Kahlotus. Road is constructed mostly on late Pleistocene lake beds, probably equivalent to the Touchet Beds of Flint (1938).
11.7	9.5	Turn right at intersection toward Ice Harbor Dam.
14.6	2.9	Turn left, onto another paved road, just before dam. Sign at intersection points to Boat Landing.
14.9	0.3	Intersection with gravel road. Keep left on gravel across narrow wooden plank bridge.
15.3	0.4	Intersection of track roads. Both roads lead to same place; left-hand route is best.
15.5	0.2	End of road near lake level. Bus may not be able to drive this far, but passenger cars easily can. Bus parking, at driver's option, is possible at several places near road end.

Stop 1. Examine railroad cuts 500-1200 m upriver from end of road. Flows of the Pomona and Elephant Mountain Basalt Members of Schmincke (1967b) are well exposed at railroad level. An Ice Harbor 1 flow overlies the Elephant Mountain above the the railroad. Examine invasive contact relation of

Mileage		
Cumulative	Difference	
		Pomona and a white vitric tuff. Three dikes of Basin City chemical type (Helz and others, in press) intrude the Elephant Mountain at locality 7 of Swanson, Wright, and Helz (1975, table 2). Caution - the dikes are difficult to spot. The dikes occur along a prominent linear aeromagnetic anomaly that extends 30 km south of the Snake River and 50 km north of the river. They form part of a linear vent system for the Ice Harbor flows described by Swanson, Wright, and Helz (1975).
		Retrace route to intersection with road across dam.
16.4	0.9	Turn left to drive across dam which is open during daylight hours. (Toilet facilities available at south end of dam, near fish ladder.) Keep right on pavement at south end of dam.
17.5	1.1	Turn right toward river at T-intersection.
17.65	0.15	Bear left onto gravel road. Follow road closest to river bank in downstream direction. The bluffs on the left are flows of Ice Harbor 1 type overlying Elephant Mountain.
18.8	1.15	Parking for bus and automobiles.
		<u>Stop 2</u>. The craggy bluff near the parking area is the remnant of a tuff cone built over a vent for Ice Harbor 1 (locality 16 of Swanson, Wright, and Helz, 1975, table 2). Note the poorly bedded nature of the cone, the palagonitic alteration of most of the glassy tephra, and the angular unconformity

Mileage		
Cumulative	Difference	
		visible on the northwest face. A flow of Ice Harber 1 type overlies the cone.
		Walk 600 m downriver along old road to cuts exposing Elephant Mountain, Ice Harbor 1, and Ice Harbor 2 flows (locality 12 of Swanson, Wright, and Helz, 1975, table 2). The flows occupy a shallow northwest-trending syncline, also recognizable across the river. Note the plagioclase-clinopyroxene clots in the Ice Harbor 1 flow. A dike of Ice Harbor 2 chemical type cuts the Ice Harbor 1 flow. Breccia interpreted as drainback rubble occurs in upper part of dike; the rubble merges into thin vesicular flows, overlain by a thicker flow of Ice Harbor 2 type. At this locality, the upper Ice Harbor 2 flow and the columnar Ice Harbor 1 flow have both been dated by E. H. McKee, using whole rock K/Ar methods, at 8.6 $\pm$ 0.3 m.y. These are the youngest dates yet obtained for the Yakima Basalt.
		Retrace route back across dam to intersection with Kahlotus road.
24.1	5.3	Turn right (east) toward Kahlotus. From here road goes down section and then follows for almost 10 miles the alluviated upper part of an Elephant Mountain flow.

Mileage		
Cumulative	Difference	
35.3	11.2	Climb up to hills of loess from dip slope of Elephant Mountain.
36.0	0.7	Ghostly appearing sand dunes visible to left. The dunes are formed by wind reworking of Pleistocene deposits.
45.9	9.9	Continue straight ahead at intersection with Burr Canyon road, an alternate route to Lower Monumental Dam. A feeder dike for a Frenchman Springs flow can be reached by following the Burr Canyon road to the lowest railroad right of way shown on the Lower Monumental Dam 7-1/2' quad. The tracks have been removed from this right-of-way, and the route was drivable with care in 1974. From Burr Canyon, follow the abandoned railroad about 2.5 mi to near Abe triangulation station (Elwood 7-1/2' quad). Several small faults offset the red, oxidized contact of lower Yakima basalt and Frenchman Springs Member exposed along the way. The plagioclase-phyric dike, evident in cuts, projects across the river and feeds the prominent flow exposed at top of dike. By climbing up hill (poor exposure) above Abe, the top of the dike can be seen in cuts along the relocated railroad. A shallow pool of columnar basalt fills the flared top of dike, apparently the result of drainback into the fissure after magma withdrew. The pool merges laterally into an extensive porphyritic flow.

