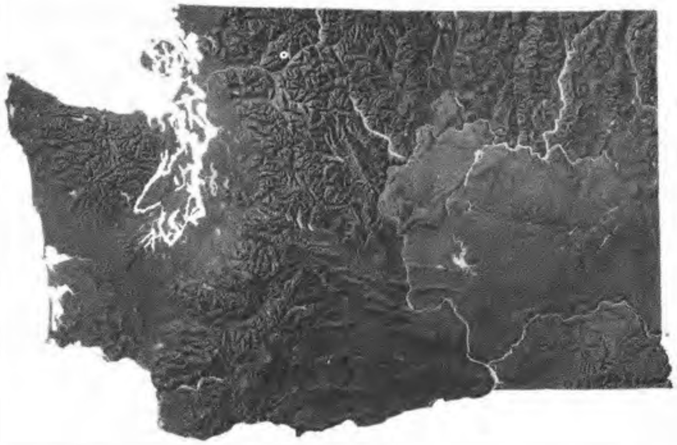

WASHINGTON GEOLOGY

formerly

WASHINGTON GEOLOGIC NEWSLETTER

Washington Department of Natural Resources, Division of Geology and Earth Resources Vol. 19, No. 3, Oct. 1991

Seattle was the site of the First International Symposium on Volcanic Ash and Aviation Safety this July, which devoted a special session to the Pinatubo volcano eruption in the Philippines. Shown here is a view of the June 12 eruption column as seen from Clark Air Base, 20 km east-northeast of Pinatubo. Photograph by Robert S. Culbreth.

WASHINGTON GEOLOGY

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Sunrise Review of the Practice of Geology (18.118 RCW)

Executive Summary

In 1989, legislation (SHB 1597) was enacted that required a sunrise review of the practice of geology in Washington State. State policy as delineated under 18.118 RCW makes it clear that additional regulation of business professions be imposed *only in those cases where such regulation is necessary to protect the interests of the public.*

Proponents of regulation claim consumer and public protection as the rationale for regulation. Another factor, at least as important to geologists, is that they favor regulation as a means of gaining parity as professionals among their colleagues in other western states. It is believed regulation would also help assure public identification of professional geologists.

During the sunrise review process, some case histories were presented to show that regulation would be in the public interest. At first glance, it would appear that there might be some justification for regulation, especially in the environmental disciplines. However, in the majority of the cases presented, the department believes that the regulation of geologists would not have changed the outcome of these cases, because there are no laws or ordinances that require that assessments be made by geologists in the first place. Although there are "sensitive area ordinances" in some cities and counties requiring geotechnical reports, there are none in effect, that the department is aware of, that require geologists to do these reports.

Based on the information collected thus far and on the sunrise review criteria, the department's recommendations to the legislature are:

1) That no state licensing of geologists be required at this time;
2) That further data gathering and analysis be performed, with the focus on environmental geology to see if additional data can support regulation;
3) Consider regulation at a future time when local ordinances require that geologists perform site assessments in specific instances and/or when additional data can support regulation based on the public interest criteria.

(From: Report to the Committee on State Government, Washington State House of Representatives, Representative Mike Todd, Chair. Prepared by the Management Analysis Unit, Budget and Program Support, Department of Licensing, State of Washington, April 1991.) ⚒

Geologic Guide for State Routes 240 and 243 in South-Central Washington

by

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This road log is taken from a series of geologic guides for major routes in south-central Washington. The guides are currently in preparation for a formal DGER publication.

INTRODUCTION

This guide describes the geology along two major highways in south-central Washington (Fig. 1). Part 1 of the road log covers the area from Richland on the south to the junction of State Route (SR) 240 with SR 24. Part 2 covers the area from that junction west and north along SR 243 to Vantage.

This guide takes the traveller across that part of the Columbia Plateau (or Basin) known as the Yakima Fold Belt. The fold belt is a series of anticlinal ridges and synclinal valleys (Fig. 1) and covers about 5,500 mi^2 (Reidel and Campbell, 1989) of the western part of the Columbia Plateau. In this region, basalt flows of the Columbia River Basalt Group and associated sediments were folded and faulted under north-south-directed compression. Readers are referred to papers in Reidel and Hooper (1989), in particular papers in that volume by Campbell (1989) and by Reidel and others (1989a, 1989b), for more detailed information about the geology of this area.

STRATIGRAPHY

The rock types and sequence of strata in the area of this guide are generalized in Figure 2. The dominant rocks of the area are lava flows of the Columbia River Basalt Group and interbedded sedimentary rocks of the Ellensburg Formation. These are overlain by younger sedimentary rocks of the Ringold Formation and by catastrophic flood deposits, which are informally named the Hanford formation.

Columbia River Basalt Group

The Columbia River Basalt Group, commonly referred to as CRBG, is the principal rock unit in the Yakima Fold Belt. The CRBG is a series of basalt flows that were erupted between 17 million and 6 million years ago. The flows originated from northwest-striking feeder dikes near Clarkston and Lewiston in eastern Washington and western Idaho, respectively, and spread westward across the Columbia Basin. The flows now cover approximately 63,205 mi^2 and total about 41,830 mi^3 of basalt (Tolan and others, 1989). The CRBG is divided into five formations; only the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt are exposed in the western part of the Columbia Plateau discussed in this guide (Fig. 2).

Geologists distinguish the various flows of the CRBG by examining their physical features, geochemistry, and paleomagnetism (Swanson and others, 1979). Chemical composition and paleomagnetic data have proven to be the most reliable criteria for flow recognition and correlation. With this information it is possible to confidently identify individual flows of the Grande Ronde Basalt. On the other hand, physical features can be relied on for distinguishing many flows in the Wanapum and Saddle Mountains Basalts.

Ellensburg Formation

The Ellensburg Formation consists of the sedimentary rocks that are intercalated with and overlie flows of the CRBG (Waters, 1961; Swanson and others, 1979; Smith and others, 1989). Most material in the Ellensburg Formation was directly produced by or derived from volcanism in the Cascade mountains. In the Cascade foothills, deposits were laid down primarily by volcanic debris flows (lahars) and related stream and sheet floods. Farther east on the central plateau, the Ellensburg Formation is a mixture of volcaniclastic material and sediments deposited by the ancestral Clearwater and Columbia rivers (Fecht and others, 1987). The Ellensburg Formation ranges in age between 16.5 million and about 5 million years (Smith, 1988; Smith and others, 1989).

Younger Sediments

Sediments continued to accumulate in most synclinal valleys long after the last eruptions of Columbia River basalt. The Ringold Formation of late Miocene and Pliocene age was deposited by main and tributary streams of the Columbia and Salmon–Clearwater river systems. The Ringold contains both fine sediments (indicating a lake or a stream overbank depositional setting) and stream gravels (Fecht and others, 1987; Lindsey and Gaylord, 1990).

More recent deposits are those of the cataclysmic Spokane (or Missoula) floods and post-flood streams. Periodic releases of water from glacially dammed lakes in eastern Washington, Idaho, and Montana resulted in as many as 40 of these floods during the Pleistocene (Waitt, 1980). The flood deposits are called the Hanford formation and are divided into two end members: fine silt and sand of slackwater environments (Touchet beds) and coarse gravel deposits (Pasco gravels). Many Hanford formation deposits are composed of sediments that are gradational between these end members or of intermediate grain or clast sizes.

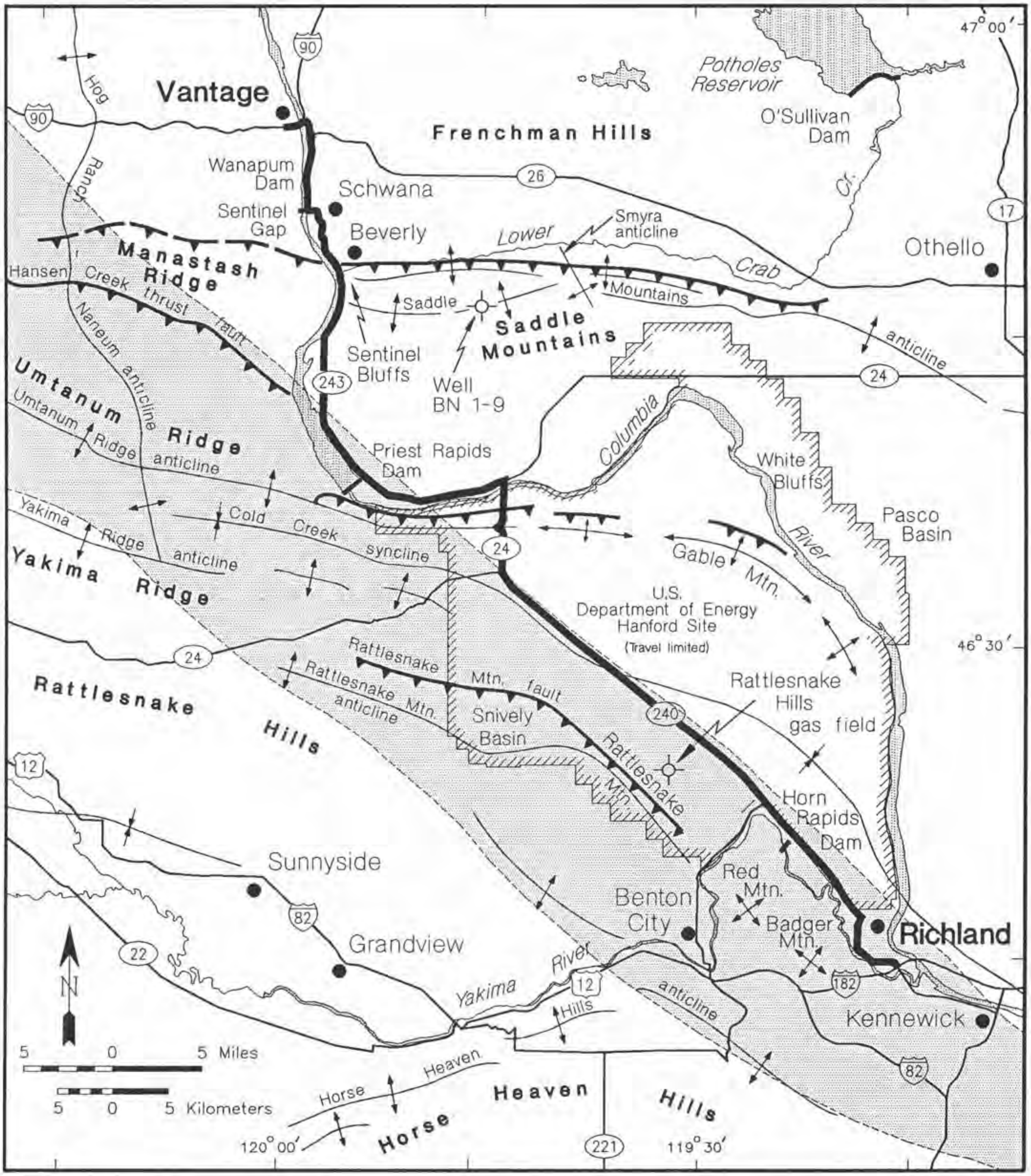

Figure 1. Route of the road log from Richland to Vantage, Washington, showing major geologic structures and geographic locations discussed in this guide. Shaded area is the Olympic–Wallowa lineament. (Redrawn from Reidel and others, 1989a.)

Figure 2. [next page] Diagrammatic stratigraphic section for the area between Richland and Vantage. The interbeds named on the right are part of the Ellensburg Formation. N, normal magnetic polarity; R, reversed magnetic polarity; T, transitional polarity; N_2, R_2, upper normal and reversed magnetostratigraphic units in the Grande Ronde Basalt, respectively.

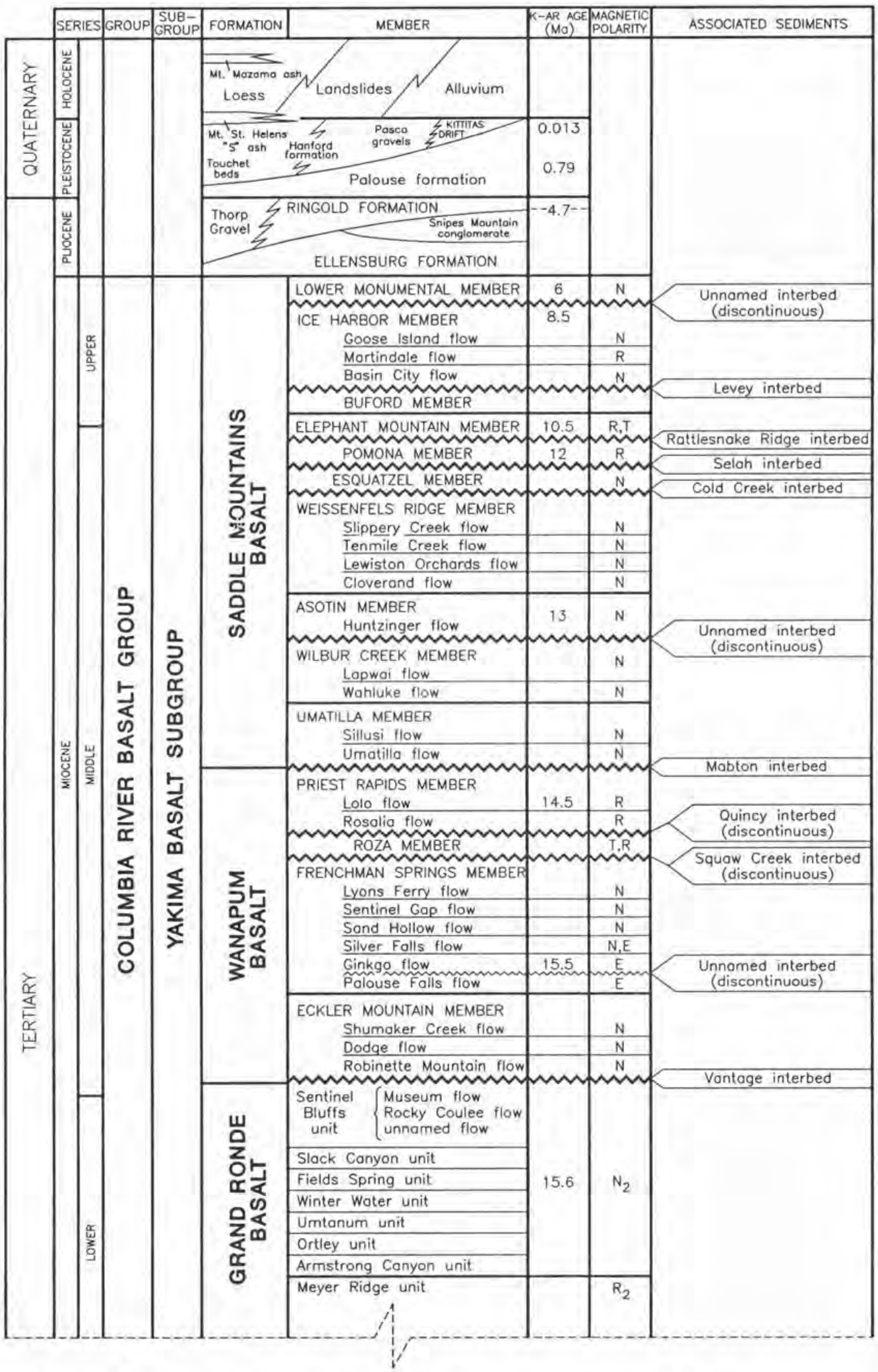

Figure 2. Diagrammatic stratigraphic section for the area between Richland and Vantage. See page 4 for explanation.

Some Pleistocene and Holocene sediments are of eolian origin. Windblown dust and fine sediment (loess) overlie the older rocks and sediments and constitute most of the soil on the surface of the Columbia Basin.

Tectonic Setting of the Columbia Basin

Geophysical evidence indicates that both the Columbia River Basalt Group and sub-basalt sedimentary rocks thicken to the southwest and west from the Palouse slope into the area of the Yakima Fold Belt (Reidel and Campbell, 1989). Columbia River basalts are about 4,000 to 5,000 ft thick on the Palouse slope, but as much as 13,000 ft thick in the fold belt. The pattern of thickness of both the basalts and the sub-basalt units suggests that the fold belt area had been a depression in the early Cenozoic and that both continental sedimentation and the accumulation of basalt kept pace with continuing subsidence of the area. Post-CRBG sedimentation also reflects this subsidence; the Ringold Formation is relatively thicker in the fold belt area. Basalt flows pinch out toward the Blue Mountains to the southeast, indicating that these northeast-trending mountains were rising during and after the accumulation of the flows.

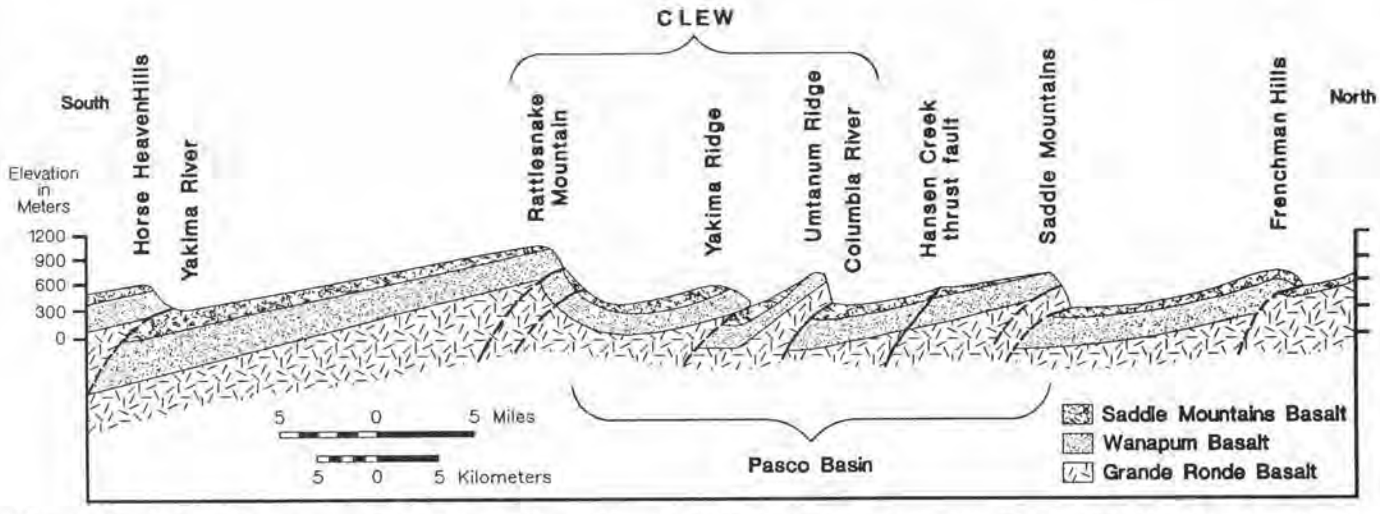

Figure 3. Schematic cross section through the Yakima Fold Belt at about longitude 120°W. CLEW, Cle Elum–Wallula deformed zone. (Redrawn from Reidel and Campbell, 1989).

The folds in the Yakima Fold Belt are typically asymmetrical (Fig. 3); north sides of both anticlines and synclines are steeper. Fold lengths range from several miles to more than 60 mi. Wavelengths reach about 12 mi. Structural relief in most places is about 2,000 ft, but it varies along the fold length.

A major structural trend, the Olympic–Wallowa lineament (OWL), cuts across the fold belt from northwest to southeast (Fig. 4). The part of the OWL in the Yakima Fold Belt is referred to as the Cle Elum–Wallula deformed zone, or CLEW. Within the CLEW, most anticlinal axes trend about N50°W. In contrast, north of the CLEW, anticlinal axes trend more nearly east-west. An important exception is the Hog Ranch–Naneum Ridge pre-basalt structure, which passes under other anticlines and extends south across the entire width of the CLEW and possibly beyond.

For a more complete description of the tectonic setting of the Columbia Basin, see the papers in Reidel and Hooper (1989).

GEOLOGIC ROAD LOG

The mileage column in this road log enables travellers to determine the distance between points. To allow for differences in car odometers, numerous check points are included. Easily identified points, such as creek crossings, campgrounds, and road junctions, are noted.

Many points of interest away from the highway are indicated by a clock position such as "...on your right at 3:00 [o'clock]." This direction system is based on the assumption that the hood of your car is pointed to 12:00 [o'clock], 9:00 is out the left window, 3:00 is out the right, and the rear window is 6:00.

Please park safely off the roadway if you choose to stop and examine geologic features.

Part 1—State Route 240: Richland to the Junction with State Route 24

Miles

0.0 Begin this 65-mi excursion on the north side of Richland at the stop light on the corner of Stewart Street and State Route (SR) 240. Turn north onto SR 240 toward Vantage.