Mileage		
Cumulative	Difference	
46.7	0.8	Outcrop of a Priest Rapids flow (Lolo chemical type) below Elephant Mountain in gulley to left.
54.2	7.5	Continue straight ahead at intersection with Wallace Walker road.
56.5	2.3	Head of Devils Canyon. Park at turn-out to right near locked gate.
		<u>Stop 3.</u> A thick, well-exposed section of middle Yakima basalt is exposed in Devils Canyon. At stop 3, a Priest Rapids flow of Lolo chemical type overlies a Roza flow in roadcuts just beyond parking area. Note the olivine phenocrysts (difficult to see except on a sunny day) and sparse plagioclase phenocrysts in the Priest Rapids, typical of flows of Lolo chemical type. The underlying Roza is typically plagioclase-phyric. Note that most of its phenocrysts are single crystals, not glomerophyric clots as are found in many Frenchman Springs flows.
58.4	1.9	Turn right at intersection with road down Devils Canyon to Lower Monumental Dam.
59.0	0.6	<u>Stop 4</u>. Optional. Problem with bus parking. Several flows of the Frenchman Springs Member are exposed in roadcuts. Some flows are virtually aphyric, others are sparsely phyric, and still others are highly phyric. Note uneven distribution of phenocrysts and clots in some flows and the generally larger phenocrysts than in the overlying Roza.

Mileage		
Cumulative	Difference	
63.2	4.2	Look ahead at a remnant of the Lower Monumental flow, which forms cliff overlying river gravel across river beyond dam.
63.9	0.7	Large parking area to right opposite turn toward dam.

Stop 5. Contact of Frenchman Springs and lower Yakima basalt. Lowest exposed flow is lower Yakima. It has an oxidized top and is overlain by a Frenchman Springs flow with sparse, small plagioclase phenocrysts. The oxidized zone is an incipient soil horizon. Traced eastward, this zone gradually thickens into a true saprolite, which is well exposed at stops 14 and 25. As the soil zone thickens, the overlying Frenchman Springs thins and finally dies out, leaving the Roza resting directly on saprolite. This is evidence that the Frenchman Springs flows were erupted in a basin, presumably created by early subsidence of the Columbia Plateau.

Stop 6. Optional. From stop 5, drive across Lower Monumental Dam and park along road 1 mi beyond southeast end of dam, at base of the Lower Monumental flow. This flow, the youngest intracanyon flow on the Columbia Plateau, extends at least as far east as Clarkston. It has not been recognised farther west than this locality. The flow overlies river gravel consisting of basalt, quartzite, metavolcanic rocks, and a very few plutonic rocks with lenses of quartz-feldspar-muscovite sand. This assemblage is clearly that of an ancestral Snake River, not a small stream heading on the plateau itself.

Mileage		
Cumulative	Difference	At the time of the writing (summer 1975), the Lower Monumental flow had not been dated, as all samples so far collected are too glassy for whole rock K/Ar methods (at least 48 percent tachylyte).
64.6	0.7	Retrace steps from stop 5. Looking up Devils Canyon from this point, a good cross-sectional view of flows filling a steep-walled gorge is exposed on the northeast wall of Devils Canyon.
66.2	1.6	Park in turnout to right.

Stop 7. Intracanyon flows. Before Lower Monumental time, the ancestral Snake River apparently occupied a gorge 2-3 km north of the present canyon. Four different lava flows poured down this gorge, with renewed canyon cutting between each eruption, resulting in the compound lava fill exposed in cross section in the cliffs on either side of the road. East of the road, a "triple junction" is well exposed. Here, the Pomona (right) filled an almost vertically walled gorge cut into the oldest known intracanyon flow in this area (left). Note the nearly horizontal columnar jointing in the Pomona along the contact. After a period of erosion, which beveled the Pomona and older intracanyon flow, the Elephant Mountain was erupted. It forms the uppermost flow in contact with both of these older intracanyon flows. West of the road, relations are more confusing. Four flows are present here, and they meet in a "four corners"

Mileage	
Cumulative	Difference

area above the railroad grade. The same three flows in the cliff east of the road are also here, with a fourth, the Mesa flow, between the unnamed intracanyon flow and the Pomona in age. It is advisable to climb the talus to the railroad cut in order to examine the contact of the Pomona and the oldest flow and to view the "triple junction" east of the road. Bring camera! Those who desire to forego the climb can walk to the quarry at the end of the dirt road across the fence, where large (3-5 cm or more) clots of plagioclase, pyroxene (some orthopyroxene, but mostly clinopyroxene), and minor olivine occur in blocks blasted from the Pomona flow.

Eastward from a point 8 km east of Devils Canyon, the pre-Lower Monumental canyon of the Snake follows the present canyon rather closely. West of there, however, the older canyon continues due west, meeting Esquatzel Coulee between Mesa and Connell. The course of this old canyon can be traced using detailed aeromagnetic data, as the thick intracanyon flows exhibit narrow, sinuous anomalies of greater amplitude than the thin flows forming the wall-rock. We can speculate that the Elephant Mountain flow so thoroughly choked the canyon that the Snake spilled over a divide, located about 8 km east of Devils Canyon near Magallon ranch, into a tributary of the ancestral Columbia River leading southwest toward Pasco.

Mileage		
Cumulative	Difference	
		Erosion of this divide proceeded comparatively rapidly, and the Snake has remained in this canyon since then.
69.4	3.2	Continue up Devils Canyon from stop 7 and turn right at intersection toward Kahlotus.
70.15	0.75	Junction with State Highway 260. Turn right toward Washtucna. Route is along Washtucna Coulee, former course of the Palouse River. Erosion related to the late Pleistocene Spokane floods presumably caused diversion of the Palouse into a more direct course toward the Snake via Palouse Falls (stop 8). Prior to the floods, the Palouse River flowed down Washtucna Coulee to Connell and then south-southwestward to the Pasco area via Esquatzel Coulee. The highest continuous ledge along the coulee walls east of Kahlotus is the Roza; highest discontinuous outcrops belong to the Priest Rapids (Lolo chemical type).
75.6	5.45	View to left of gravel bar deposited by Spokane floods.
78.55	2.95	Junction with State Highway 261. Turn right toward Starbuck, Lewiston, and Little Goose Dam. For the next 4.5 mi, road climbs through section, starting in the Frenchman Springs Member and ending in the Priest Rapids Member.
83.2	4.65	View down H. U. Coulee, a scabland channel made famous by J. Harlen Bretz, at 2 o'clock position, with Blue Mountains in far distance.

Mileage		
Cumulative	Difference	
		Descend into upper H. U. Coulee into the Frenchman Springs Member and back up to the Roza Member.
85.5	2.3	Priest Rapids flow (Lolo chemical type) crops out just above road; this is youngest flow throughout this area. Good example of scabland topography (Scablandia) to left (east).
87.8	2.3	Turn left at junction toward Palouse Falls State Park. The junction is close to the elevation of the Roza-Priest Rapids contact, and the road goes down section into the Frenchman Springs Member.
90.3	2.5	Palouse Falls parking lot.

<u>Stop 8.</u> This is mainly a view stop, but a highly phyric Frenchman Springs flow can be examined in the roadcut just before the railroad crossing if desired. The lip of Palouse Falls is carved into the oldest Frenchman Springs flow in this area. An interbed 30 cm to 1 m thick, consisting of ash, peat, and sand, occurs between this flow and the overlying Frenchman Springs flow; the interbed is well exposed along the river upstream from the falls but cannot be seen from the viewpoint.

If the light is good, the red top on the uppermost lower Yakima flow can be seen on either side of the falls about 15 m below the lip of the falls. This red top is about 73 m above the free-flowing stage of the Snake at the mouth of the Palouse River, compared to only about 37 m at Lower Monumental Dam. From here eastward, the lower

Mileage		
Cumulative	Difference	
		Yakima-middle Yakima contact continues to climb above the river, as the basinward dip of the flows is greater than the gradient of the river.
92.8	2.5	Retrace route to State Highway 261 and turn left toward Snake River.
95.8	3.0	Base of Roza Member.