0.3 Cross the railroad tracks.

0.6 The ridges at 9:00 are part of a series of small, southwest-trending hills known locally as the "rattles". The hills are doubly plunging anticlinal ridges along trend with the Rattlesnake Mountains (11:00). These anticlines form the Rattlesnake–Wallula alignment (RAW), which extends from Wallula Gap on the Columbia River to the northeast end of the Rattlesnake Mountain–Snively Basin anticlinal ridge. This alignment is part of the Olympic–Wallowa lineament, which extends from the Wallowa Mountains in northeastern Oregon northwest to the Olympic Peninsula (Fig. 4).

0.7 You will be traveling over stabilized sand dunes and catastrophic flood deposits (Hanford formation) for the next 12 mi. The silty, medium to coarse sand was deposited by the Spokane floods and reworked by wind for several thousand years before vegetation stabilized it. Gravel in roadcuts along this part of the highway has been placed by the Washington State Department of Transportation to reduce movement of the sand and silt during high winds.

3.8 Cross Gross Cup Road. The Richland municipal landfill site is on the right.

4.9 Horn Rapids ORV park on the right.

6.6 Horn Rapids Road on the right (east extension).

7.0 Snively Road on the left.

8.0 The Horn Rapids Dam on the Yakima River is at 9:00. The rapids are cut into the Elephant Mountain and Ice Harbor Members of the Saddle Mountains Basalt; these units are visible upstream and downstream of the dam. The path of the Yakima River here (north from Benton City and then southeast to Richland) was influenced by the uplift of the Horse Heaven Hills anticline to the south (Fig. 1). Prior to this uplift, the Yakima River flowed south of Benton City around Badger Mountain and into the Columbia River near Kennewick. The rising Horse Heaven Hills anticline forced the river east of Benton City into a northerly path. The bend in the river (the "horn") at the rapids was influenced by the plunging anticlinal structure that trends northwest from Red Mountain. The river has eroded a channel across the nose of the structure and exposed the Ice Harbor, Elephant Mountain, and Pomona Members. This structure continues north across the road (3:00) where the gently southeast-dipping Elephant Mountain Member can be seen projecting above the flood gravels.

8.5 Horn Rapids Road (west extension). The Benton City turnoff is on the left.

9.6 Cross under a power line. The quarry at 9:00 is in the Elephant Mountain Member. Rattlesnake Mountain is on the skyline at 10:00 (Fig. 5).

12.1 Milepost 17. This is a good place to study the east face of Rattlesnake Mountain (Figs. 5, 6, and 7). The hummocky southeast end of the ridge is a large landslide. When Pleistocene flood waters undercut the steeply dipping basalt at this loca-

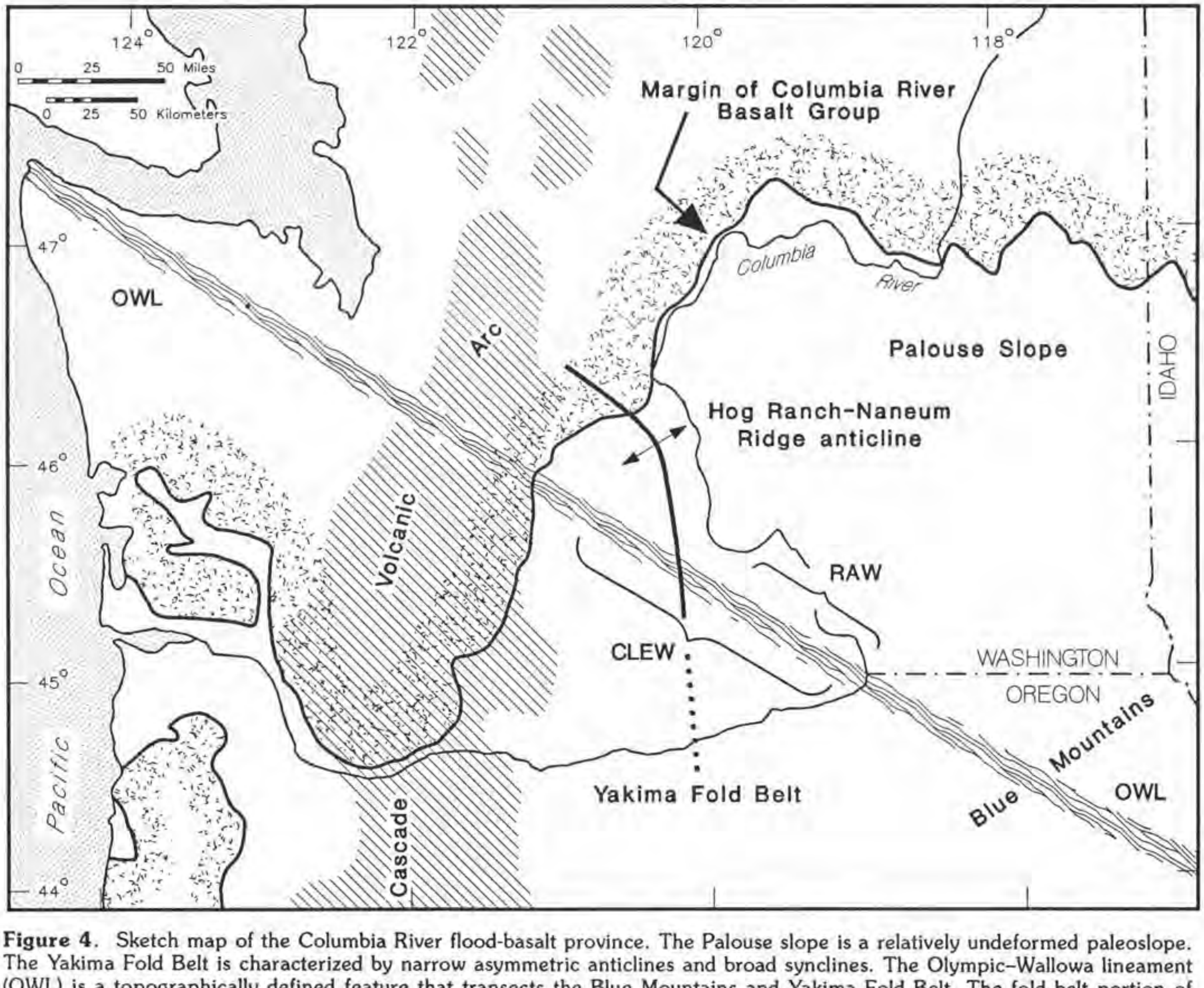

Figure 4. Sketch map of the Columbia River flood-basalt province. The Palouse slope is a relatively undeformed paleoslope. The Yakima Fold Belt is characterized by narrow asymmetric anticlines and broad synclines. The Olympic–Wallowa lineament (OWL) is a topographically defined feature that transects the Blue Mountains and Yakima Fold Belt. The fold belt portion of this lineament is the product of structural deformation; it includes the Cle Elum–Wallula deformed zone (CLEW) and the Rattlesnake–Wallula alignment (RAW). The Hog Ranch–Naneum Ridge anticline is a regional cross-structure in the fold belt. Although the surface expression of the anticline appears to die out south of the CLEW, subsurface data suggest it continues southward to near the Columbia River. (Modified from Reidel and others, 1989a.)

tion, basalt higher on the slope slid on the sedimentary interbed between the Wanapum and Saddle Mountains Basalts.

The mountain is capped by the Pomona Member and, in places, the Elephant Mountain Member; Esquatzel, Umatilla, Priest Rapids, Roza, and Frenchman Springs flows are exposed sequentially down the slope (Fig. 7). An important structure in this area is the Rattlesnake Mountain fault. This is a reverse fault that has two parts: a main lower fault and a secondary upper fault. Faulting has pushed Wanapum flows over younger Saddle Mountains flows.

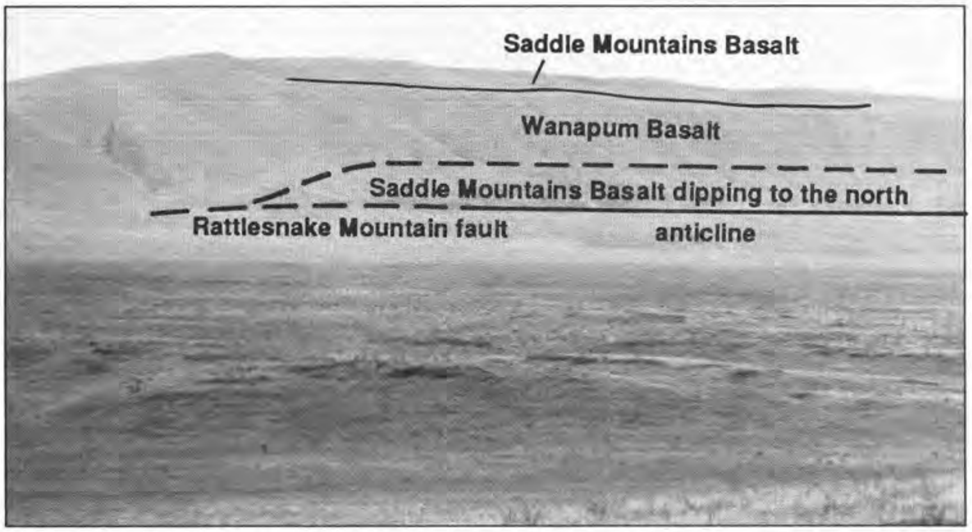

Figure 5. (Mile 9.6) View to the west of the southeast-trending Rattlesnake Mountain anticline, at the faulted and steeply dipping east limb. The crest of the fold is on the skyline. See Figures 6 and 7 for other views. The landslide shown in Figure 6 is to the left of this view.

14.2 For the next 1.2 mi, boulders left by the Spokane floods are visible on the right (east) side of the road. As flood water rushed down the Columbia River after having been temporarily dammed at Wallula Gap, icebergs carrying boulders and smaller fragments of granite, basalt, and other rock types were left stranded at various places in

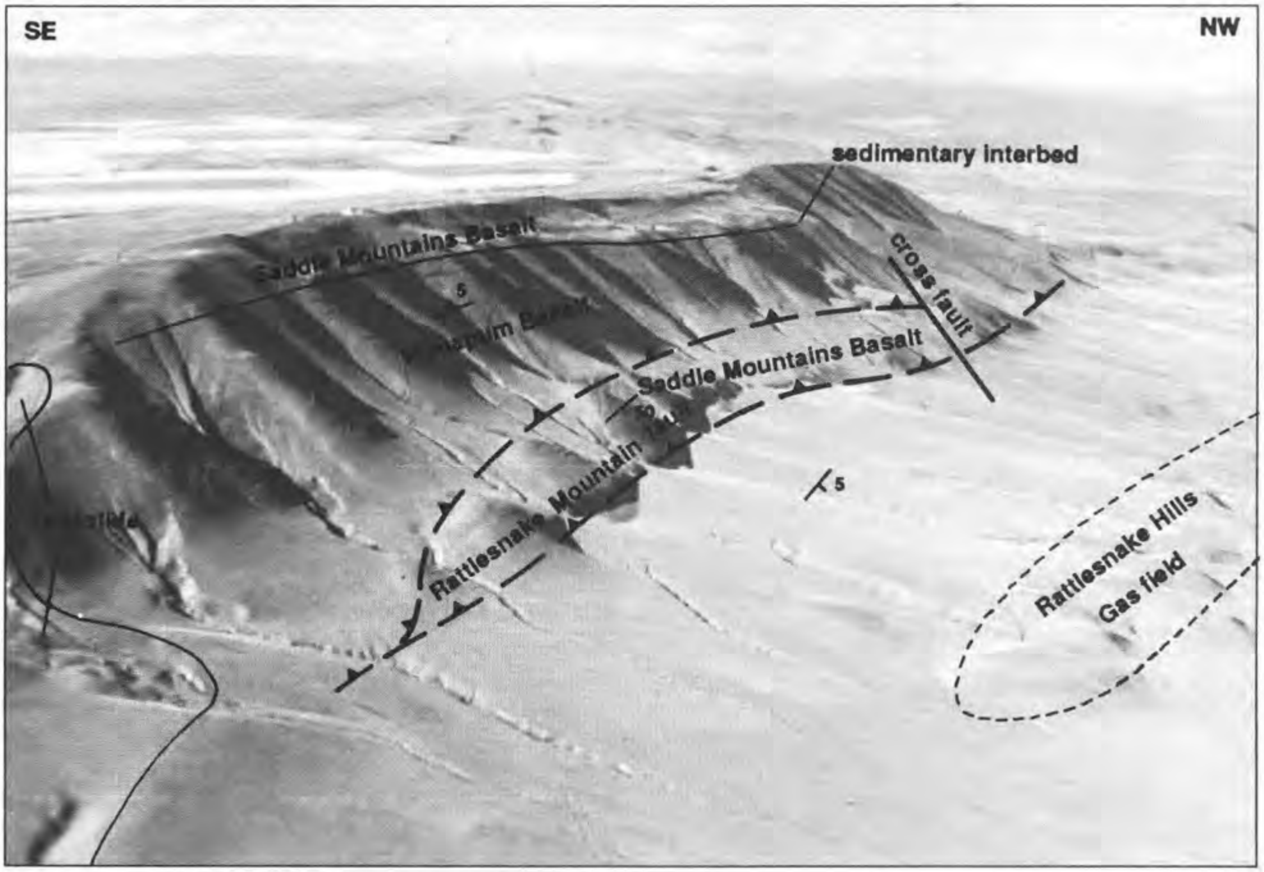

Figure 6. (Mile 12.1) Aerial view of the northeast face of Rattlesnake Mountain. The elevation of the crest of the mountain is 3,600 ft. The upper end of the landslide is just visible on the left side of the photo. See Figure 7 for detailed stratigraphy near faults.

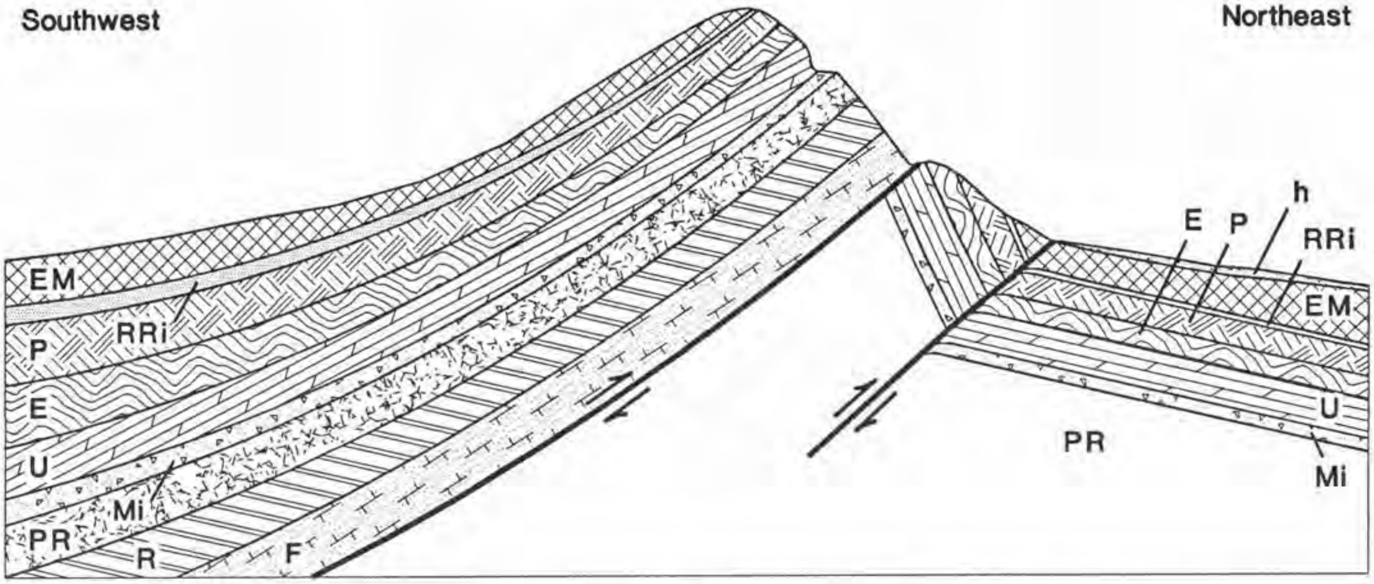

Figure 7. Diagrammatic cross section of southeast-trending Rattlesnake Mountain; view to the northwest and not to scale. F, Frenchman Springs Member; R, Roza Member; PR, Priest Rapids Member; Mi, Mabton interbed; U, Umatilla Member; E, Esquatzel Member; P, Pomona Member; RRi, Rattlesnake Ridge interbed; EM, Elephant Mountain Member; h, Hanford formation. Capital letters indicate units of Miocene age; lower case letters indicate Pleistocene or Holocene age.

the Pasco Basin. When the ice melted, the "foreign" debris was left behind as erratics.

The evenly spaced ridges on the right skyline are dunes. They resemble giant ripple marks as seen from ground level.

16.9 Cross under a power line. At 10:00 is a good view of a small anticline just northeast of the main Rattlesnake Mountain. This is the site of the former Rattlesnake Hills gas field, one of the few commercial fields ever found in Washington. The field produced moderate quantities of low-pressure natural gas from the Wanapum and Saddle Mountains section of the Columbia River basalt in the 1930s. Enough gas was produced in the field's history to supply a city the size of Richland for about a year. The field was depleted and abandoned in the early 1940s.

17.0 This is your first view of a large alluvial fan at the base of the Rattlesnake Hills to the southwest. The southeast bend of Yakima Ridge is visible at 11:00.

19.1 Milepost 10. At 9:00 the sharp west turn in the Rattlesnake Mountain–Rattlesnake Hills anticline is visible. From here, there is an excellent view of a large alluvial fan. Landslides can be seen on both sides of this fan.

21.9 SR 240 turns more westerly. At 11:00 Snively Basin can be seen between Yakima Ridge and Rattlesnake Mountain. This area is the junction between Rattlesnake Mountain and the Rattlesnake Hills. At 12:00 you can see the southeast bend in the Yakima Ridge anticline. The fold plunges beneath basin fill (flood sediment and dune sand) ahead. Also ahead are several small basalt outcrops at road level along the south side of the road. These are the Elephant Mountain Member and are at the crest of the buried Yakima Ridge anticline.

23.8 SR 240 turns more northerly again.

24.2 Cross under a power line. The highway is now crossing the Cold Creek syncline. This area was at one time a proposed location for a high-level

Figure 8. (Mile 1.8 on SR 24) This giant flood bar deposited by Spokane floods lies just across the Columbia River. The Saddle Mountains anticline is on the skyline. The arrow marks the site of the abandoned Shell BN 1-9 well.

Figure 9. (Mile 3.6) Steep dip slopes at the base of the ridge in Grande Ronde Basalt on the north flank of the Umtanum Ridge anticline. Compare these 70° dips with the nearly flat-lying flows on the skyline.

nuclear waste repository. At 9:00 the southeasternmost exposure on the crest of the Yakima Ridge anticline reveals the Pomona member. At 12:00, the east-trending Umtanum Ridge can be seen.

The RAW does not extend to Yakima Ridge. The reason for its sudden termination near here is unknown.

25.7 The highway crosses the axis of the Cold Creek syncline here.

27.8 Cross under the power lines. The hills at 1:00 are part of a large flood bar, the Cold Creek bar, made up of Pasco gravels deposited by a Spokane flood.

28.4 The gravel pit at 9:00 is in Pasco gravels.

28.7 You are climbing onto the Cold Creek bar. Huge gravel bars lie on both sides of the Columbia River where the flood water spilled out of Sentinel Gap, a narrow gorge in the Saddle Mountains to the north. To the east, many of the plant facilities of the U.S. Department of Energy's Hanford Site, including the waste separation areas, are built on this feature.

29.4 Junction with SR 24 (west) to Yakima and the "Yakima Barricade" (east), entrance to the Hanford Site.

End of Part 1.
Reset your odometer at this junction.

Part 2—State Route 240: From the State Route 24 Junction to Vantage

Miles

0.0 Head north on SR 24 East. The ridge at 12:00 is the Saddle Mountains anticline. A Shell Oil Company well site is at 12:30. (See Fig. 8.) The well, drilled to a total depth of more than 17,000 ft, penetrated 11,500 ft of Columbia River basalt and passed into pre-basalt sedimentary rocks here. (See Campbell and Banning, 1985, and Reidel and others, 1989b.)

Cross the Umtanum Ridge anticline. Gable Mountain is at 3:00; it is an extension of Umtanum Ridge and is capped by the Elephant Mountain Member.

You are traveling across Pasco gravels; the coarse deposits here were left by the last Pleistocene flood, which occurred about 13,000 years ago.

1.3 Milepost 40.

1.8 Curve to the left in the road. The turnoff at the right gives you a good view of the northern part of the Pasco Basin. At 12:00, beyond the Vernita Bridge across the Columbia River, is a giant gravel bar deposited by a Spokane flood (Fig. 8). Good places to examine the lithology of this bar are along SR 24 across the river and in a roadcut along Road L-SW. White cliffs at 2:00 across the river, known as the White Bluffs, are sediments of the Ringold Formation.

The Shell Oil Company BN1-9 well site is at 12:30. The well was drilled west of a cross-structure, the Smyrna anticline, in the Saddle Mountains fold.

The Saddle Mountains at 12:30 are capped by the Pomona Member; the sequence of basalt flows exposed on the Saddle Mountains to the east is (from youngest to oldest) the Asotin, Priest Rapids, Roza, and Frenchman Springs Members and Grande Ronde Basalt.

At 11:00 is Sentinel Gap, a water gap cut by the Columbia River as the Saddle Mountains were uplifted. It is interesting to speculate on why the Columbia was able to cut down through the Saddle Mountains here but was forced eastward around Umtanum Ridge as that area was elevated also. The ancestral Columbia River, prior to the uplift of these ridges, was flowing westward toward Yakima, across what is now Satus Pass, and to the present location of the Columbia River near Goldendale. Uplift of the Horse Heaven–Rattlesnake–Yakima–Umtanum ridge system pushed the river eastward to its present position. The Columbia River has flowed through here since at least Vantage interbed time (about 15.6 million years ago).

2.0 Roadcuts here are in Pasco gravels.

2.7 Basalt cliffs on right side of roadway. The quarry at 3:00 is cut in the upper part of the cliffs, which consist of the Pomona Member. The lower cliffs are the Umatilla Member.

At 12:00 are several inactive reactors of the Hanford project. The B and C reactors are the closest to you. The B reactor tower to the south was the site of the first plutonium production.

3.1 Cross under several power lines.

3.6 Midway Power Station Road is at 9:00. You are still traveling on flood gravels.

At 9:00 is a good view along the north limb of the Umtanum Ridge anticline. Here, flows of the Grande Ronde and Wanapum Basalts dip about 70 degrees to the north (Fig. 9). Farther west the Grande Ronde Basalt is overturned and dips steeply to the south (Fig. 10).

5.0 You are crossing the Vernita Bridge over the Columbia River. The last free-flowing segment of the Columbia River in Washington, the Hanford Reach, lies between here and Richland; it is 51 mi long. The hill directly ahead is part of the giant flood bar described at mile 1.8.

5.5 Junction of SRs 243 and 24. Turn left onto SR 243.

6.1 Travel west on SR 243. Road L-SW, at 3:00, is a good place to examine flood bar deposits. The best exposures are along cuts in the road 0.6 mi north.

7.7 Cross under the power lines. The road here lies on the Pasco gravels. A giant flood bar makes up the hill at 3:00. The Umtanum Ridge anticline is directly ahead.

8.2 Sign: "Leaving Saddle Mtn. National Wildlife Refuge". Grande Ronde and Wanapum Basalts can be seen dipping 70 degrees north in cliffs at 9:00. (See Fig. 9.) Frenchman Springs basalt flows are on the skyline. The eroded north limb of Umtanum Ridge offers good views of the complex geology here for the next 3.5 mi.

9.3 Road O-SW is at 9:00. To the south, flows of the Grande Ronde Basalt are nearly vertical; at 12:00 they are overturned and dip steeply to the south (Fig. 10, section B-B′, and Fig. 11). Umtanum Ridge here is broken by several thrust faults on the north flank. The total shortening along these faults is considered by Bentley (1977) to be several miles. Bentley has mapped at least five thrusts along Filey Road west of Priest Rapids Dam. (See Fig. 12.)

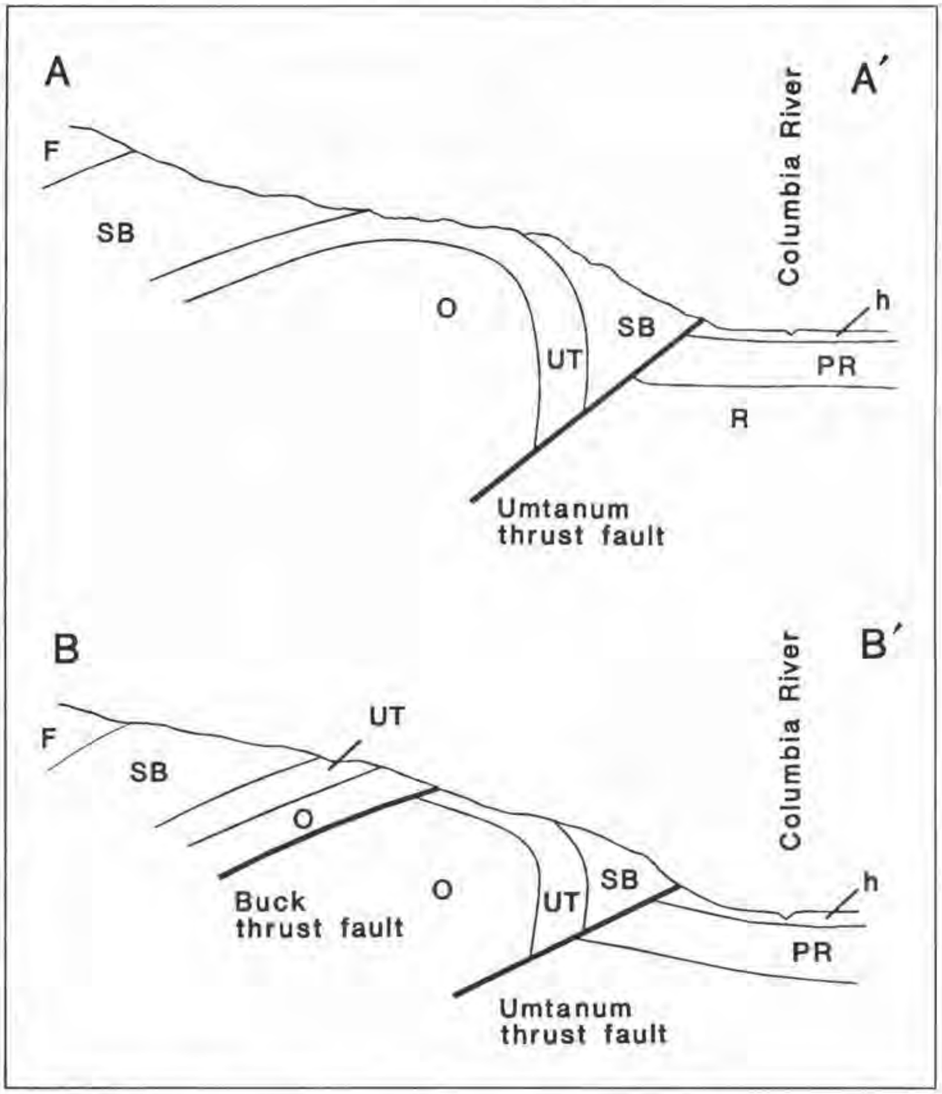

Figure 10. (Mile 9.3) North-south cross sections showing changes in the character of the Umtanum anticline. Section A-A′ is from about 1.5 mi east of Priest Rapids Dam. Section B-B′ is at Priest Rapids Dam. SB, Sentinel Bluffs unit; UT, Umtanum unit, and O, Ortley unit; these units are part of the N_2 magnetostratigraphic unit of the Grande Ronde Basalt. See Figure 7 for an explanation of other letter symbols.

11.4 Borrow pits on both sides of road are in flood gravels.

11.6 Cross under the power lines. Flood gravels are exposed in roadcuts here.

12.5 At 10:00 is a good view of Priest Rapids Dam and the thrust faults of the Filey Road area (Fig. 12). Many of the thrust faults are partially concealed by landslides, fanglomerates, and loess, but at least one is visible. (For detailed cross sections, see Bentley, 1977.) The thrust faults place the Priest Rapids Member and older rocks onto the nearly flat-lying Elephant Mountain, Pomona, and Priest Rapids Members. Flood gravels near the river level mask the bedrock geology.

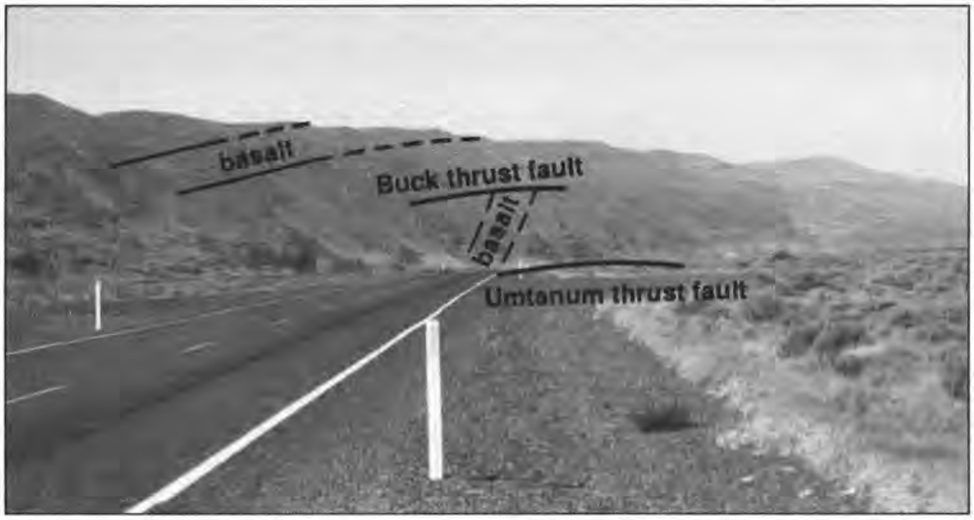

Figure 11. (Mile 9.3) Overturned Columbia River basalt flows on the north limb of Umtanum Ridge. See section B-B′ of Figure 10. Flow attitudes are indicated by the dashed lines.

14.2 Priest Rapids Dam turnoff. Basalt erratics at 3:00 were left by the Spokane floods.

15.5 Desert Aire community on the left. The flow at 3:00 is the Pomona Member.

16.3 At 9:00, rock units west of the Columbia River are, from river level up: Priest Rapids Member, Pomona Member, and Ellensburg Formation (visible in the quarry as a white layer).

16.6 Milepost 11.

17.8 Road 26SW. You are still traveling along flood gravels.

At 12:00 is an excellent view of Sentinel Gap. The antecedent Columbia River maintained its course as the Saddle Mountains were uplifted, cutting down through this ridge at Sentinel Gap (Fig. 13).

At 9:00, the Hansen Creek thrust fault extends to the west shore of the Columbia River; it is covered by flood bar gravels on this side of the river. This thrust places Priest Rapids and Roza basalt flows over the Priest Rapids flows. The Hansen Creek fault has been traced by Bentley (1977) along Manashtash Ridge at least as far as the Yakima River canyon. The Asotin Member, which crops out at lower elevations of the Saddle Mountains anticline at 10:00, fills a former channel of the Columbia River through Sentinel Gap.

18.3 Large boulders, mostly basalt, on both sides of the road were probably plucked from near Sentinel Gap by the Spokane floods and deposited here.

19.7 Mattawa Road (Road 24SW). The giant flood bar extends from this point eastward to SR 24.

20.1 The flow at 1:00 is part of the Elephant Mountain Member. Sentinel Gap lies ahead.

20.6 At 2:00, the south flank of the Saddle Mountains anticline is visible. There, the Elephant Mountain flow dips toward you. The quarry upslope exposes a thick, white interbed of the Ellensburg Formation (Fig. 14).

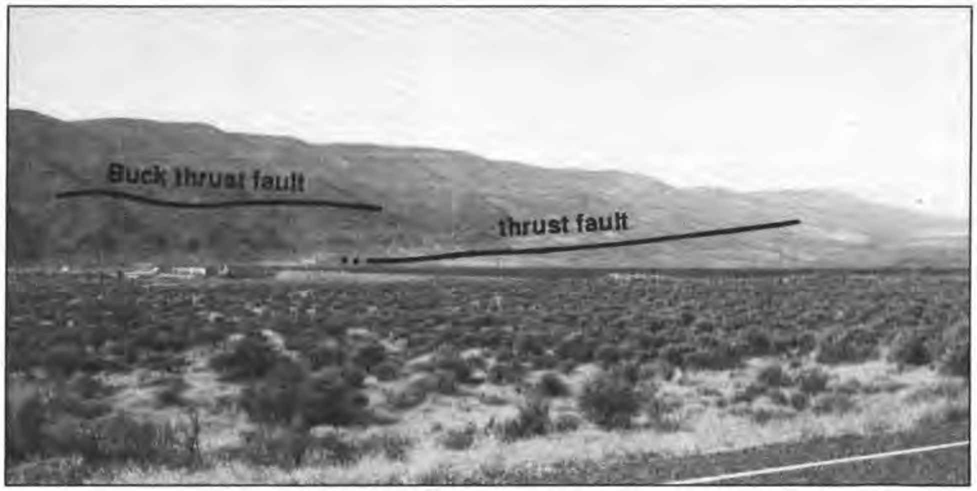

Figure 12. (Mile 12.5) Priest Rapids Dam and Filey Road. A thrust fault is visible at about dam level. Several other thrust faults may be present here, but they are at least partly covered by landslide debris.

21.7 At 1:00 along the right (east) side of Sentinel Gap, the Frenchman Springs, Roza, and Priest Rapids Members form the upper cliffs (Fig. 14). The bench below the upper cliffs is the result of erosion along the Vantage interbed of the Ellensburg Formation. The lower cliffs here are flows of the Grande Ronde Basalt.

At 11:00, west of Sentinel Gap, the white patch high on the cliff face is the Vantage interbed. Frenchman Springs basalt lies above it and Grande Ronde basalt below (Fig. 15).

22.4 The road to the right leads to a quarry exposing an interbed of the Ellensburg Formation. (The name Beverly was formerly applied to this interbed. The name is no longer used because this unit is a composite of several interbeds; the intervening flows are not present.) This quarry is a good place to see this 180-ft-thick interbed (Fig. 16). The lower part contains conglomerate deposited by the ancestral Columbia River, and the upper part is made up of poorly indurated siltstone, sandstone, and tuff. Here, during pre-Elephant Mountain time, the ancestral Columbia River flowed in nearly the same location as it does today.

Figure 13. (Mile 17.8) Sentinel Gap, which was cut by the Columbia River through the Saddle Mountains anticline.

23.2 A landslide on the Vantage interbed can be seen at 1:00. However, the interbed is not exposed here.

23.4 Grande Ronde Basalt at 3:00.

23.8 Milepost 18. Mazama ash is exposed in the roadcut at 3:00 (Fig. 17). Its age is 6,600 years, and it originated during the explosive eruption that formed Crater Lake in Oregon.

At 11:00 are excellent exposures of Grande Ronde Basalt, the Vantage interbed, and the upper part of the Frenchman Springs Member, as well as a good cross-sectional look at the Saddle Mountains (Fig. 18).

The Grande Ronde Basalt has been divided into 17 units (Reidel and others, 1989b). The Sentinel Bluffs unit, the youngest of the Grande Ronde units, consists of flows that have a high magnesium content relative to other Grande Ronde units; it has normal magnetism. At 9:00 all but the lowest two flows are Sentinel Bluff flows. At 3:00 the lower flows are exposed here, the Umtanum and Ortley units. A thick section of these units is exposed just out of sight on the west side of Sentinel Gap (Fig. 18).

A large thrust fault at the base of the north flank of the Saddle Mountains places Grande Ronde Basalt on top of the Priest Rapids Member. Horizontal shortening is at least several miles. The fault cuts across the Columbia River somewhere between here and the town of Schwana. In addition, a north-trending right-lateral strike-slip fault cuts through the ridge at the gap (Reidel, 1984, 1988) (Fig. 19).

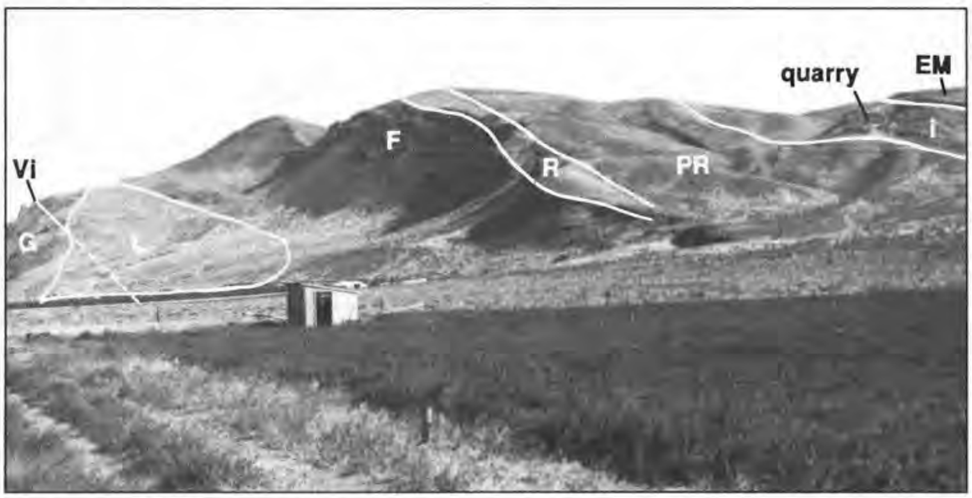

Figure 14. (Mile 21.7) The quarry on the hillside at the right is in a thick interbed (i). The Elephant Mountain Member (EM) lies above it. The small landslide (L) is composed of colluvium and Vantage interbed sediments that slid on the bench of the Grande Ronde Basalt (G). The cliffs above are Frenchman Springs (F), Roza (R), and Priest Rapids (PR) Members.

24.0 Sediments deposited by the Spokane floods are visible at 3:00. Sentinel Gap was greatly enlarged by the floods, especially the last and largest one, which occurred about 13,000 years ago. The entire Columbia River Gorge from here to Vantage shows the effects of catastrophic flooding: wide, flat, scoured valley bottoms, giant ripples and flood bars, erratics, and flood sediment plastered or smeared against cliffs and canyon walls.

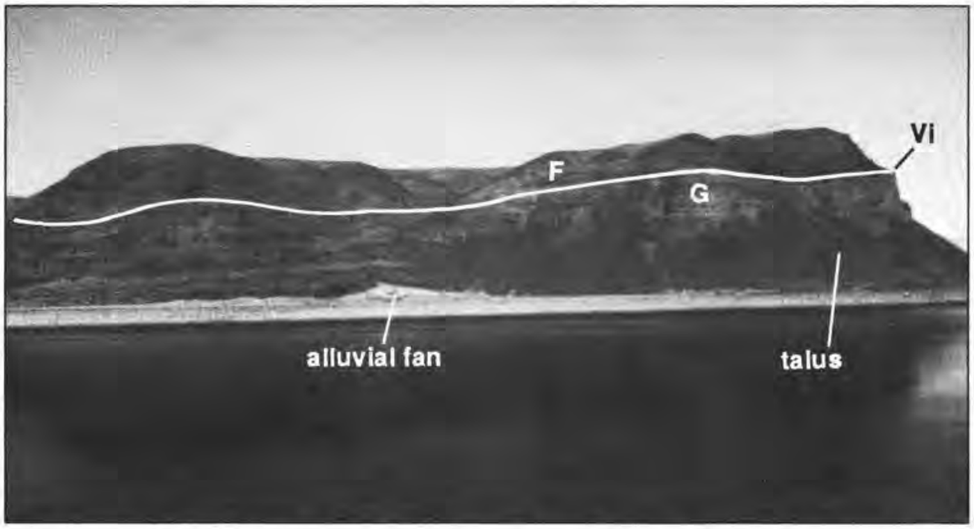

Figure 15. (Mile 21.7) The white line on the cliff face is the Vantage interbed (Vi). It is overlain by the Frenchman Springs Member (F); Grande Ronde Basalt (G) lies below it. View to the northwest.

24.3 Well-developed columns in the lowest flow of the Sentinel Bluffs unit (Grande Ronde Basalt) are exposed here. This is the colonnade portion of the flow. Entablatures of the Grande Ronde flows are hackly or broken and were therefore easily removed by flood action.

24.5 Very strong winds blow through this part of Sentinel Gap. The dunes at 3:00 are composed of flood sediment, chiefly from the Touchet beds, reworked by the wind.