Mileage		
Cumulative	Difference	
97.2	1.4	Prominent bench across both the Palouse and Snake Rivers is developed along the lower Yakima-Frenchman Springs contact. Road crosses contact (poorly exposed) and continues in the lower Yakima to river level.
98.35	1.15	Junction to Lyons Ferry State Park. Continue straight ahead over bridge.
99.0	0.65	Dark mesas in 12 and 1 o'clock positions are remnants of the Lower Monumental flow.
100.5	1.5	Outcrops beyond steel bridge are of Pomona intracanyon flow.
101.6	1.1	<u>Stop 9</u>. An optional stop to examine the origin of tiers in thick Yakima flows. Are tiers the result of some process completely internal to a ponded flow, or does each tier record a separate pulse of lava into a gradually deepening pond? In other words, is a tiered flow a single or multiple-flow cooling unit? Good exposures of vesicular layers defining boundaries of tiers are found along the slope across the railroad tracks to right of road.
101.9	0.3	Road curves up Tucannon River. Hackly cliff across Tucannon is Lower Monumental flow overlying the same tiered lower Yakima flow seen at stop 9.
102.2	0.3	White deposit on hillside in 12 o'clock position is Mazama ash, which in this area locally occurs in drifts several metres thick.

Mileage Cumulative	Mileage Difference	
102.5	0.3	At 9 o'clock, sand and silt deposit related to backfilling of Tucannon River during Spokane Flood.
103.3	0.8	Black cliffs across river are all in Lower Monumental flow.
105.4	2.1	Junction. Turn sharply left toward Little Goose Dam.
106.5	1.1	Stop 10. Optional stop, companion to stop 9. Roadcut exposing contact of two lower Yakima flows. Criteria for determining flow contacts will be discussed. How does this vesicular zone differ from those at stop 9? How is it similar? Can we tell which way the upper flow was moving?
106.7	0.2	Roadcut in Lower Monumental flow.
107.45	0.75	Stop 11. Optional. The exposure in roadcuts on either side of the highway is complicated and tests one's observational abilities. Within a short distance horizontally, and at nearly the same elevation, the Frenchman Springs overlies the lower Yakima and the Lower Monumental overlies the Frenchman Springs. Both the Frenchman Springs and Lower Monumental are pillowed, and both flows overlie micaceous sediments. The compositions of the three units are distinctive and provided the first indication we had of the complexity of the contact relations. In the field, the key to unraveling the stratigraphy is a saprolite developed on the top of the lower Yakima. The saprolite is poorly exposed below the Frenchman Springs pillows. This is an excellent locality to use for a field examination of students, and it shows the usefulness of combined field and laboratory observations in mapping the Yakima Basalt.

Mileage		
Cumulative	Difference	
108.2	0.75	For next 0.4 mi, good exposures of complexly jointed Pomona intracanyon flow in 12 and 1 o'clock positions, erosionally overlying lower Yakima flows.
110.7	2.5	At 10-11 o'clock, Lower Monumental flow overlooks mouth of Alkali Flat Creek at Riparia.
111.5	0.8	Stop at turnout on right to road leading up to quarry. Locked gate.

<u>Stop 12.</u> Go through or over gate and walk up road to old quarry. (CAUTION - this quarry is dangerous. The highest face is peeling away from the hillside. Gaping cracks occur behind the face. Stay away from it!) Pomona intracanyon flow is exposed in quarry, overlying 3-4 m of imbricated river gravel (mostly basalt, including large blocks eroded from one of the Dodge flows, but with some metavolcanic rocks, vein quartz, and quartzite) and micaceous sand. A thin deposit of hyaloclastic rock, apparently formed as the Pomona flowed into water, locally underlies the flow. In places, a vitric tuff, probably correlative to the tuff invaded by the Pomona at stop 1, occurs either directly in contact with the Pomona or below the hyaloclastite. The vitric tuff is thoroughly fused to a gray or black glass in many places, presumably because of heating by the Pomona. A similar tuff, also commonly welded, is associated with the Pomona Basalt Member on the western Columbia Plateau (Schmincke, 1976a), and its presence here supports the correlation of the intracanyon flow to the Pomona in the Yakima Valley.