25.5 Lower Crab Creek at 3:00.

25.8 Entering Schwana. You have a good view of the Crab Creek floodway at 3:00. Crab Creek acted as an overflow channel as flood waters farther up the Columbia spilled out of the channel and spread across the Columbia Basin. Some of this water scoured out the Crab Creek drainage as it returned to the Columbia River here.

At 5:00 a thrust fault (or a high-angle reverse fault) has formed a very steep cliff along the north flank of the Saddle Mountains (Fig. 19).

At 10:00 fault breccia from the Saddle Mountains thrust fault is barely visible across the river (Fig. 18).

27.0 Town of Beverly and Crab Creek Road at 3:00.

27.1 Railroad underpass. Erratics at 3:00.

27.5 At 2:00 the flows are the Frenchman Springs (above), Roza, and Priest Rapids Members. At 9:00 across the river is the same sequence.

30.2 Wanapum Dam Road at 9:00. The west abutment of the dam is in the Frenchman Springs Member. The view at 5:00 is of the Saddle Mountains front.

30.4 SR 243 lies on Frenchman Springs flows for the next 0.6 mi. The Roza Member forms cliffs above the highway level.

31.0 Touchet slackwater sediment is exposed in the roadcut at 3:00. The Mount St. Helens S ash (13,000 years old) is visible in the sediment here as a 1-in.-thick white layer.

31.7 Well-developed columns in the colonnade of the Roza Member can be seen at 2:00 (Fig. 20). Floodwater scouring removed much of the entablature here.

This is a good place to search for phenocrysts in basalt. The Roza has several hundred 2-5-mm

Figure 16. (Mile 22.4) A thick interbed (i) is exposed as a white layer between the Elephant Mountain (EM) and Priest Rapids (PR) Members. View to the east.

phenocrysts per square meter of surface area; this is a distinctive characteristic of this flow. (In contrast, most Frenchman Springs flows have fewer phenocrysts and Priest Rapids flows contain almost no phenocrysts.)

33.1 Basalt of the Frenchman Springs Member (Sand Hollow flow). Note the white "sand" clinging to the sides of the roadcut. This is tephra from the May 1980 Mount St. Helens eruption.

33.5 View of Vantage, Vantage bridge, and the Columbia River at 11:30. The town of Vantage rests on the Museum flow of the Grande Ronde Basalt. The Vantage interbed forms the bench along the river here; the Frenchman Springs and Roza flows lie above that level.

Figure 17. (Mile 23.8) Lens of Mazama ash (at arrow) exposed in colluvium in a roadcut.

34.2 Intersection of SRs 243 and 26; road sign for SR 26 to Royal City.

The type section of the Ginkgo and Sand Hollow flows of the Frenchman Springs Member is 0.2 mi east along SR 26. Excellent pillow palagonite complexes in the Ginkgo flow are exposed in the roadcut (Fig. 21). The petrified wood shown in the museum at Ginkgo Petrified Forest State Park at Vantage comes from this pillow complex throughout the area.

Continue north on SR 243–26 toward I-90.

35.6 I-90 intersection. Turn left and cross the bridge to reach Vantage. (See Carson and others, 1987, for information about this area.)

End of log.

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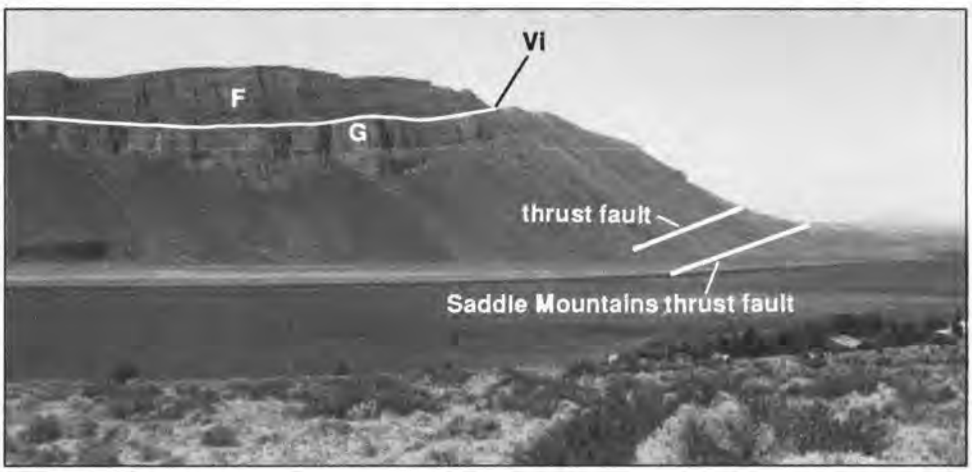

Figure 18. (Mile 23.8) View of the north and west side of Sentinel Gap. G, Grande Ronde Basalt flows; Vi, Vantage interbed; F, Frenchman Springs Member flows. The basalt is folded over here, and two faults are exposed, the Saddle Mountains fault and an upper fault of limited extent. The Saddle Mountains fault places basalt over the Ringold Formation. The Columbia River follows a tear fault at this location.

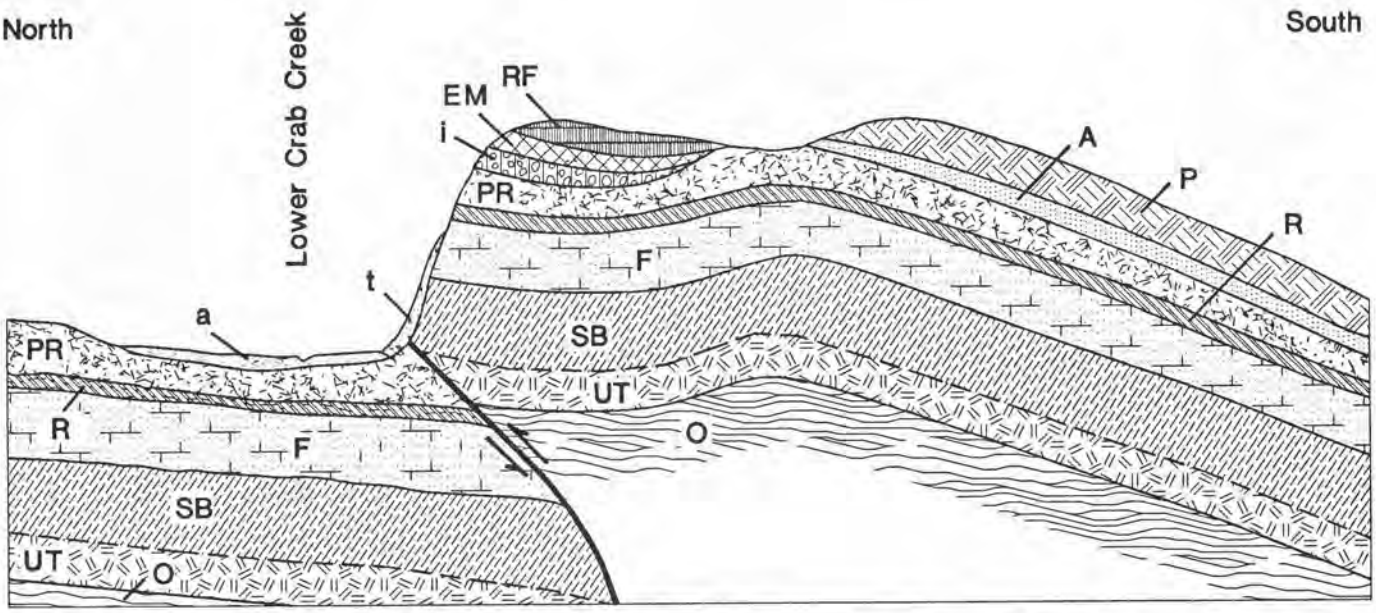

Figure 19. Diagrammatic cross-section through the Saddle Mountains east of Sentinel Gap. View to the east; not to scale. UT, Umtanum, and O, Ortley units of the Grande Ronde Basalt; SB, Sentinel Bluffs unit of Grande Ronde Basalt; F, Frenchman Springs Member flows; R, Roza Member; PR, Priest Rapids Member; A, Asotin Member; P, Pomona Member; i, sedimentary interbed; EM, Elephant Mountain Member; RF, Ringold Formation; a, alluvium; t, talus. Uppercase symbols indicate units whose age is Miocene or Pliocene; lower-case letters indicate units of Pleistocene or Recent age. Note that the Elephant Mountain, Ringold fanglomerate, and interbed on the north face pinch out to the south. The Pomona, interbed, and Asotin pinch out to the north. (Modified from Reidel, 1988.)

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Figure 20. (Mile 31.7) Columns in the Roza Member.

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Figure 21. (Mile 34.2) Pillows in Ginkgo flow of the Frenchman Springs Member along State Route 26. Petrified wood is found locally at this stratigraphic level. Pillows are created when basalt comes in contact with water or damp sediments. A common product of this contact is palagonite, a hydrated basaltic glass. The pillows and palagonite form foreset beds, as in a delta, and dip to the east. This pillow palagonite complex is in essence a delta built by the Ginkgo flow as it flowed out into a lake that once existed here.

Bulletin 78 Wins AEG Award

The *Claire P. Holdredge Award* has been given to the Division's **Bulletin 78, Engineering geology of Washington**. The Association of Engineering Geologists (AEG) presents this honor to the publication (by an AEG member) released in the previous five years that makes an outstanding contribution to the engineering geology profession.

Richard W. Galster was the chairman of the editorial committee for this two-volume collection of papers. C. P. Holdredge was a founding member of AEG, as well as its first president.

Correction

The second from the last paragraph in the right-hand column of p. 22 of Washington Geology, vol. 19, no. 2, June 1991 (Geology of the Yacolt Burn State Forest) should read: A tourmaline-bearing breccia pipe, called the Black Jack breccia pipe, is associated with the quartz diorite dikes and plugs of the Silver Star pluton. The breccia pipe is about 500 ft wide, 800 ft long, and 800 ft deep. Reserves identified on the basis of drilling are 2.9 million tons of rock containing 1.62 percent copper, 0.035 percent molybdenum, and 0.35 oz of silver per ton.

Significance of the Eocene Fossil Plants at Republic, Washington

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The fossiliferous beds in and near Republic, WA, continue to provide abundant, well-preserved plant specimens. Paleobotanists have already recognized about 210 species from these beds. Many of these fossil plants have been found only at Republic and are known from only one or two specimens. Moreover, species new both to the Republic flora and to science are still being discovered.

Fossil plants offer important information about Earth's history. The Republic fossils are giving us a glimpse of the ancient environment in the Republic area. From the flora, we can deduce what the climate was like and what the elevation of the area must have been when the plants were accumulating in the sediments. Further, these fossils tell us much about the evolution and biogeography of many groups of plants that now grow in temperate climates.

Paleobotanists and neobotanists distinguish between a flora, which is the *kinds* of plants (species) in a given area at a given time, and *vegetation*, which is the general physical aspect that the plants present in a specific area at a specific time. In Republic today we have many plant species, but the vegetation is preponderantly conifer forest. If we were to go to an area in Asia that has a climate like that of Republic, we would also find a conifer forest, but the flora would contain different species. The term conifer forest simply implies that the dominant trees have needle leaves and that broad-leaved trees and shrubs (angiosperms) may be important elements in the forest.

The flora itself, such as the presence of maples, may be of only general help in telling us about ancient environments. For example, vine maple (*Acer circinnatum*) is quite common in the conifer forests of western Washington and Oregon. Maples live in the mild climate of moderate elevations in Indonesia and also in the very cool and extreme climate of Manchuria and adjacent maritime provinces of the Soviet Union. Members of the maple family are present in both kinds of environments, but the species respond to this climatic range by exhibiting a wide range of leaf forms.

In the Indonesian maple species, the leaves are leathery and evergreen and have no lobes or teeth along the leaf margin. These simple margins are also found in unrelated species in other families and orders of plants that also live at these elevations. The maples in Manchuria, however, have thin, deciduous leaves that have lobes on which are many sharp teeth. And when we contrast the very small, rounded leaves of plants in the desert vegetation near Phoenix with the very large leaves that have elongate drip-tips of the trees and shrubs that grow in tropical rain forests, we can see that physical characteristics, or physiognomy, of leaves can be important climatic indicators.

However, climate is a complex interaction of temperature and rainfall. Attempting to characterize an ancient environment from leaves is a complicated task. Like many other areas of science, paleobotany has benefitted from the development of computer programs. Programs that fall into the general category of multivariate analysis can simultaneously analyze all physiognomic characters of leaves. From this analysis we can tell which characters have the same pattern of variation as particular climatic factors. In Figure 1 we show results of a multivariate analysis. The vertical axis represents temperature; characteristics of tropical rain forests in Fiji and New Caledonia and of Sonoran desert plants all plot high on this axis. The horizontal axis represents the degree of water stress. The Sonoran desert samples are on the far right, and the tropical and temperate rain forests on the left. The fields indicated for other samples are based on plants from areas for which there is a sound meteorological data base. The climatic data–leaf physiognomy analysis is accurate to about 1°C (less than 2°F). Thus, by analyzing the physiognomy of leaves in a fossil flora, we can arrive at an accurate picture of the climate in which the plants were living. This method of analysis is known by its acronym, CLAMP, for Climate–Leaf Analysis Multivariate Program.

Using CLAMP, the yearly mean temperature for the leaves in the three fossil localities in and near Republic was about 10°C (50°F). Rainfall is estimated to have been about 120 cm (47 in.), with much of that falling during the growing season. We conclude that winters were warm in comparison to the present and that the average January temperature was about 7°-8°C (45°F). This Eocene climate would have been very similar to that along the Pacific coast today or in the coastal valleys of southern Oregon, except the Republic climate had more summer rains.

Many paleobotanists use a plot like that in Figure 2 (called a nomograph or nomogram) to portray modern and ancient temperature regimes. In this plot, mean annual temperature, mean temperatures of both warm and cold months, and mean annual range of temperature are all shown. Clearly, the Eocene temperatures near Republic were significantly different from those of the 1990s.

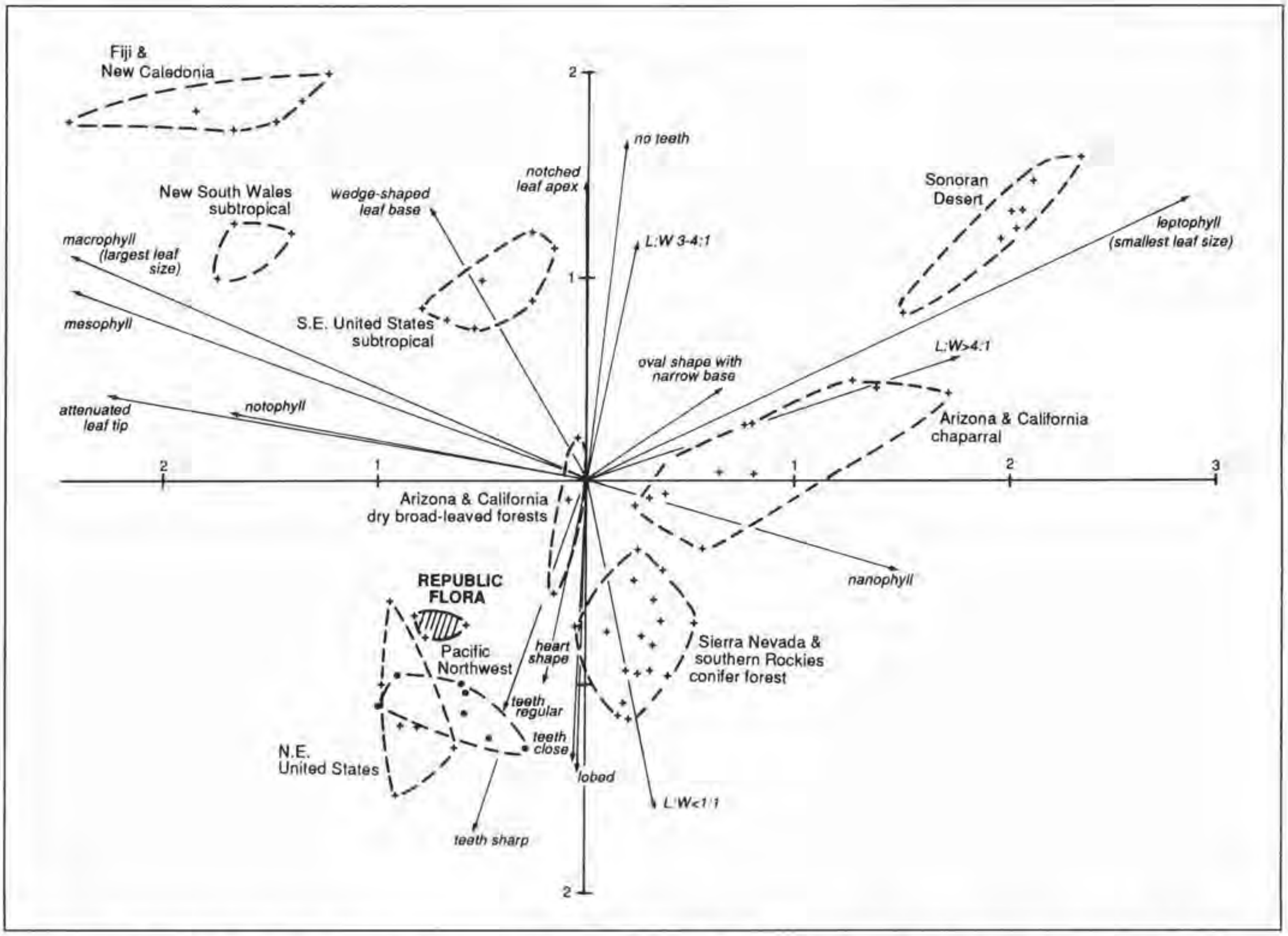

Figure 1. Results of multivariate (correspondence) analysis of leaf characteristics, or physiognomy, from a wide range of modern climates. Fields are based on 85 samples of modern vegetation, each with a minimum of 20 species. The vertical axis is related to temperature, and the horizontal axis is related to water stress; the scale is arbitrary. Leaf size is indicated by the terms ending in -phyll and increases clockwise from leptophyll to macrophyll. Teeth are the marginal projections on leaves. L, length; W, width. Refer to the photographs on Plate 1 for examples of leaf shapes and marginal tooth types.

The Republic flora was once thought to be of Miocene age because it resembles some Miocene floras of the Pacific Northwest. It does not look like the flora in the Eocene Puget Group of the Seattle–Tacoma area. The Puget Group contains abundant coal, which suggests a climate that was different from that in which the coeval Republic flora was growing. This difference raises two questions: (1) Are we sure of the age of the Republic flora—that is, could it be Miocene?—and (2) If the Republic flora is the same age as the Puget Group flora, why is it so different?

Over the years, geologists have pieced together the complex history of northeast Washington. Rocks exposed at the surface and found in the mines of the Republic area indicate that volcanism that started in the Paleocene continued in the Eocene. The volcanic activity was a result of tectonic forces that bowed the region upward and thinned the crust, facilitating the rise of magmas to the surface. A unit of volcanic flows and breccias is present over much of the Republic area; it is known as the Sanpoil Volcanics. These rocks have been radiometrically dated at about 51 or 52 Ma (Pearson and Obradovich, 1977).

Following deposition of the Sanpoil Volcanics, widespread faulting associated with the tectonic upwarping resulted in the creation of fault-bounded depressions or grabens. The sediments deposited in these grabens are now the rocks known as the Klondike Mountain Formation. The lacustrine beds in which the plant fossils are found at the three Republic sites are all in the lower part of the Klondike. Pearson and Obradovich (1977) report ages ranging from 42.3 ± 2.0 to 50.3 ± 1.7 Ma for flows that lie about 300 m above the horizon of the fossil beds. Two older ages among these samples are in close agreement and suggest that the upper age limit for the Republic flora is about 49 Ma. The Sanpoil Volcanics lie unconformably below the Klondike Mountain Formation, and we believe the flora is probably closer in age to 49 Ma than to the age of the underlying

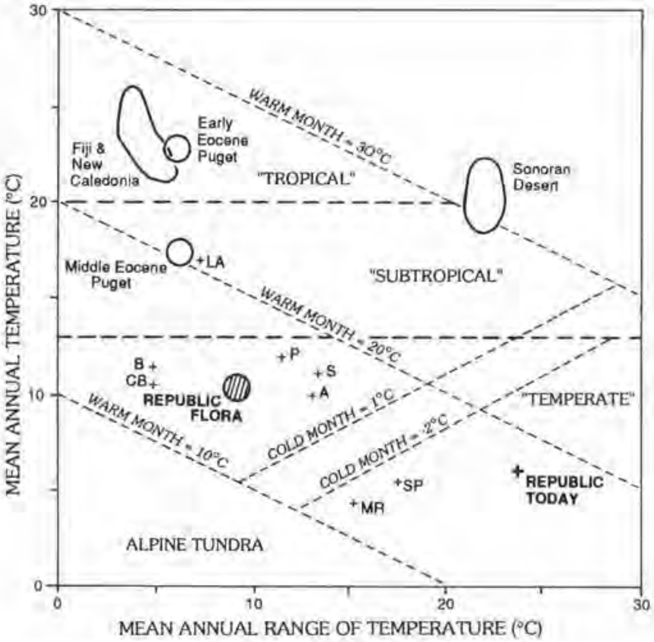

Figure 2. This nomogram shows the general relation of modern vegetation to temperature. Forests are generally limited to areas in which the warm-month average temperature is between 10° and 30°C. "Temperate" forests are found in areas where the average annual temperature is between 13° and 20°C, and "tropical" forests live where the average annual temperature is above 20°C. Dominantly coniferous forests generally require a warm-month average temperature below 20°C. Broad-leaved evergreens are generally common where the cold-month average temperature is above -2°C and especially above 1°C. The temperature ranges inferred for the Eocene climate at Republic are found today along the southern coast of Oregon. LA, Los Angeles; P, Powers, OR; B, Bandon, OR; CB, Cape Blanco, OR; S, Seattle; A, Aberdeen, WA; SP, Snoqualmie Pass; MR, Mount Rainier (Paradise).

unit (Wolfe and Wehr, 1987). This age places the flora in the middle Eocene.