Mileage

Cumulative	Difference	
112.6	1.1	Continue along river in lower Yakima section to east end of wide parking area on river side of road.
		Stop 13. Roadcut across from parking area shows log mold near base of second flow above road. Bark impressions are preserved in the mold. Such molds are fairly common near the base of Yakima flows, and rarely they occur in the interior of a flow because of floating or rafting.
		A discussion of lower Yakima stratigraphy will be conducted at the parking area.
119.8	7.2	Return to State Highway 261. Turn left toward Starbuck. Road along Tucannon stays in lower Yakima basalt.
128.9	9.1	Junction with U.S. 12. Turn right toward Dayton.
132.1	3.2	Turn right onto dirt road just beyond school bus sign.
133.3	1.2	Stop near Y in road, but should check with rancher (John Hinchliff) at house a short distance beyond.
		Stop 14. Drainage ditch exposes saprolite developed on top of lower Yakima basalt. Some fine-grained clayey and tuffaceous deposits are also present.
		A sparsely phyric Frenchman Springs flow overlies the saprolite and clastic deposits. Contrast this contact with that at stop 5 (near Lower Monumental Dam), where only an incipient soil is developed. Much of the ground water in this area occurs along the top of the saprolite, which apparently acts as a barrier to water percolating downward.

Mileage		
Cumulative	Difference	
134.5	1.2	Return to U.S. 12, turn right toward Dayton.
138.1	3.6	Saprolite between lower Yakima basalt and the Franchman Springs Member excellently exposed in roadcut at uphill end of sharp curve.
139.9	1.8	Base of Roza Base of Roza Member in roadcut.
141.2	1.3	Roza in roadcut.
145.7	4.5	Approach to Dayton. Blue Mountain vista, with dip slopes of Frenchman Springs (in most places) and lower Yakima.
146.9	1.2	Columbia County Courthouse on main street of Dayton. End of first day.
		<u>Second day, Dayton to Pullman</u>
0		Columbia County Courthouse, downtown Dayton. Drive east on U.S. Highway 12.
0.5	0.5	Highway Department quarry in 2 o'oclock position has excellent exposures of tiered lower Yakima flow.
15.7	15.2	Junction with State Highway 261. Keep right toward Spokane and Lewiston.
24.6	8.9	Junction with State Highway 127 at Dodge. Keep left on 127 toward Colfax and Spokane.
25.55	0.95	Roadcut at type locality of Dodge flows, the oldest unit of flows in the middle Yakima basalt in this area.
25.9	0.35	<u>Stop 15</u>. Optional. Bus parking and turn-around. Walk down road to type locality of the Dodge flows. Note the coarse grain size, grusy weathering, and scattered large plagioclase phenocrysts. These distinctive characteristics, together with a "low-Fe Picture Gorge" major-element chemistry, make the

Mileage		
Cumulative	Difference	
		Dodge flows an excellent marker unit throughout a wide area south of here. The Dodge was apparently erupted during the time that a soil was developing on the surface of the lower Yakima basalt, as we find saprolite both below and above the Dodge in places. Generally the saprolite below the Dodge flows is relatively thick compared with that above. Consequently we assign the Dodge to the Frenchman Springs Member. The Dodge flows were probably erupted from a linear vent system, judging from its elongate outcrop area and the presence of dikes of appropriate chemistry along the projected trend of the outcrop belt (Swanson and others, 1975, fig. 5). No spatter or other near-vent material has yet been recognized, however. The flows above the Dodge at this locality have unusual compositions unlike any of the chemical types defined by Wright, Grolier, and Swanson (1973). In most places, flows of Franchman Springs chemistry overlie the Dodge flows.
27.0	1.1	Return to junction with U.S. 12. Turn left toward Pomeroy and Lewiston.
27.3	0.3	Eastward from here, a ledge-forming flow is evident on hillsides and is especially prominent at cumulative mileage reading of 31. This flow, informally named the Pataha flow, is of high-Mg Yakima chemical type and is near the top of the lower Yakima section in this area.