Having established that the Republic flora is indeed Eocene, we can turn to the second question. The simplest explanation for the difference in floras is that the Republic area had a different climate. Because the Republic area was not at the margin of the continent and was in a tectonically raised area, we surmise that it was at a higher elevation than the area in which Puget Group and coal-bearing sediments near Ellensburg were accumulating. We can use these coeval fossil floras to help estimate the elevation of the Republic area.

The middle Eocene lowland vegetation of those areas to the west was primarily broad-leaf evergreens. CLAMP analysis estimates that the average temperature was about 17° or 18°C (63-64°F, similar to that of Los Angeles today). This is about 7°C (~13°F) warmer than Seattle today, and this difference is a little more than the difference between today's average annual temperatures at Seattle and Snoqualmie Pass at (3,022 ft). Temperature decreases with increasing elevation, which helps us to estimate relative elevation for the Republic plant community. But arriving at an answer is not simply a matter of straight-line calculations; we must take into account meteorological evidence that shows that the rate of decrease in temperature with elevation is less in large mountainous regions and in regions that are not affected by the "Arctic Express", the mass of very cold air that now sweeps south from boreal areas.

A middle Eocene flora from British Columbia (Arnold, 1955) indicates that similar environmental conditions existed there; this leads us to believe that the Republic area was part of a large upland. Further, the worldwide Eocene climate was warmer than that of today, which would have prevented the Arctic Express from forming. We therefore used a lower rate of temperature/altitude decrease, only 3°C/km, to estimate the Eocene altitude of Republic. We conclude that the lake beds were formerly at about 2,300 m (7,500 ft, or about 5,000 ft higher than today).

Because organisms respond to many environmental factors, we have to consider both the climate and the elevation if we want to understand plant evolution. Paleobotanical work has shown that in the early Eocene thermal maximum, subtropical climates extended at least to the Arctic Circle. The Eocene Arctic flora was like the temperate flora of the Paleocene. But this old northern flora contains many plant types that are considered archaic and are now extinct. Even if the Republic area was already at 2,300 m in the early Eocene, it was still not cool enough to support temperate vegetation—temperate conditions would have prevailed at 3,300 m (11,000 ft) or higher. Furthermore, the older temperate flora was so unlike the Republic flora that we cannot explain this middle Eocene plant community as having descended from the northern flora.

The answer to the development of the Republic flora may lie in the mix of plant types. In modern subtropical areas there are many different kinds of deciduous plants. Many examples can be found in the dominantly broad-leaved evergreen forests of southern and central China and Japan. Many of these deciduous plants live along streams and are parts of plant communities that develop after natural disasters such as floods or fires. Fossils from other parts of the world show that subtropical floras contained uncommon representatives of the alders, birches, elms, maples, and dogwoods. These same plant groups are common fossils in the Republic deposit.

How can we explain the presence of these plants in such abundance at Republic? We think that as the Republic highlands became increasingly temperate, the broad-leaved evergreens began to disappear, leaving the broad-leaved deciduous plants to flourish. Before the middle Eocene, neither maples nor the rose family had many species or genera. Major evolutionary bursts occurred in both these groups in the highlands. These bursts supplied the genetic diversity for continuing evolution.

The Republic flora has no close analog today. Maples and members of the rose family are widely represented in the forests of eastern Asia, and other Republic

Table 1. Broad-leaved deciduous plants and conifers of the Republic flora

("aff." indicates that the Republic genus is extinct but is related to the living genus named. "Carib.", Caribbean)

Family or group	Abundance	Present distribution
CONIFERS AND OTHER GYMNOSPERMS		
Ginkgo family		
Ginkgo (maiden-hair fern tree)	common	China
Yew family		
Amentotaxus (Chinese yew)	rare	W China
Redwood family		
Metasequoia (dawn redwood)	common	central China
Sequoia (redwood)	scarce	Pacific N America
Sciadopitya (umbrella pine)	rare	Japan
Pine family		
Abies (true fir)	scarce	northern temperate
Picea (spruce)	scarce	cool northern hemisphere
Pinus (pine)	common	northern temperate
Pseudolarix (golden larch)	scarce	E China
Tsuga (hemlock)	rare	temperate N America
Cedar family		
Chamaecyparis (false-cypress)	scarce	E Asia and N America
Thuja (arborvitae)	scarce	E Asia and N America
FLOWERING PLANTS OR ANGIOSPERMS		
Magnolia family		
Talauma	*rare*	*S Asia, S N America, Carib.*
Laurel family		
Phoebe	scarce	S Asia, S N America, Carib.
Sassafras	common	E N America and E Asia
Trochodendroid group		
Nordenskioldia	rare	extinct genus
Eobaileya	rare	extinct genus
Cercidiphyllum (katsura)	common	China and Japan
Joffrea	common	extinct genus
Witch-hazel family		
Langeria	scarce	extinct genus
Corylopsis	rare	E Asia and Himalayas
aff. *Hamamelis*	rare	extinct
Sycamore family		
Macginitiea	scarce	extinct genus
Birch-alder family		
Alnus (alder)	common	N hemisphere
Betula (birch)	scarce	N temperate
Corylus (hazelnut)	rare	N temperate
Beech family		
Castanea (chestnut)	rare	N temperate
Fagopsis	scarce	extinct genus
Fagus (beech)	rare	northern temperate
Quercus (oak)	rare	
Wax myrtle/sweet-fern		
Comptonia (sweet fern)	scarce	E North America
Walnut family		
Pterocarya (wingnut)	rare	Caucasus, E Asia
Elm family		
Ulmus	scarce	N temperate
Zelkova (Chinese elm)	rare	Caucasus and E Asia
Tea-camellia family		
Gordonia (Carolina bay)	scarce	SE Asia and SE N America
Heath family		
Rhododendron	rare	N hemisphere
aff. *Arbutus*	rare	extinct
Linden family		
Tilia (linden)	rare	N temperate
Hydrangea family		
Hydrangea	rare	N temperate
Virginia-willow family		
Itea (Virginia willow)	scarce	E Asia, E N America
Currant family		
Ribes	rare	N hemisphere
Rose family		
Spiraea (bridal wreath)	rare	N temperate
Crataegus (hawthorn)	rare	N temperate
Malus (apple)	rare	N temperate
Rubus (blackberry)	rare	N and S hemispheres
Prunus (cherry)	scarce	N hemisphere
Photinia (toyon)	scarce	E Asia, S N America
aff. *Sorbus*	scarce	extinct
aff. *Prunus* (cherry)	scarce	extinct
Sumac family		
Rhus (sumac)	scarce	N hemisphere
Soapberry family		
Bohlenia	scarce	extinct genus
Koelreuterua (golden rain tree)	rare	E Asia
Maple family		
Acer (maple)	rare	N hemisphere
aff. *Acer*	scarce	extinct
Dogwood family		
Cornus (dogwood)	rare	N and S temperate
Olax family		
Schoepfia	rare	tropical, subtropical
Unknown affinity		
Republica	rare	extinct genus

species have modern representatives in these forests. But the modern Asian forests also contain many plants that are poorly represented or not found in the Republic flora—for example, oak (*Quercus*), beech (*Fagus*), and rhododendron. The Republic flora also contains numerous extinct genera (*Macginitiea, Plafkeria, Barghoornia*). In Table 1 we list elements of the Republic flora and indicate their present status.

After Republic time, other genera of poorly represented families were added to the highland temperate flora—Oregon grape, willow, redbud, and ash. Therefore, we believe the Republic flora represents a very early stage in the evolution of modern temperate forests. Plate 1 on the next three pages illustrates selected leaves found at Republic and that were used in the CLAMP analysis.

Among the Republic specimens there are tens of species of the rose family, including members of all four subfamilies. Many of these species remain undescribed. The arrangement of veins in one type of Republic rose leaf is probably a primitive type for the family. Other leaves seem to resemble the hawthorn, others are somewhat like *Photinia*. And still others seem to combine characters that are found in more than one modern genus, which suggests that Eocene species gave rise to these genera or they have characteristics that are intermediate between the original rose ancestor and a modern genus. The Republic flora is proving to be im-

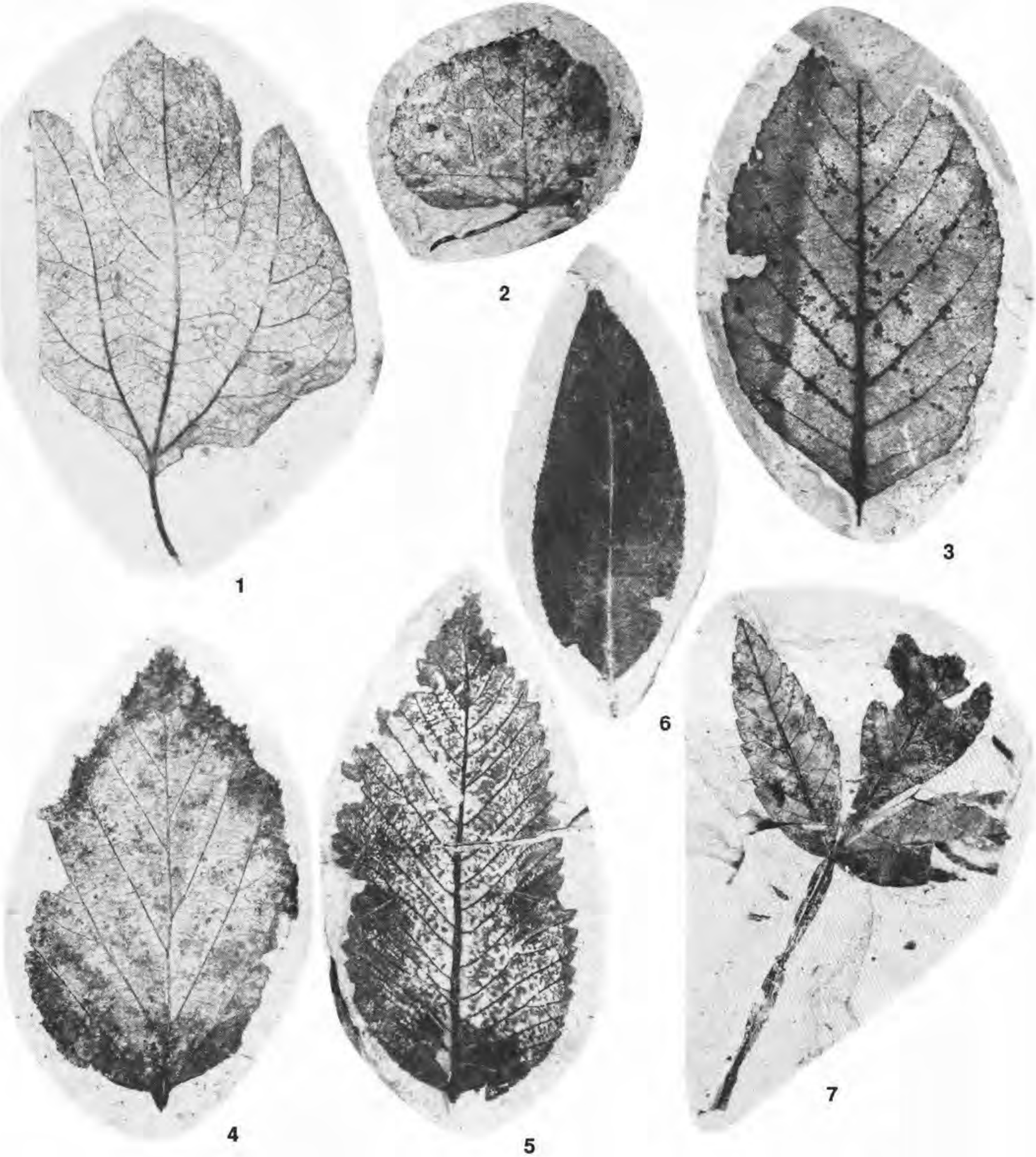

Plate 1. Leaves of plants in the Republic flora. Leaves of most temperate trees and shrubs have many, regularly and closely spaced marginal teeth (nos. 2-7, 10, 13, 16, 17), and the teeth tend to be sharply pointed. Lobed leaves (nos. 1, 10, 14) are also common among temperate plants. In contrast, leaves of most subtropical to tropical trees and shrubs are large, have no teeth, or if teeth are present, they are distantly and irregularly spaced and rounded (as in no. 12); these leaves also have attenuated, narrow tips, called drip-tips (nos. 11, 12). The subtropical to tropical characteristics are rare among the Republic leaves. Unless otherwise indicated, all photos are X 1. **1.** *Sassafras* (this leaf may be lobed, as in the photo, or unlobed); Family Lauraceae. **2.** *Joffrea*, related to the modern katsura; Family Cercidiphyllaceae. **3.** *Alnus* (alder); Family Betulaceae. **4.** *Betula* (paper birch); Family Betulaceae. **5.** *Ulmus* (elm); Family Ulmaceae. **6.** *Itea* (Virginia willow); Family Iteaceae. **7.** *Rhus* (sumac); Family Anacardiaceae; this is a compound leaf, that is, it has more than one leaflet, and it has a winged extension of the leaf stalk, or rachis. With the exception of *Betula*, all these leaves are abundant to common at Republic.

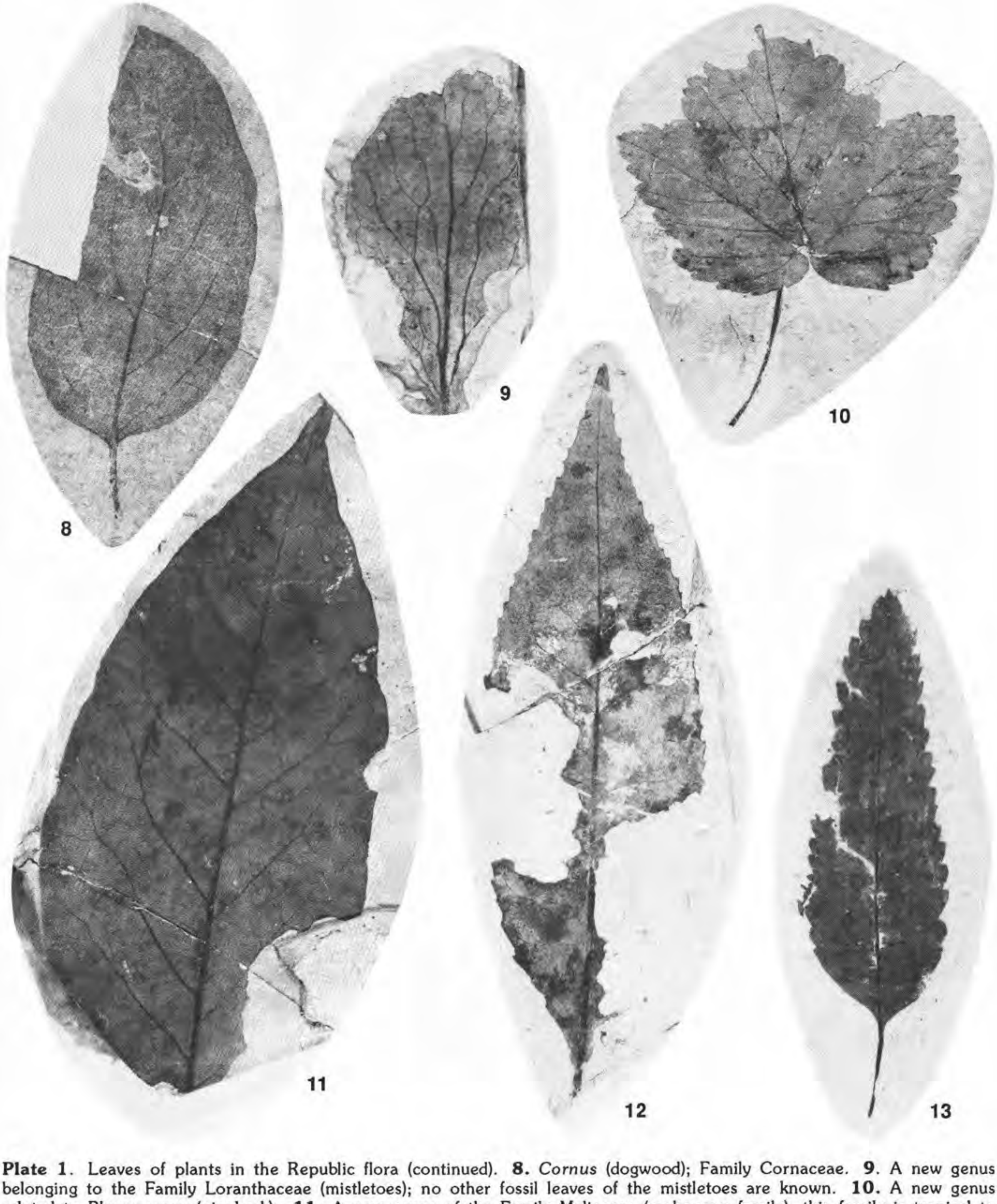

Plate 1. Leaves of plants in the Republic flora (continued). **8.** *Cornus* (dogwood); Family Cornaceae. **9**. A new genus belonging to the Family Loranthaceae (mistletoes); no other fossil leaves of the mistletoes are known. **10.** A new genus related to *Physocarpus* (ninebark). **11.** A new genus of the Family Meliaceae (mahogany family); this family is tropical to subtropical today, and the leaves have no teeth and can have a pronounced drip-tip, as in this Republic specimen. X 0.93. **12.** *Gordonia* (Carolina bay); Family Theaceae; this family is predominantly subtropical and, as in other subtropical leaves that are toothed, the teeth are rounded and irregularly and distantly spaced. X 0.93. **13.** A new genus related to *Sorbus* (mountain ash). Numbers 10 and 13 are members of the Family Rosaceae.