Mileage		
Cumulative	Difference	
34.6	7.3	Junction with State Highway 126. Continue ahead on U.S. 12. A good section across the lower Yakima-middle Yakima contact, including Pataha, Dodge, and Roza flows, is exposed along State Highway 126 on the Marengo Grade, 2.5-3.5 miles from junction with U.S. 12. Caution - S.H. 126 is virtually impassable for buses.
40.9	6.3	Junction with State Highway 128 in east part of Pomeroy. Continue straight on U.S. 12. S.H. 128 leads to the Benjamin Gulch section, 2 mi south (right) of intersection, where flows of Dodge, Yakima, and Frenchman Springs chemical types are interbedded. This section is of great importance, for it demonstrates the local overlap in time between eruptions of greatly different magma chemistries. Presumably this locality contains flows that were erupted throughout the time interval during which a soil horizon was forming elsewhere in southeast Washington.
43.8	2.9	Junction with Bell Plain road. Stay right on route 12.
46.45	2.65	Junction with Kirby-Mayview road. Stay right on route 12.
49.0	2.55	On left, the Roza Member overlies leaf-bearing, micaceous sands and silts deposited on top of lower Yakima basalt. Roza is exposed in roadcuts from here to top of grade.
50.7	1.7	Turn right to Alpowa Summit viewpoint.
50.8	0.1	<u>Stop 16.</u> Alpowa Summit viewpoint (Restrooms open only during summer). A good panorama of the area we will be in for the rest of the day. Discussion of regional structure relating to uplift of the Blue Mountains.

Mileage		
Cumulative	Difference	
50.9	0.1	Continue east and rejoin U.S. 12.
51.05	0.15	Junction with Fairview Road. Turn right on Fairview. (Caution - there are several roads that intersect U.S. 12 in this general area. Be sure you turn on Fairview.)
51.7	0.65	Keep left at junction.
51.95	0.25	Sharp left turn on Fairview.
54.2	2.25	Bus stop and turn-around just before gate. Walk down road for 1/4 mi to outcrop.
		<u>Stop 17</u>. (Locality 14 in Swanson and others, 1975, table 1.) Ledges are spatter, welded spatter, and thin flows belonging to the Roza Member. The spatter implies a nearby vent. Discussion of criteria for recognition of spatter and welded spatter. Walk back to bus and observe, on a clear day, Potter Hill and Big Butte, both Roza vent areas (localities 15 and 17 respectively, in Swanson and others, 1975, table 1).
57.35	3.15	Return to U.S. 12. Turn <u>left</u> on 12, toward Alpowa Summit.
57.9	0.55	Junction with Ledgerwood Road on right. Turn right on Ledgerwood.
59.5	1.6	Small outcrop of Roza spatter on right (locality 13 in Swanson and others, 1975, table 1).
60.35	0.85	Junction with Kirby-Mayview Road. Continue straight (northward) on pavement.
61.25	0.9	Junction with Valentine Ridge Road. Turn right.

Mileage		
Cumulative	Difference	
61.35	0.1	For next 0.3 mi, roadcuts reveal four thin Roza flows with oxidized tops. Two layers of spatter are present, both of which are welded more densely at top than base, showing effect of overlying flow (locality 11 of Swanson and others, 1975, table 1).
63.85	2.5	Junction with Malone Hill Road. Continue straight ahead on Valentine Ridge Road.
64.35	0.5	Junction with road to Clarkston. Continue straight along ridge.
66.6	2.25	Turn right on narrow farm road, possibly impassable in wet weather. Follow road along line of short telephone poles.
67.2	0.6	Go through gate.
67.3	0.1	Bear left at Y-intersection.
67.35	0.05	Bus parking and turn-around near buildings.
67.65	0.3	Car parking in gulley.