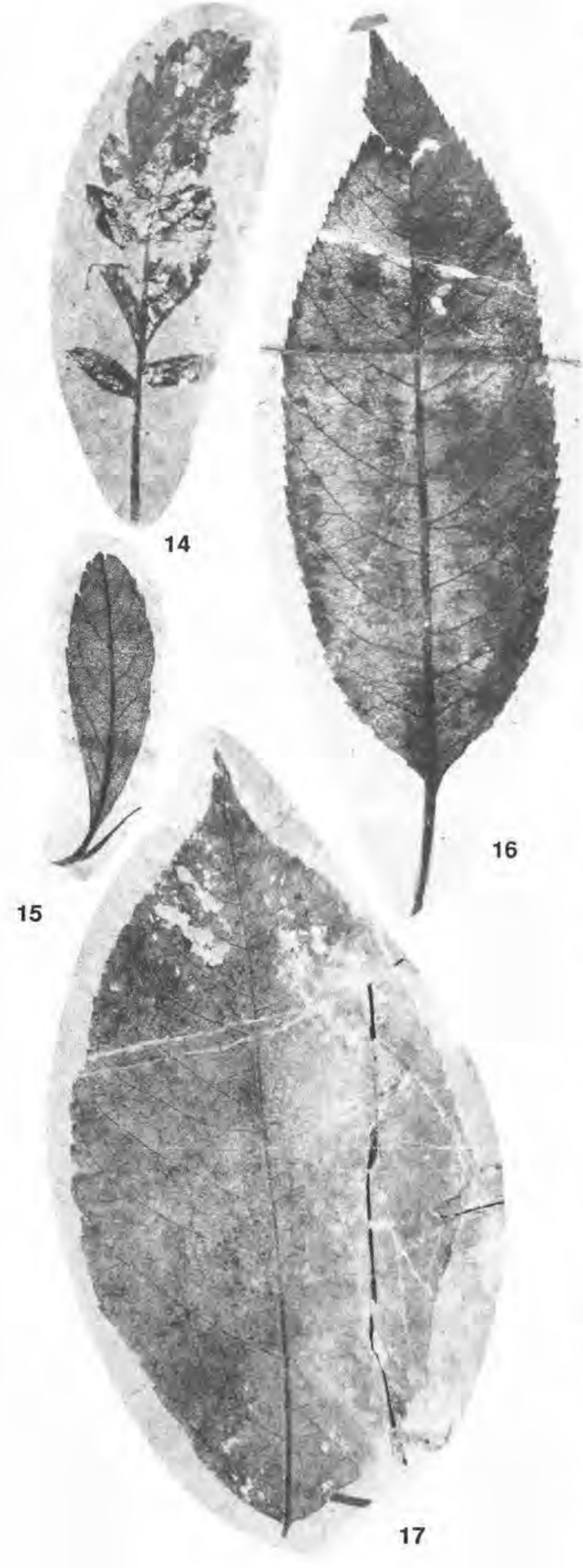

Plate 1. Leaves of plants in the Republic flora (continued). **14.** A new genus related to *Crataegus* (hawthorn). **15.** A new genus related to *Spiraea* (bridal-wreath); unlike modern *Spiraea*, the Republic genus has the primitive character of stipules, which are leaf-like structures that enclose the leaf bud and are located at the base of the leaf stalk. **16.** *Photinia* (toyon or christmas-berry). **17.** *Prunus* (cherry). These plants are also members of the Family Rosaceae.

portant in understand how modern members of the rose family are related. The name of the site's interpretive center, Stonerose, was taken from these fossils.

Because new species of plants (and rare animal forms) are still being found at Republic, it is important that visitors understand the potential value of their finds. Many leaf fossils preserve the vein structures well. Each leaf form contributes to our understanding of both paleoenvironment and evolutionary trends. We recommend a visit to the Stonerose Interpretive Center so as to get an overview of the plant forms found to date. We hope that fossils will be brought to the center so that plants can be identified and specimens of new or rare plants can be saved for study.

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Highlights of the Volcanic Ash and Aviation Safety Symposium

By Patrick T. Pringle

The First International Symposium on Volcanic Ash and Aviation Safety convened in Seattle July 8 through 12. The meeting was sponsored by the Air Line Pilots Association, the Air Transportation Association of America, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS). Cosponsors included the Aerospace Industries Association of America, the American Institute of Aeronautics and Astronautics, the Flight Safety Foundation, the International Association of Volcanology and Chemistry of the Earth's Interior, and the National Transportation Safety Board. Twenty-three nations were represented at the meeting.

Although the meeting was engendered by the aircraft/ash plume encounters at Mount St. Helens (1980), Indonesia's Galunggung volcano (1982), and Alaska's Redoubt volcano (1989), it gained additional impetus from 15 jumbo-jet encounters with eruption plumes of Philippine volcano Pinatubo several weeks prior to the meeting. (See cover photo.) A special session on the Pinatubo eruption took place on the first evening of the conference.

Luncheon speakers included **Dallas Peck**, Director of the USGS, **Zygmund Przedpelski** of the General Electric Corporation, and **Eric Moody**, who piloted the British Airways 747 that encountered an ash cloud from Galunggung volcano in Indonesia in 1982. (That plane "glided" more than 20,000 ft vertically before power was regained.)

Table 1. Major volcanoes whose eruptions have been associated with aviation-safety incidents.

Year of Eruption	Volcano	Country
1944	Vesuvius	Italy
1955, 1976, 1986	Augustine	USA (Alaska)
1973	Asama	Japan
1975, 1986	Sakurajima	Japan
1977	Usu	Japan
1980	Mount St. Helens	USA
1982	Galunggung	Indonesia
1982	El Chichon	Mexico
1983	Colo (Una Una)	Indonesia
1983, 1985	Soputan	Indonesia
1985	Nevado del Ruiz	Columbia
1989	Redoubt	USA (Alaska)
1991	Pinatubo	Philippines

The following paragraphs review the field trips and highlights of sessions. Affiliations are included only for speakers (bold lettering). The symposium was dedicated to Maurice and Katia Krafft and Harry Glicken, volcanologists who perished at Unzen volcano in Japan on June 3, and to Kazuaki Nakamura, Denis Westercamp, Johannes Matahelumual, and K. Kusumadinata, other volcanologists who died this year.

Field Trips

Many conference attendees participated in the pre-conference field trip to the FAA's Air Traffic Control Center (ATCC) in Auburn and the Boeing Airplane Co. factory in Renton where Boeing 737 and 757 aircraft are assembled. The ATCC, one of 20 regional centers in the conterminous United States, is responsible for monitoring and communicating with air traffic in a 300,000 mi^2 area in the Pacific Northwest.

A post-conference field trip to Mount St. Helens, led by **Steven Brantley** (USGS), visited Bear Meadows, Meta Lake, Harmony Falls, and Windy Ridge interpretive areas.

Redoubt Eruptions

The opening session centered on aircraft interactions with ash plumes from Redoubt volcano, 110 mi southwest of Anchorage. The most noteworthy ash cloud/aircraft interaction during the Redoubt activity was that of the December 15 KLM flight, which lost power in all four engines and then dropped nearly 12,000 ft before regaining power.

Tom Miller and J. N. Davies of the USGS Alaska Volcano Observatory (AVO) discussed the eruptive history of Redoubt volcano and described the 1989–1990 eruptive events. Photographs of one eruption show the ash column rising off a pyroclastic flow, illustrating that the origin of the column is not necessarily the central vent. Miller provided an overview of the types of eruptions and corresponding eruption return intervals that could be expected from Alaskan volcanoes.

Ernest Campbell of the Boeing Commercial Airplane Group gave a detailed account of the KLM/ash cloud encounter, of impairments to the aircraft's control system during the emergency, and of damage to the Boeing 747-400 aircraft. Total cost to put the plane back in service was $80 million.

Zygmund Przedpelski of the General Electric Corporation and **Thomas Casedevall** (USGS) discussed details of engine deterioration due to ash ingestion. They conducted tests to analyze damage sustained by different components of jet engines and used petrographic thin sections and scanning electron microscope and electron microprobe techniques to evaluate the results. Because the principal components of volcanic ash (volatile-poor glass and minerals) are unlikely to melt at temperatures below 900°–1,000°C, engine power can be reduced to minimal settings to lower engine temperature and reduce the likelihood of ash melting in the engine during an ash cloud/aircraft encounter.

Charles Criswell of the FAA's Alaska Region described the setting of Mount Redoubt in the midst of a route complex connecting the Orient, Europe, eastern North America, and the west coast of North America. This coincidence of flight routes illustrated one of the major reasons for concern about aircraft/ash interactions—that the routes that traverse and/or are linked to routes traversing the Pacific rim also traverse geographic regions hosting an abundance of volcanoes. Criswell compared aircraft-control center operating procedures and types of communications during and after the Redoubt incident and noted the current difficulties in getting digital information into the cockpit.

Peter Hobbs of the University of Washington Atmospheric Sciences Department reported on lidar detection of ash plumes and the distribution of volcanic emissions. Lidar uses wavelengths of 1 and 0.5 microns, much shorter than radar, and hence can "see" smaller particles. Radar uses 1-mm wavelengths, which results in possible confusion of meteorological and eruptive phenomena because that wavelength is close to the diameter of rain droplets.

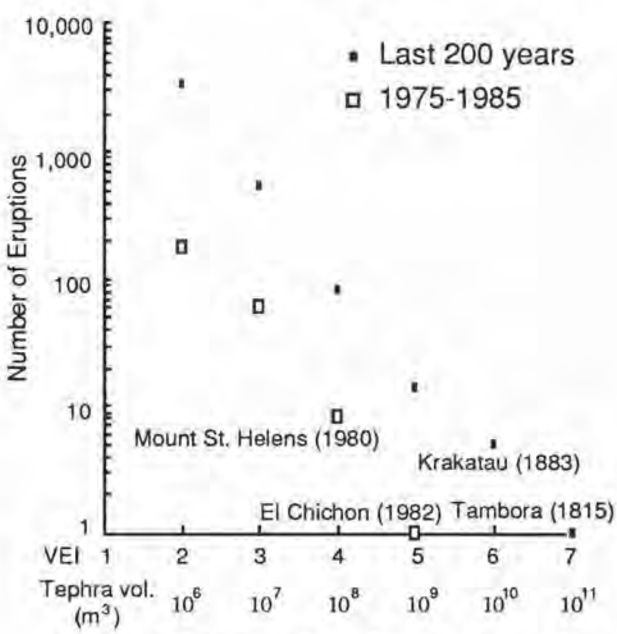

Figure 1. Log-normal distribution showing the frequency of volcanic eruptions of different VEI groups over the 200-year period 1490–1990 and over the decade 1975–1985 (modified from Simkin and others, 1981). VEI, "Volcanic Explosivity Index", is a measure of the magnitude of an explosive eruption (Newhall and Self, 1982). VEI is roughly proportional to tephra volume.

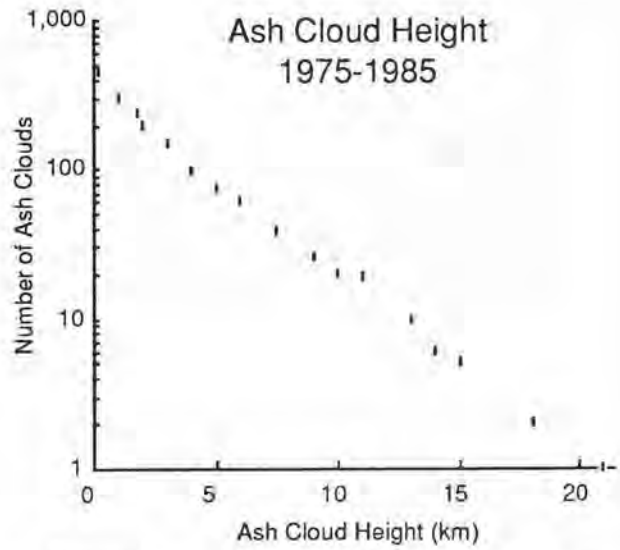

Figure 2. Log-normal regression curve showing the number of ash clouds reaching a certain altitude between 1975 and 1985 (modified from Simkin and others, 1981).

Edward Haeseker of Alaska Airlines described the difficulties faced by airlines and air travelers because the Redoubt eruptions occurred during the peak of the Christmas season travel. Haeseker noted that Alaska Airlines was unable to get information about the ash clouds in time to benefit their flights.

Volcanoes And Ash Clouds

Tom Simkin of the Smithsonian Institution summarized the occurrence and geographic distribution of volcanic eruptions around the world during various time intervals (Table 1, p. 25). Using data compiled by the Smithsonian for 1975 to 1985, he gave a perspective of the relation between eruption frequency and volume, and between eruption-cloud height and frequency of occurrence for volcanoes worldwide (Figs. 1 and 2).

Steven Self and George Walker of the Department of Geology and Geophysics at the University of Hawaii focussed on the characteristics and dynamics of eruption columns (Fig. 3) and divided these columns into groups based on height. He suggested that vulcanian eruptions (explosive eruptions producing much ash and hot blocks) were the most common type and large enough to cause problems with aircraft.

Steven Sparks of Bristol University, United Kingdom, discussed the nature of ash dispersion downwind from the vent. In order to be able to predict the particle concentrations downwind, he combined laboratory experiments with field data and developed models for plume distribution. However, he suggested that new knowledge of atmospheric-diffusion and particle-aggregation processes would further modify future models.

Grant Heiken of Los Alamos National Laboratory in New Mexico discussed the nature of volcanic ash and controls on its formation. **Thomas Casedevall** of the USGS elaborated on the gases and aerosols that make up volcanic eruption clouds.

Donald Swanson of the USGS summarized the strengths and weaknesses of the current state of volcano monitoring. He noted that while we can foresee eruptions, (1) there are too many volcanoes and too few volcanologists, (2) false alarms and failed eruptions continue to make predictive efforts troublesome (especially where large populations must be evacuated), and (3) the size and destructiveness of eruptions cannot be assessed with consistency. "Failed eruptions" have occurred in recent years at Phlegreaen Fields in Italy, Long Valley Caldera in California, and at Rabaul in New Guinea. In those complex volcanoes, high seismicity, deformation, and changes in gas discharge suggested the onset of eruptive activity, but no eruption occurred. Swanson suggested that seismic precursors are still the best (deformation tools having proven reliability only in dealing with the repeated behavior at Mount St. Helens) and that hazards maps and close media contacts are necessities for effective response to volcanic disasters.

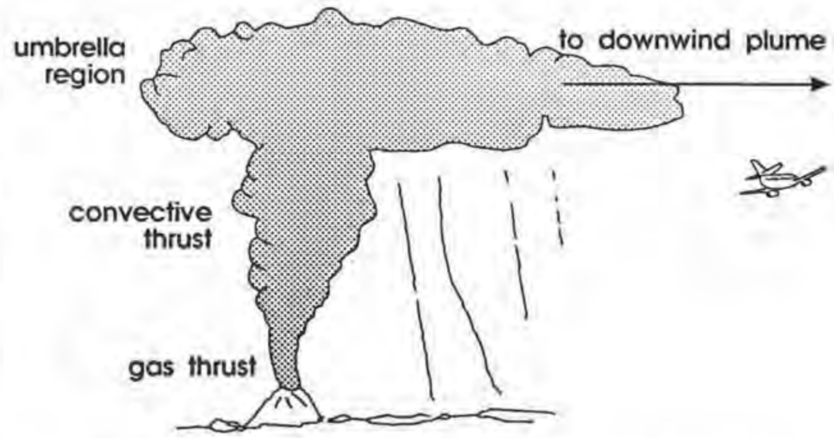

Figure 3. Characteristics of volcanic eruption columns (redrawn from Self and Walker, 1991).

Damage and Impacts

Michael Dunn of the Calspan Advanced Technology Center discussed damage to gas turbine engines and elaborated on potential damage mechanisms such as erosion of the compressor (and other rotating equipment), glassification of ash, deposition on fuel nozzles, deterioration of engine control systems, and contamination of oil and fuel supplies. Dunn noted that if engine operating temperature is higher than about 1,100°C, glassification and deposition will occur on the nozzle guide veins, choking fuel supplies.

Alan Weaver of Pratt and Whitney talked about the perception of relative risk with respect to volcanic-ash ingestion. He noted that the increased flight range and efficiency that go along with higher inlet temperatures enhance the threat of ash ingestion.

David Bailey of the Grant County Airport (Washington) related how the airport was able, by trial and error, to cope with and ultimately dispose of more than 3 cm of Mount St. Helens ash in 1980. Due to low precipitation in central Washington (6-7 in./yr), snowplows could not be used—dust-sized ash contaminated the machines and flowed around the blades. Lawn sprinklers finally were used to wet down the ash, which was then graded and hauled off by front-end loaders. It took 30 days to fully restore operations at the airport. Performance problems with vehicles and removal equipment were minimized by keeping air filters 3-4 ft above the ground and by covering air intakes with panty-hose dipped in oil.

John Labadie of JAYCOR provided an overview of techniques to mitigate of the effects of volcanic ash on aircraft operating and support systems. The 1980 Mount St. Helens ash maintained a high static charge two to three days after the eruption. The biggest problem for electronic systems was that the ash was invasive, making computers extremely vulnerable.

Communications and Procedures

Jim Evans of the Weather Sensing Group at Massachusetts Institute of Technology stressed that volcanic ash cloud hazards should be treated as a weather hazard and that maximum advantage should be taken of the weather information dissemination system under development by the FAA and National Weather Service.

R. W. Johnson of the Bureau of Mineral Resources in Canberra, Australia, summarized the problems of coping with aircraft/ash cloud interactions in Australia and the history of known encounters of aircraft with ash plumes (Table 1).

Meteorology and Ash Cloud Tracking

Both **Anthony Mostek** and **Gary Hufford** of NOAA/National Weather Service talked about the limitations of NOAA's ability to relay information during the 1989 Redoubt eruption and of the attempts to improve forecasting of plume movement via the Alaska Volcano Project. This project consists of developing new observing capabilities (C-band radar to help distinguish steam from ash emissions), new computer and communications equipment (including a wind profiler to provide continuous (real-time) wind reports to forecasters in Anchorage and for numerical models), and studies to enhance the numerical modelling system.

Thomas Schlatter discussed how the current difficulty in predicting the lower stratospheric wind field has inhibited our abilities to track ash-plume movement. Increasing availability of digital terrain data will allow refinement of the model for topographic surface roughness. A lack of current temperature data is a major obstacle to improved tracking. A new trajectory model will be developed to accommodate the anticipated "real time" data received from aircraft.

Detection and Tracking

A. J. Prata and Ian Barton of CSIRO, Division of Atmospheric Research, Australia, talked about the theoretical and experimental detection and discrimination of volcanic ash clouds using infrared radiometry. One ground-based problem is masking of the signal by water-vapor effects. Further, ash and sulfuric acid have nearly identical infrared signatures, making discrimination of these two emissions components difficult.

Michael Matson of NOAA/NESDIS in Washington, D.C., evaluated the current and future applicability of satellites for tracking ash plumes. Meteorological satellites use thermal and infrared sensors to detect ash clouds. The main advantage of satellites is large spatial coverage—the entire western hemisphere can be covered in 30 min. However, the problems of tracking ash plumes cannot be solved by satellites alone. Plume altitude and trajectory estimation require the use of additional technology. Modelers need to know the altitude of the plume to get the trajectory right, and they need better discrimination algorithms to enhance multispectral images operationally with fewer errors. Additional radiosonde data would help to assess plume location and trajectory.

William Rose and Alex Kostinski of the Department of Geology and Geological Engineering at Michigan Technological University provided an overview of the use of radar remote sensing of volcanic clouds. Ground-based radar systems can contribute much useful information including duration of eruption, rate of ascent of the ash plume, ashfall locations and times, and particle concentrations. Rose compared the better sensitivity of the higher powered (5,000 kW) Auburn, Washington, radar facility with that of the 230 kW facility at the Portland (Oregon) International Airport. Height limitations with regard to detection must be considered because they are so important to dispersion models—the July 22, 1980, plume from Mount St. Helens extended above the top of the radar. Rose suggested that Doppler radar might be employed to detect ash fallout and determine particle-size distributions in ash clouds, and that polarimetric techniques could be used to provide additional information. Cheaper portable radar units and the ability to change wavelengths of the radar (especially to a shorter wavelength) could also help with the discrimination problem.

Arlin Krueger of NASA's Earth Science Directorate discussed volcanic hazards detection using the Total Ozone Mapping Spectrometer. Although originally designed to measure ozone, it also can detect sulfur dioxide, which absorbs sunlight in a spectral range similar to that of ozone. Data-processing techniques can then separate the two gaseous components.

Special Session on the Pinatubo Eruption in the Philippines

One of the emotional highlights of the symposium was the evening session on the eruption of Pinatubo volcano in the Philippines. The scale of the June 15 eruption, one of the two largest eruptions this century, drew worldwide attention. American interest was particularly keen because of the volcano's proximity to two large military installations, Subik Bay Naval Base to the southeast and Clark Air Force Base to the northeast of the volcano.

Chris Newhall (USGS) and **Edward Wolfe**, Chief Scientist at Cascades Volcano Observatory (CVO), provided an overview of the events leading up to the climactic eruption of June 15. Numerous USGS scientists, including a contingent from CVO, cooperated with Philippine Institute of Volcanology and Seismology (PHIVOCLS) to establish volcanic monitoring and to prepare a preliminary volcanic hazards analysis around the volcano in April and May, shortly after seismic activity began. Because of their efforts, more than 200,000 people were successfully evacuated before the June 15 eruptive events. **Perla de Los Reyes** of PHIVOLCS provided a detailed account of how and when air traffic was disrupted by the eruption.

Poster Sessions

More than 50 posters were presented in sessions on topics including ash cloud damage and impacts, communications and procedures, meteorology and ash cloud monitoring, and detection and tracking of ash clouds. Before each session, authors were permitted to give a 3-min presentation summarizing their poster.

Steven Brantley of the CVO premiered a video tape on volcanic hazards that he had prepared with Maurice Krafft and Chris Newhall. Their video dramatically shows the impact of various volcanic processes using a combination of animation and film footage.

Catherine Hickson of the Geological Survey of Canada provided an overview of Holocene volcanism in British Columbia and the Yukon. She noted that a sizeable eruptive event (30 km^3) occurred only 1,200 years ago in the Canadian Cordillera.

William Scott of CVO and **Robert McGimsey** of the AVO evaluated the grain-size characteristics of the Mount Redoubt tephra deposits, noting that the polymodal grain-size characteristics of the ash might reflect the sizes of crystals in the eruption cloud.

Chris Jonientz-Trisler of the University of Washington, along with Bobbie Myers and John Power of the USGS, have developed criteria to discriminate volcanic explosions from other volcanic events.

Stephen McNutt of Sacramento, Calif., noted that volcanic-tremor amplitudes are empirically related to eruption explosivity. Therefore, tremor amplitudes of an eruption could be used to estimate its size; likewise, tremor duration could be used to estimate the eruption duration.

Yoshiro Sawada, Shizuoka Meteorological Observatory, Japan, demonstrated use of infrared images from the Geostationary Meteorological Satellite (GMS) to detect widely dispersed ash clouds caused by big eruptions. Detection rate is low (14%), mostly because of atmospheric cloud cover and resolution limitations of ground-based stations for smaller eruption clouds. However, large explosions are more easily detected, and the eruption temperature and intensity of the explosion can be estimated.

Bobbie Myers of CVO and George Theisin of the U.S. Forest Service provided a detailed description of the volcanic hazard notification procedures used at Mount St. Helens during the 1980-1986 eruptive events.

Summary

Probably the most fundamental challenge in tackling the volcanic ash cloud/aviation safety problem is improving communication among scientists, airlines, and air crews. However, this communication must be combined with an improved understanding of the hazards and agreements on who will take responsibility for alerting air crews about ash cloud hazards. Standards for reporting real-time ash-cloud conditions will likely be developed on a worldwide basis. Although several speakers stressed that reports of current conditions only (and not predictions of future/imminent eruptive activity) were needed, some anticipation of probable ash-plume hazards in a flight path will be helpful to air crews.

In general, there is a need for mutual understanding of the terminology used by, and bureaucratic functions of, the various disciplines involved. This appears to be a widespread problem in the applied sciences, and explanation and dialogue are important functions of symposiums like this one.

How much will future research and development be hampered by funding uncertainties? This issue is important because technological problems abound in areas ranging from ash cloud modeling to detection and tracking. Trackers can ascertain where an ash plume started, but they do not know what threshold concentrations effectively delimit where/when the plume is no longer a hazard. Existing communications networks and satellite systems could be used in conjunction with personal computer hardware and the Geographic Information System to locate the volcano, determine eruption status, analyze wind and other meteorological data, analyze the plume trajectory, and overlay air routes to delineate hazardous areas. Following interpretation of the data, uncomplicated messages still must be relayed to pilots in a timely fashion.

The USGS (in particular Thomas Casedevall and Chris Newhall) deserves much credit for this well-organized and well-attended symposium. Planning is underway for a future symposium.

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Last Map Celebrated

A ceremony to mark completion of the topographic mapping of the State of Washington by the U.S. Geological Survey (USGS) was held in Gov. Gardner's Conference Room on October 1. USGS Director Dallas Peck attended.

The final product in the map series is known as the "Mazama Map"; it covers parts of the Okanogan National Forest and Pasayten Wilderness. The Division of Geology and Earth Resources and its predecessors made financial contributions to this long-term effort from 1909 to about 1980.

At the ceremony, the USGS presented Gov. Gardner with a certificate recognizing the completion of the mapping, a framed original 1897 map of Seattle (also used as the background for the certificate), and a framed "last map" of the Mazama area.

Volcano News Erupts Again

Volcano News was an interdisciplinary forum where volcanophiles of all stripes—professional and amateur, "hard" and "soft" scientists, alike—could exchange information. *Volcano News* unfortunately became extinct when editor-publisher, Chuck Wood, became involved in editing *Volcanoes of North America*.

Janet Cullen Tanaka, a former contributing associate editor of *Volcano News* is planning the publication of a new interdisciplinary volcano newsletter to cover all facets of volcano studies from geophysics to emergency management. Persons interested in contributing articles and/or subscribing should contact Janet as soon as possible at P.O. Box 405, Issaquah, WA 98027-0405 or call 206/392-7858 between 10:00 a.m. and 10:00 p.m. PDT.

USSR Trip Promotes Exchange of Seismic Research Information

by Raymond Lasmanis

During April of 1990, the Division hosted the Fourth Annual Workshop on Earthquake Hazards in the Puget Sound and Portland Regions. At that time, we were able to invite the Vice President of the Uzbek SSR Academy of Sciences, Professor Tursun Rashidovich Rashidov (Fig. 1), to attend this Seattle meeting. He presented a lecture titled "Problems of Underground Structure Seismodynamics". Also present was Professor Bekhzah S. Yuldashev, Director of the Uzbek Institute of Nuclear Physics. (See Washington Geologic Newsletter, vol. 18, no. 2, p. 20.)

On September 14, 1990, Deputy Supervisor Stan Biles, State Geologist Ray Lasmanis, and Environmental Geology Section Manager Tim Walsh were invited by the Uzbek Academy of Sciences to visit the Republic of Uzbekistan in the Soviet Union (Fig. 2). The Division's federal National Earthquake Hazards Reduction Program grant was amended to cover travel costs to Moscow, and Professor Rashidov, on behalf of the Academy, offered to cover our costs during the stay in Uzbekistan.

Figure 1. Tursun R. Rashidov, Vice President of the Uzbek SSR Academy of Sciences, with Cretaceous petrified wood (species belonging to the Taxodiaceae) from Tashkent.

Figure 2. Uzbekistan and its setting in the U.S.S.R. Major cities visited are shown.

The trip was planned for June 1991 with the purpose of holding discussions to develop a scientific exchange program. Specifically, the agenda included items of mutual interest relating to seismic risk and mitigation.

We arrived in Tashkent, Uzbekistan, on June 4 and were greeted by a high-ranking delegation headed by Rashidov. During subsequent days, visits were arranged to various institutes where we had fruitful discussions with directors and staff. The following institutes and organizations were visited:

- Institute of Mechanics and Seismoresistance of Structures
- Institute of Geology and Geophysics
- Institute of Seismology
- Institute of Nuclear Physics
- Uzbek SSR Academy of Sciences
- Union of Scientific and Engineering Societies of USSR
- Science Education Center (Geological Museum)

We were also given the opportunity to present lectures to the Academy and a joint scientific and engineering society meeting. Stan Biles presented an overview of the Department of Natural Resources, Ray Lasmanis reviewed the geology and mineral resources of Washington, and Tim Walsh presented a lecture on geologic hazards (including seismic risk).

There was an opportunity to visit sites of historic and cultural significance. In Tashkent, a sister city of Seattle, we saw an impressive monument dedicated to the survivors of the devastating earthquake of April 26, 1966 (Fig. 3); Lenin Square; the public market; Moslem Friday Mosque, dating from the 16th century; and the Applied Arts Museum housed in the former Russian ambassador's residence dating from 1850.

Our hosts provided air transportation to Urgench; from there we drove to Khiva. The mayor of Khiva and the city architect guided us through the ancient inner city, Ichan Qala, declared a world heritage site by UNESCO. (See Fig. 4.) A flight the following day took us to Samarkand, the location of architectural treasures such as: the Shah-e-Zindeh site (constructed between 1360 and 1434); the Gur Emir mausoleum (1434); Registan, a site containing the madrasas, or complexes of buildings housing religious institutions (1417-1420); Shir Dar (1619-1636), Tilla Kari (1646-1660); and a 15th century observatory. Samarkand is a sister city of Olympia. Both Khiva and Samarkand were major cities on the ancient Silk Route; these cities were used as headquarters by Alexander the Great and Ghengis Kahn during their military campaigns.

Figure 3. Monument in downtown Tashkent dedicated to the survivors of the devastating earthquake of April 26, 1966. The quake had a magnitude of 5, but destroyed 28,000 buildings, including 200 hospitals and clinics (Bulletin of the Seismological Society of America, v.56, no. 5, p. 1192).

Figure 4. From left: Ray Lasmanis, Tim Walsh (on camel), and Stan Biles, at Ichan Qala (royal court), the inner walled city at Khiva.

Time spent at the Institute of Seismology was enlightening. The Institute was established after the 1966 Tashkent earthquake to conduct basic and applied research in geological engineering for construction sites. In particular, earthquake wave amplification research is carried out for the loess soils that mantle the Tashkent basin. Of special interest is the earthquake forecast program housed in the Hydrology Section of the Institute. The prediction program uses 13 deep wells located throughout Uzbekistan. These are monitored daily for radon and helium emissions, water levels and pressures, electromagnetic fields, acoustic emissions, and other data. We were given the opportunity to visit the site of a 2,500-m-deep well near Tashkent in which two high-pressure artesian aquifers are isolated for measurement purposes. In the 25 years that the program has been operating, the Institute has successfully predicted five earthquakes, although there have also been false

Figure 5. Almalyk porphyry copper pit, the largest mine in the U.S.S.R. The mine was operated in the 12th century and rediscovered by re-entering old workings in 1926.

alarms. On May 17, 1976, a visiting USGS scientist witnessed a successful 3-day prediction for a location in western Uzbekistan.

Tours of new construction and industrial sites included the modern Tashkent subway system and a field trip to Charvak Dam and Lake in the Tien Shan Range. One day was spent in the Almalyk porphyry copper district. We were shown the largest open-pit porphyry copper mines in the Soviet Union (Fig. 5). The deposit has a length of 3.5 km, a width of 2.5 km, and a depth of 1 km, with reserves of 3 billion metric tons of ore averaging 0.5 percent copper as well as other minerals.

At the end of our stay, agreement was reached between the Department of Natural Resources and the following organizations: the Uzbek Republican Association of Scientific and Engineering Societies of the USSR, Uzbek Academy of Sciences, and the Institute of Mechanics and Seismoresistance of Structures. The agreement is to provide for scientific and cultural exchange opportunities. The specific items are:

1. Facilitate opportunities for post-graduate work in earth sciences, including seismic, structural, and engineering geology.
2. Facilitate access to technology, including software, sand and gravel removal, seismic wave propagation theory, and earthquake and seismic hazard prediction methodology.
3. Facilitate communication with scientific and cultural institutions.
4. Jointly sponsor and implement conferences of mutual interest.
5. Facilitate a joint scientists exchange program.
6. Share scientific samples, studies, and papers of mutual concern.
7. Investigate opportunities for joint geochemical and trace element studies of mineral deposits.

Professor Yuldashev visited Washington again in late August, and communications continue with the Uzbek scientists. ⚒

1991 Geological Projects, Washington Colleges and Universities

This list is taken from material submitted by press time by the geology departments of the state's colleges and universities. Names in parentheses with the faculty projects are student collaborators unless otherwise noted; with student projects, they are faculty collaborators unless otherwise noted. Affiliations other than with the pertinent college or university are bracketed. Some projects involve areas outside Washington.

CENTRAL WASHINGTON UNIVERSITY

Faculty projects

Geologic thin skinned model for Yakima Fold Belt—*Robert D. Bentley and Haufu Lu [Nanjing University, Peoples Republic of China]*

Flow-thickness variations across Yakima Fold Belt—*Robert D. Bentley (John Kieling, Chrissie Phelps, and Martyne Smith)*

Guidebook to Yakima folds in Yakima Canyon area—*Robert D. Bentley and Jack E. Powell*

Evolution of Selah Butte anticlinal ridge—Robert D. Bentley (Andrew Miner)

Geology of Cleman Mountain area—*Robert D. Bentley and Jack E. Powell (Steve Jensvold)*

Geologic map of Yakima East quadrangle—*Robert D. Bentley, Jack E. Powell and Newell Campbell*

Propagated fault folds in Yakima folds—*Robert D. Bentley, Haufu Lu [Nanjing University, Peoples Republic of China]* and Jack E. Powell

Geologic evolution of Burbank Valley area—*Robert D. Bentley and Haufu Lu [Nanjing University, Peoples Republic of China] (Andrew Miner)*

Was timing of deformation of Yakima folds episodic?—*Robert D. Bentley and Jack E. Powell*

Ellensburg Basin with 1.5 km of latest Miocene sedimentary fill - contractional wrench: a "squeeze down" basin—*Robert D. Bentley, Jack E. Powell and Haufu Lu [Nanjing University, Peoples Republic of China] (Ronald Owens)*

Microprobe study of Frenchman Springs basalt plagioclase phenocrysts—*James R. Hinthorne, Robert D. Bentley, and Jack E. Powell*

Construction of global transect along 117 degrees in Washington and Oregon—*Steven E. Farkas*

Digitizing of 1:100,000 geologic maps: the Wenatchee sheet—*Jack E. Powell*

Student project

Geology of the Ryegrass sanitary landfill site, Kittitas County—*Gerda Smeltzer (Robert D. Bentley)*

EASTERN WASHINGTON UNIVERSITY

Faculty Projects

Mineralogy of the Golden Horn batholith, North Cascades, Washington—*Russell C. Boggs*

Structural states of feldspars as an indicator of sedimentary provenance—*Russell C. Boggs*

Mineralogy of the Sawtooth batholith, Idaho—*Russell C. Boggs*

Geomorphic mapping of Blue Creek to evaluate the potential for enhancing fish habitats—*John P. Buchanan*

Hydrogeology of Long Lake, Spokane and Stevens Counties, Washington—*John P. Buchanan*

Radon gas distribution in cave systems in the Pacific Northwest—*John P. Buchanan*

Survey of karst features in the Pryor Mountains, Montana—*John P. Buchanan*

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington—*Ernest H. Gilmour*

Biostratigraphic studies of Pennsylvanian and Permian bryozoans in North America and Pakistan—*Ernest H. Gilmour*

Carbonate petrology and paleoecology of the Antler Peak Limestone, northeastern Nevada—*Ernest H. Gilmour*

Rare earth element geochemistry of gold deposits—*Mohammed Ikramuddin*

Distribution of immobile trace elements in hydrothermally altered rocks associated with various types of gold deposits—*Mohammed Ikramuddin*

Thallium—a potential guide to mineral deposits—*Mohammed Ikramuddin*

Geochemistry of sediment-hosted precious metals deposits—*Mohammed Ikramuddin*

Development of new analytical methods by inductively coupled argon plasma and electrothermal atomic absorption—*Mohammed Ikramuddin*

Hydrogeochemical and biogeochemical methods of exploration for gold and silver—*Mohammed Ikramuddin*

Geochemistry of volcanic rocks and its relationship to gold-silver mineralization—*Mohammed Ikramuddin*

Use of cesium as a guide to mineral deposits—*Mohammed Ikramuddin*

The use of boron in gold exploration—*Mohammed Ikramuddin*

Reconnaissance lithogeochemical survey of northwest Pakistan—*Mohammed Ikramuddin*

Study of toxic elements in environmental samples—*Mohammed Ikramuddin*

Chemical analysis of ultrapure electronic materials—*Mohammed Ikramuddin*

Glacial and catastrophic flood history of eastern Washington—*Eugene P. Kiver*

Quaternary map of northeastern Washington east of the Okanogan River—*Eugene P. Kiver*

Geology of national parks—Eugene P. Kiver

Structure and stratigraphy of the Middle Paleozoic Antler orogen in northwestern Nevada—*Linda B. McCollum*

Stratigraphy, sedimentology, and paleontology of the Cambrian System of the Great Basin—*Linda B. McCollum*

Paleozoic continental margin sedimentation in western U.S.—*Linda B. McCollum*

Transcurrent faulting and suspect terranes in the Great Basin—*Linda B. McCollum*

Alkaline igneous rocks and related precious metal deposits—*Felix E. Mutschler*

Space-time tectonic and magmatic maps of the Cordillera—*Felix E. Mutschler*

Compilation of computer data base of whole-rock chemical analyses of igneous rocks—*Felix E. Mutschler*

Styolites in igneous rocks—*James R. Snook*

Petrology of the Quartz Hill molybdenum deposit, Alaska—*James R. Snook*

Use of remanent magnetization direction to correlate air-fall ash deposits from Cascade volcanoes—*William K. Steele*

Mechanism of acquisition of remanent magnetization by airfall ash—*William K. Steele*

Magnetostratigraphy of Clarkia Miocene fossil site—William K. Steele [with University of Idaho]

Student projects

Computer exercises in pattern recognition applied to exploration for mineral deposits related to igneous rocks—*Glen R. Carter*

Saturated zone chemistry down-gradient from mine tailings ponds near Twisp, Washington—*Robert H. Lambeth*

Abundance and behavior of cesium, and selected trace elements in rock, soil, and water samples from the Republic area, northeast Washington—*Wilfred H. Little*

Structural states of alkali feldspar as an indicator of sedimentary provenance—*Mohammad Zafar*

Groundwater geochemistry down-gradient from a uranium mill tailings pond—*Ronald A. Stone*

Origin and mineralization of Colorado Plateau uranium-copper bearing breccia pipes—*J. Michael Faurote*

Geochemistry of igneous rocks from Newport and adjacent areas, northeastern Washington—*L. Christine Russell*

Alunite characterization of the Gold Quarry mine, Eureka County, Nevada—*Dean G. Heitt*

Biogeochemical methods of exploration for Archean gold deposits—*Richard B. Lestina*

Hydrology of Long Lake, Spokane and Stevens Counties, Washington—*Michael S. Johnson*

Hydrogeology of the Haripur Plain, Pakistan—*Christopher T. Jones*

Rare earth element geochemistry of volcanic-hosted gold deposits—*Calvin A. Landrus*

Fenestrate bryozoans of the Toroweap Formation, southern Nevada—*Miriam E. McColloch*

Platinum-group elements in alkaline igneous rocks—*Thomas C. Mooney*

Formulation of a finite-difference groundwater flow model for the Spokane Valley aquifer—*Iain A. Olness*

Gallium in Carlin-type gold deposits—*Philip A. Owens*

Trace element pollution from sulfide deposits in Hunters Creek, Stevens County, Washington—*Fazli Rabbi*

PACIFIC LUTHERAN UNIVERSITY

Faculty Project

Palynology and depositional environments of Pleistocene sea cliff deposits north of Kalaloch, Washington, using optical and SEM techniques—S. R. Benham

TACOMA COMMUNITY COLLEGE

Faculty project

Roadside geology of Mount Rainier National Park—*J. H. Hyde*

UNIVERSITY OF WASHINGTON

Faculty projects

The Chesaw fault: A terrane boundary in Okanogan and Ferry Counties, Washington—*Eric S. Cheney (Michael G. Rasmussen and Martin G. Miller)*

Regional sequence stratigraphy of the Leavenworth fold belt, central Washington—*Eric S. Cheney and Richard J. Stewart*

Rapid chemical changes in the oceans near the Cretaceous/Tertiary boundary—*Bruce K. Nelson*

Fluid-rock interaction in subduction zones: the Franciscan Complex and the Austrian Alps—*Bruce K. Nelson*

Proterozoic anorogenic granitic magmatism in the midcontinent of North America—*Bruce K. Nelson*

Early crustal history of the Brooks Range, Alaska—*Bruce K. Nelson*

Isotopic study of the provenance of sediments in the Methow-Tyaughton basin—*Bruce K. Nelson*

Student projects

Use of cosmogenic isotopes for determining the exposure age and erosion of granitic rocks—*Paul Bierman*

Evaluation of rock varnish dating techniques [USGS NEHRP Research]—*Paul Bierman and Alan Gillespie*

Geology and origin of the Overlook gold deposit, Ferry County, Washington—*Michael G. Rasmussen*

Pb isotopic variations in sulfides of the Stillwater Complex, Montana—*Mark Thurber*

WASHINGTON STATE UNIVERSITY

Faculty projects

Exploration targets for the next century—metals in the metasomatic environment—*Lawrence D. Meinert*

Geologic and geohydrologic site characterization studies, Hanford Site, Washington—*David R. Gaylord and Eileen P. Poeter [Colorado School of Mines and Technology]*

Eolian morphology, sedimentology, and paleoclimatic significance, Hanford Site, Washington—*David R. Gaylord*

Sedimentology and stratigraphy of middle Eocene volcanogenic deposits, northeastern Washington and southern British Columbia—*David R. Gaylord*

Biostratigraphic analysis of three potential mid-Carboniferous boundary stratotypes in the Great Basin—*Gary D. Webster and Larry E. Davis*

Early Carboniferous crinoid faunas of the western United States (includes materials of Kinderhookian and Osagean age from MT, UT, ID and NV)—*Gary D. Webster*