Stop 18. This is a hiking stop. We will be away from the bus for 1 to 1-1/2 hrs. Walk to small quarry on hillside 50 m or less east of car parking area. Spatter, some welded, suggests proximity to a vent for a lower Yakima flow. Return to parking area and walk along southeast side of Davis Canyon, contouring above the brush, for 700-800 m. Look across canyon at what appears to be one very thick, platy, viscous-appearing flow. Note the layers. What are they? Drop down to canyon bottom, cross creek, and slowly climb up northwest side of canyon examining the rocks. Spatter and welded spatter are intimately associated

Mileage		
Cumulative	Difference	
		with flows. If we have time, we will examine the flows above this complex. The Priest Rapids, not the Roza, rests on a saprolite developed on a thick vent complex in the lower Yakima basalt. Return to car. We interpret this complex to have been erupted along a vent system, traceable for at least 40 km along a NNW-SSE trend. The lava was apparently viscous and built up low ridges rather than spreading outward as sheets. Occasionally bursts of spatter took place, much as light pumice showers often accompany extrusion of silicic domes and flows. The thick complex still stood high during Roza time, and was not covered until Priest Rapids time or, in places, even later.
74.05	6.4	Retrace route to Kirby-Mayview road. Turn right.
75.7	1.65	Stop just beyond junction with Connell Hill Road.
		Stop 19. Optional. Will stop only if bad weather wipes out stops 17 and 18. Thin Roza flows, with little or no spatter. Experience has shown that such thin flows are likely to be near a vent.
81.45	5.75	Continue on Kirby-Mayview Road to intersection with Tramway Road. Turn right toward Tramway.
85.7	4.25	Cliffs ahead are in a Priest Rapids flow (Lolo chemical type).
86.1	0.4	Stop at white stile over fence.
		Stop 20. Walk over stile and go to lip of Snake River canyon. Discussion of stratigraphy as seen in the canyon walls. Quarry is in a Priest Rapids flow (Lolo chemical type).

Mileage		
Cumulative	Difference	
86.55	0.45	Continue north on Tramway Road. Keep left at intersection with East Wawawai Grade Road.
87.5	0.95	Junction with Kirby-Mayview Road. Turn right.
87.6	0.1	Junction with Wawawai Grade Road. Continue on pavement.
89.85	2.25	Mayview. Continue straight.
90.5	0.65	Bus parking for stop 21. Optional. 0.05 mi farther.
		Stop 21. (Locality 10 of Swanson and others, 1975, table 1.) In roadcut, two thin Roza flows separated by welded spatter. Keep this in mind as we descend toward the Snake.
91.1 91.6	0.6 0.5	Continue on Kirby-Mayview Road to stop 22.
		Note: Bus lets off passengers at 91.1, then drives to 91.6 and waits to pick up passengers, who will walk down road.
		Stop 22. Roadcuts show Roza Member overlying thin, discontinuous silt resting on sparsely phyric Frenchman Springs Member (2 flows). A thin saprolite and red clay separate the Frenchman Springs from lower Yakima basalt. Note how thin the Frenchman Springs is here (20-25 m) compared with Devils Canyon (150 m). No Frenchman Springs is known east of here. Eastward thinning of the Frenchman Springs is typical throughout southeast Washington and is interpreted to mean that the Frenchman Springs was erupted in a basin created by early subsidence of the Columbia Plateau. This also suggests that most of this member's vents are west of the Chief Joseph dike swarm, and indeed many may be hidden beneath the central part of the Columbia Plateau.

Mileage		
Cumulative	Difference	
91.95	0.35	Oxidized contact between two lower Yakima flows.
92.15 92.4	0.2 0.25	Bus lets passengers off at 92.15, then drives to 92.4 and waits. Stop 23. Thin lower Yakima flows. By analogy with the Roza, such thin flows may imply nearby sources. Walk down road for about 400 m. A Roza feeder dike is exposed in the curve (locality 9 of Swanson and others, 1975, table 1). Perhaps this dike erupted spatter at stop 21. We are now on the axis of the Roza vent system. This vent system, described by Swanson, Wright, and Helz (1975), is at least 120 km long and less than 15 km (perhaps less than 5 km) wide. The vent system is defined by dikes such as this one (including many between Little Butte and Potter Hill found after the above-cited paper was written) and occurrences of spatter and pumice. Using the observed dimensions of the vent system and the Shaw and Swanson (1970) rheologic model, eruption rate for the Roza is calculated to be 1 km^3/day/km.
93.85	1.45	Three plagioclase-phyric dikes within 0.2 mi. Two are Roza chemistry and lithology; the third has a composition unlike most other flows.
94.6	0.75	Remnant of intracanyon Pomona flow to left. Not visible from road.
94.75	0.15	At 12-1 o'clock, remnant of Lower Monumental flow capping ridge.

Mileage		
Cumulative	Difference	
95.4	0.65	The Almota-Schultz Bar measured section is directly across river.
99.85	4.45	Bear left at Y-intersection. In 1975-6, a pass is needed to cross Lower Granite Dam, still under construction.
100.6	0.75	Lower Granite Dam.
101.0	0.4	Bear left on road down river.
102.7	1.7	Entrance to Boyer Park. Restrooms.
104.55	1.85	Bear right under railroad bridge and start climb up Almota Grade.
107.65	3.1	Stop 24. Optional. Layer of welded spatter in lower Yakima basalt. May be correlative to the thick, viscous-appearing flow and associated spatter we visited at stop 18.
108.25	0.6	Stop 25. Roadcuts just beyond parking area on right show Roza resting on tuffaceous sedimentary rocks that overlie saprolite developed on the lower Yakima. No Frenchman Springs is present. How long would it take to develop such a thick soil horizon?
108.75	0.5	Roadcut in Roza. Three flows.
111.4	2.65	T-intersection. Turn left toward Colfax.
111.65	0.25	Keep right on pavement.
116.7	5.05	Turn left after sharp right-hand curve.
118.45	1.75	Keep left on pavement.
118.9	0.45	Roza. Note platy jointing similar to that in Roza in Frenchman Springs Coulee.
121.1	2.2	Intersection with State Highway 127. Turn left (west) toward Dusty.

Mileage		
Cumulative	Difference	
129.8	8.7	Junction, S.H. 127 to left, S.H. 26 straight ahead. Continue straight toward LaCrosse, passing through scattered outcrops of a Priest Rapids (Lolo chemical type) flow.
139.15	9.35	Turn right to LaCrosse.
142.3	3.15	Turn right on truck route just within LaCrosse city limit. Cross railroad.
142.35	0.05	Turn right just across tracks toward Winona.
142.8	0.45	Road is in the easternmost scabland channel in this area, virtually along the Roza-Priest Rapids contact.
144.7	1.9	Scabland vista at 11 o'clock. Isolated islands of loess within broad channel.
149.85	5.15	Right turn across railroad tracks.
151.5	1.65	Bear left on main road toward Winona.
152.75	1.25	Small outcrop of Priest Rapids (Lolo chemical type). Priest Rapids covers Roza everywhere in this area, indicating that the Roza vent system at Winona did not build much of a constructional high.
154.1	1.35	Cross railroad, bear right to stop sign. Turn right toward roadcut.
154.6 155.1	0.5 0.5	Bus lets out passengers at 154.6, turns around, and drives to 155.1, parking area next to tracks in Winona. Passengers walk from stop 26 to stop 27.
		Stop 26. Roadcut at locality 5 of Swanson and others (1975, table 1). Bedded Roza pumice and spatter, some of which is welded. Relics of cones and ramparts. Narrow

Mileage		
Cumulative	Difference	
		dike cuts pumice deposit. Roza flow caps outcrop, and thin flows are interbedded with the tephra.
		<u>Stop 27.</u> (Locality 4 of Swanson and others, 1975, table 1.) Railroad cut across the Palouse River from Winona. Walk across railroad bridge from bus parking area. Relic spatter cones and ramparts of Roza lithology scoured and highly modified in shape by bulldozer action of thick, overlying Roza flow. Note the basaltic pumice, still fresh enough to float in the murky Palouse (try it).
		Stops 26 and 27 are among the most convincing of the Roza vent areas. It is easy to imagine how quickly such tephra could be eroded away were it not for a protective capping of some sort (in this case thick flows). Probably cones and tephra deposits like these were formed at most Yakima vents, only to be removed, either by bulldozing during the eruption or erosion after the eruption, before being covered. It is no wonder that vent areas for such flows are difficult to find. These localities are about 8-9 km south of the northernmost known Roza vents. The southernmost known vent areas (actually dikes) are near the Oregon border, 110 km away. Ever since stop 17 this morning, we have been within the general area of Roza venting, yet have traversed only 60 per cent of the length of this vent system. This gives some idea as to the magnitude of the Roza linear vent system.
159.4	4.3	Drive east, past stop 26, toward Endicott. Quarry exposing contact of Priest Rapids (Lolo chemical type) over Roza.