Permian crinoids of Western Australia—*Gary D. Webster*

Bibliography and index of Paleozoic crinoids—*Gary D. Webster*

Annotated bibliography of Carboniferous conodonts—*Gary D. Webster and Carl B. Rexroad [Indiana Geological Survey]*

The significance of orogen-parallel lineations—*A. John Watkinson*

Refold geometries observed in the Loch Monar region, Scotland—*A. John Watkinson*

Refold analysis of multiply deformed mines and mining districts—*Richard L. Thiessen and A. John Watkinson*

Geophysical investigations of the cratonic margin in the Pacific Northwest—*Richard L. Thiessen*

Structural analysis of the central Columbia Plateau utilizing radar, Landsat, digital topography, and magnetic data bases—*Richard L. Thiessen*

A three-dimensional computer analysis of modelling system for remote sensing-structural geologic problems—*Jay R. Eliason*

Deformation along the Olympic/Wallowa Lineament, Oregon and Washington—*Peter R. Hooper*

The Columbia River basalts in the Lewiston Basin and along the Blue Mountains uplift (Oregon and Washington)—*Peter R. Hooper*

Primitive basalt flows in the Pacific Northwest.—*Peter R. Hooper (David G. Bailey and Richard M. Conrey)*

Paleomagnetism of volcanics in the Pacific Northwest—*Peter R. Hooper and William K. Steele [Eastern Washington University] (David G. Bailey, Richard M. Conrey, Kevin M. Urbanczyk, and Sandra P. Lilligren)*

Alkali basalts and ultramafic nodules of eastern China—*Fan Qicheng [Institute of Geology, Beijing, China] and Peter R. Hooper*

Alkali basalts of the Harrats of Saudi Arabia—*Victor E. Camp [U.S. Geological Survey] and Peter R. Hooper*

Deccan basalts—Peter R. Hooper and John Mahoney [University of Hawaii] *(John E. Beane)*

Prineville Basalt—*Peter R. Hooper, William K. Steele [Eastern Washington University], Terry Tolan, and Gary Smith (Richard M. Conrey, David G. Bailey, Kevin M. Urbanczyk)*

Age and determination of Cascade tephras in the Pacific Northwest—*F. F. Foit, Jr.*

Crystal chemistry of the tourmaline group—*F. F. Foit, Jr.*

High temperature gold-quartz veins in distal portions of porphyry copper districts—*Lawrence D. Meinert (John Link)*

Isotopic tracking of mineralizing fluids in skarn deposits—*Lawrence D. Meinert (Brian Zimmerman)*

Carbon cycling in vadose zones—*C. Kent Keller*

Age-dating dissolved inorganic carbon and dissolved organic carbon in groundwaters—*C. Kent Keller*

Structural evolution of metamorphic core complexes, northeast Washington—*A. John Watkinson*

Student projects

Geology and geochemistry of gold skarn mineralization in the McCoy mining district, Lander County, Nevada—*Jeffrey W. Brooks*

Geology of the Tillicum gold skarn camp, British Columbia—*Dean M. Peterson*

Gold skarn mineralization in the Fortitude deposit, Lander County, Nevada—*Greg L. Myers*

Gold skarn mineralization in clastic host rocks, Beal mine, Montana—*Kurt M. Wilkie*

Regional stratigraphy and sedimentology of the upper Sanpoil Volcanics and Klondike Mountain Formation in the Republic, First Thought, and Toroda Creek grabens, Washington and southern British Columbia—*James D. Suydam*

Sedimentology and stratigraphy of upper Sanpoil Volcanics and the Klondike Mountain Formation, Republic mining district—*Scott M. Price*

Sedimentology, stratigraphy and paleoclimatic implications of eolian deposits on the Hanford Site, Washington—*Larry D. Stetler*

Sedimentology and geoarchaeology of eolian deposits on the Hanford Site, Washington—*Grant D. Smith*

Stratigraphy and sedimentology of the O'Brien Creek Formation, northeastern Washington and southern British Columbia—*Jeffrey M. Matthews*

Stratigraphy, sedimentology, and depositional history of the Upper Cretaceous Beaverhead Conglomerate, McKnight Canyon, southwest Montana—*Holly J. Corner*

Kinematics and strain in the Lincoln gneiss dome, northeast Washington—*Jay P. Busch (A. John Watkinson)*

Fracture patterns and fold related strain using examples from the Yakima Fold Belt, Washington and the Montana fold and thrust belt—*Sarah M. Koerber (A. John Watkinson)*

Geologic analysis of a portion of the Weatherbee Formation, northeastern Oregon—*Rebecca Myers*

Correlation of fractures observed using a televiewer in the Cajon Pass DOSSEC drill hole with ones determined from Geologic Spatial Analysis applied to topographic data bases—*Mark Ader*

Structural analysis of the West Idaho suture zone—*David E. Blake*

Identification of range front fault scarps using digital topography data bases and application to the Wasatch front, Utah—*Douglas S. Neves*

Determination of the three-dimensional orientation and location of faults using earthquake foci and application to the Puget Sound—*Eric Rieken*

Syenites around the Idaho batholith, Idaho—*D. Kate Schalck*

Colville batholith and Sanpoil Volcanics—*Laureen J. Wagoner (Peter R. Hooper)*

The volcanic rocks of the eastern Clarno—*Kevin M. Urbanczyk and Sandra P. Lilligren (Peter R. Hooper)*

The Eckler Mt. Formation, Columbia River basalt gorge in Oregon, Washington, and Idaho—*Beth A. Gillespie (Peter R. Hooper)*

Relation between volcanism and tectonics in the Vale area, eastern Oregon—*Kate Lees (Peter R. Hooper)*

Dissolved organic carbon in vadose-zone pore water—*Richard Crum*

Bulk gas-phase diffusion coefficients in unsaturated loess—*Diane Foster*

Distribution of environmental tritium and groundwater recharge in the Palouse Formation—*Rachel O'Brien*

Foraminifera and conodont biostratigraphy and carbonate microfacies of Early Carboniferous shelf to basin sediments, north-central Wyoming to southeastern Idaho—*Aram Derewetzky and Chen Xiaobing (Gary D. Webster)*

WESTERN WASHINGTON UNIVERSITY

Faculty projects

Petrogenesis of the Crescent basalts and related rocks in the Coast Range Volcanic Province—*R. Scott Babcock*

Magmatic evolution of the North Cascades—*R. Scott Babcock*

Petrogenesis of the Fifes Peak Formation, central Cascades—*R. Scott Babcock*

Laser-Ar dating of tephra and paleomagnetism of early Pleistocene sediments in the Puget Lowland—*Don J. Easterbrook*

Thermoluminescence dating of middle Pleistocene sediments in the Puget Lowland—*Don J. Easterbrook (Glenn W. Berger)*

Advance and recession of the Cordilleran ice sheet and relationships to glaciomarine deposition—*Don J. Easterbrook*

Causes of debris torrents in northwest Washington—*Don J. Easterbrook*

Effects of logging on flooding in Whatcom County—*Don J. Easterbrook*

Effect of seawalls on beaches in Puget Sound—*Maurice L. Schwartz and T. Terich [WWU Geography Department]*

Sources, depositional environments, and tectonics of the peripheral sedimentary rocks of the Crescent terrane, northern Olympic Peninsula—*Christopher A. Suczek*

Student projects

Effects of 1989 and 1990 storms on Canyon Creek, Whatcom County—*Mark Ballerini*

Effects of dredging on the Nooksack River, Whatcom County—*Roger Bertschi*

Late Pleistocene marine terraces, glaciomarine drift, and late Vashon transition sediments—*Cindy Carlstad*

Effects of the 1989 and 1990 storms on Gallup Creek, Whatcom County—*Melanie Carpenter*

Historic fluctuations of glaciers on Mount Baker—*Joel Harper*

Glacier Creek flooding, Whatcom County—*Carla Cary*

Net shore-drift (longshore transport) mapping of the coastlines of San Juan, southern Snohomish, southern Island and southeastern Jefferson Counties—*Jim Johannessen*

Structure and petrology of the Eldorado Peak area, North Cascades, Washington—*Dan McShane*

Hydrostratigraphy and potential problems of seawater intrusion on northern Camano Island—*Lloyd Stevens*

Paleogeographic reconstruction of the Crescent terrane on the Olympic Peninsula—*Andrew Warnock* ⚒

USGS Starts Water Assessment of the Columbia Plateau

A long-term, comprehensive assessment of the water quality of the central Columbia plateau is being launched by the U.S. Geological Survey. The plateau is a 19,000-mi^2 basin, mostly in eastern Washington, drained by Crab Creek and the Palouse River. The project is one of 20 being initiated this year as part of a National Water Quality Assessment.

The long-term goals of NAWQA are to describe the status and trends in the quality of a large, representative part of the nation's surface- and ground-water resources and to provide a sound, scientific understanding of natural and human factors affecting these resources.

"One goal of the assessment is to provide water managers and users with a more complete snapshot of current water-quality conditions and problems in the regions," said Sandy (Alex K.) Williamson, a USGS hydrologist in Tacoma, who was recently named chief of the project.

"But even more important is the need to go beyond the snapshot to define the long-term trends in water quality in terms that will allow water managers to design long-term solutions to real problems," Williamson said. "We will work first with state, local, and federal agencies to take the pulse of the surface- and ground-water resources in the plateau. Then, we will develop an assessment program needed to build an understanding of the hydrologic health of the basin, that will, in turn, allow managers to make more effective water management decisions for the future."

Two immediate priorities for the central Columbia plateau assessment are:

- Formation of a liaison committee of representatives from state and local water-resources agencies, universities in Washington and Idaho, and other federal agencies.
- A detailed review of the hydrologic and related biologic information already collected or being collected, as part of a first-year effort to develop a practical assessment plan.

Water-quality issues discussed at the first meeting of the committee, held May 29 at Moses Lake, included:

- Elevated concentrations of nutrients and trace organic compounds in surface and ground waters
- Eutrophic conditions and nuisance aquatic plants in some streams and lakes
- Elevated concentrations of sodium in surface and ground waters in areas irrigated with ground water
- Erosion of soil caused by rainfall and snowmelt, especially on frozen ground
- Steambed deposition of fine sediment that covers spawning gravels and causes dissolved-oxygen depletion
- Elevated temperatures, pH and concentrations of ammonia and bacteria in surface water

NAWQA was started in 1986 at seven sites around the country to test its assessment methods. One of the sites was the Yakima River basin in eastern Washington.

The full-scale national program began in fiscal year 1991 with the selection of 20 study sites. Each of these 20 projects will consist of an intensive 4- to 5-year phase of data collection and analysis. In fiscal year 1994, 20 more projects will be started, with the final 20 projects to begin in fiscal year 1997, for a total of 60 projects covering a large part of the United States.

This rotational strategy will provide consistent information on a perennial basis that will be integrated to describe the quality of the nation's water resources. At the end of the first cycle of 60 intensive studies in three groups, the first 20 study units will be studied again to detect trends that may have developed. ⚒

(Modified from a USGS press release dated August 2, 1991)

Selected Additions to the Library of the Division of Geology and Earth Resources

May 1991 through July 1991

THESES

Ashford, Paul G., 1988, Geological hazard assessment of a residential development in West Vancouver, British Columbia: University of British Columbia Bachelor of Applied Science thesis, 66 p., 1 plate.

Barker, Sally E., 1988, Magma body geometry at Mount St. Helens inferred from the stress field associated with post-eruptive earthquakes: University of Washington Master of Science thesis, 76 p.

Beale, Harriet, 1990, Relative rise in sea-level during the late Holocene at six salt marshes in the Puget Basin, Washington: Western Washington University Master of Science thesis, 157 p.

Bodle, Tom R., 1990, The relation of earthquake intensity to surface geology and elevation in western Washington State: University of Washington Master of Science thesis, 119 p.

Brandon, Mark Thomas, 1984, Deformational processes affecting unlithified sediments at active margins—A field study and a structural model: University of Washington Doctor of Philosophy thesis, 159 p.

Burger, Roy William, 1984, Source mechanism of the May 18, 1980 St. Helens eruption from regional surface waves: Pennsylvania State University Master of Science thesis, 72 p.

Campbell, A. R., 1991, Petrology and petrogenesis of the Lost Peak and Monument Peak stocks, Okanogan County, Washington: University of Washington Master of Science thesis, 136 p., 1 plate.

Caress, David William, 1989, Some aspects of the structure and evolution of oceanic spreading centers: University of California, San Diego, Doctor of Philosophy thesis, 120 p.

Chambers, Richard L., 1971, Sedimentation in glacial Lake Missoula: University of Montana Master of Science thesis, 100 p.

Croasdale, Duncan Alexander, 1989, A small scale translational rock failure affecting the basal failure surface of the 1965 Hope slide: University of British Columbia Bachelor of Science thesis, 1 v., 2 plates.

Denton, Alexander W. S., 1986, Tectonics and sediment geochemistry of Tuzo Wilson seamounts, northeast Pacific Ocean: University of British Columbia Master of Science thesis, 183 p.

Dewhurst, Warren T., 1988, The simultaneous inversion of vector and total field aeromagnetic data using Bayesian inference—A case study from the Cobb Offset of the Juan de Fuca Ridge: Colorado School of Mines Doctor of Philosophy thesis, 249 p.

Eissler, Holly K., 1986, Investigations of earthquakes and other seismic sources in regions of volcanism: California Institute of Technology Doctor of Philosophy thesis, 174 p.

Feeney, Tracey, 1989, The petrology, morphology and tectonics of Explorer Seamount: University of British Columbia Bachelor of Science thesis, 55 p., 1 plate.

Ganoe, Steven J., 1983, Investigation of P_n wave propagation in Oregon: Oregon State University Master of Science thesis, 97 p.

Gardiner, Mark A., 1988, Hydrothermal reaction of groundwater with basalt from the entablature of the Cohassett flow, Grande Ronde formation, Hanford, Washington—The effect of the introduction of fresh solution to the system at 200 degrees and 300 degrees C, and 30 MPa: Temple University Master of Arts thesis, 152 p.

Hamill, Gary, 1982, Quaternary interpretation of southwest Tofino Basin, Pacific margin, Canada: University of Calgary Master of Science thesis, 148 p., 9 plates. (Note: DGER copy reproduced from microfiche; plates are dismembered and bound with the book.)

Johnson, David Andrew Lothian, 1987, Crustal structure and seismicity of the northern Gorda Ridge: University of Washington Master of Science thesis, 120 p.

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A Note from the Burke Museum at the University of Washington

A new taxon from the middle Eocene fossil flora at Princeton, BC, has been named for the museum's Affiliate Curators of Paleobotany, Jack Wolfe and Wes Wehr. The new name is *Wehrwolfea striata*, but there's no information yet about its reaction to full moons.

LOCATION OF MAIN OFFICE

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New Division Releases

The three sheets and accompanying pamphlet for the **Geologic map of Washington—Northeast Quadrant**, our **GM-39** at 1:250,000 scale, have been published. Folded sheets and the pamphlet in an envelope cost $7.42 + .58 (tax for Washington residents only) = $8.00. A limited supply of the publication with unfolded copies of the sheets is also available at $9.28 + .72 = $10.00. A topographic base map for the quadrant (**TM-2**) is also available separately: folded ($1.86 + .14 = $2.00) or flat ($3.25 + .35 = $3.50). Unfolded copies of both publications are mailed in tubes.

Open File Report 91-5, A compilation of reflection and refraction seismic data for western Washington and adjacent offshore areas, by W. S. Lingley, Jr., Linden Rhoads, S. P. Palmer, and C. F. T. Harris. This 9-page report briefly describes data available to the public from the Division's collection and shows the locations of tracklines on a 1:500,00-scale map ($.93 + .07 tax = $1.00). Disc versions of the plate are available as files in .DWG and .DXT formats.

The **Washington State Issue of *Rocks & Minerals*** (v. 66, no. 4), devoted to geologic features of the state, contains articles about zeolites, petrified wood, and fossil crabs, as well as descriptions of minerals from selected claims and mines. Also included are a list of collecting sites for agates and a list of geology, mineral, and fossil collections and displays in Washington. The lead article, by Raymond Lasmanis, is a discussion of the state's geology by physiographic province; it includes a page-size geologic map (1 in. = approx. 60 mi). The Division has a supply of issues for sale at $2.32 + .18 tax = $2.50.

The Association of Engineering Geologists Bulletin for August features an article by R. W. Galster and W. T. Laprade about **engineering aspects of the geology of Seattle**. The 67-p. article also features a generalized geologic map of the Seattle area (5 in. = 4 mi).

Please add $1 to each order for postage and handling. Our mailing address is given on p. 2 of this publication. We would appreciate having your Zip Code and the four-digit extension for your address with your correspondence. ⚒

Smithsonian Research Fellowships and Internships Available for 1992-1993

The Smithsonian Institution has announced its research fellowships for 1992-1993 in the following earth sciences: meteoritics, mineralogy, paleobiology, petrology, planetary geology, sedimentology, and volcanology. Fellowships are also available in the areas of: history of science and technology, social and cultural history, history of art, anthropology, biological sciences, and materials analysis (archaeometry and conservation science).

Applications are due January 15, 1992. Stipends supporting these awards are $26,000 per year plus allowances for senior postdoctoral fellows; $13,000 per year plus allowances for predoctoral fellows, and $3,000 for graduate students for the ten-week tenure period. Pre-, post-, and senior postdoctoral stipends are prorated on a monthly basis for periods of less than twelve months.

Awards are based on merit. Smithsonian fellowships are open to all qualified individuals without reference to race, color, religion, sex, national origin, age, or condition of handicap of any applicant. For more information an application forms, write: Smithsonian Institution, Office of Fellowships and Grants, Suite 7300, 955 L'Enfant Plaza, Washington, D.C. 20560. Please indicate the particular area in which you propose to conduct research and give the dates of degrees received or expected.

Smithsonian Minority Internship Program

Internships, offered through the Office of Fellowships and Grants, are available for students to participate in research or museum-related activities for periods of nine to twelve weeks during the summer, fall, and spring. U.S. minority undergraduate and graduate students are invited to apply. The appointment carries a stipend of $250 per week for undergraduate and $300 per week for graduate students, and may provide a travel allowance. For applications and deadline information, write: Smithsonian Institution, Office of Fellowships and Grants, Suite 7300, 955 L'Enfant Plaza, Washington, D.C. 20560. ⚒

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Table 1. Broad-leaved deciduous plants and conifers of the Republic flora

("aff." indicates that the Republic genus is extinct but is related to the living genus named. "Carib.", Caribbean)

Family or group	*Abundance*	*Present distribution*
CONIFERS AND OTHER GYMNOSPERMS		
Ginkgo family		
Ginkgo (maiden-hair fern tree)	common	China
Yew family		
Amentotaxus (Chinese yew)	rare	W China
Redwood family		
Metasequoia (dawn redwood)	common	central China
Sequoia (redwood)	scarce	Pacific N America
Sciadopitya (umbrella pine)	rare	Japan
Pine family		
Abies (true fir)	scarce	northern temperate
Picea (spruce)	scarce	cool northern hemisphere
Pinus (pine)	common	northern temperate
Pseudolarix (golden larch)	scarce	E China
Tsuga (hemlock)	rare	temperate N America
Cedar family		
Chamaecyparis (false-cypress)	scarce	E Asia and N America
Thuja (arborvitae)	scarce	E Asia and N America
FLOWERING PLANTS OR ANGIOSPERMS		
Magnolia family		
Talauma	*rare*	*S Asia, S N America, Carib.*
Laurel family		
Phoebe	scarce	S Asia, S N America, Carib.
Sassafras	common	E N America and E Asia
Trochodendroid group		
Nordenskioldia	rare	extinct genus
Eobaileya	rare	extinct genus
Cercidiphyllum (katsura)	common	China and Japan
Joffrea	common	extinct genus
Witch-hazel family		
Langeria	scarce	extinct genus
Corylopsis	rare	E Asia and Himalayas
aff. *Hamamelis*	rare	extinct
Sycamore family		
Macginitiea	scarce	extinct genus
Birch-alder family		
Alnus (alder)	common	N hemisphere
Betula (birch)	scarce	N temperate
Corylus (hazelnut)	rare	N temperate
Beech family		
Castanea (chestnut)	rare	N temperate
Fagopsis	scarce	extinct genus
Fagus (beech)	rare	northern temperate
Quercus (oak)	rare	
Wax myrtle/sweet-fern		
Comptonia (sweet fern)	scarce	E North America
Walnut family		
Pterocarya (wingnut)	rare	Caucasus, E Asia
Elm family		
Ulmus	scarce	N temperate
Zelkova (Chinese elm)	rare	Caucasus and E Asia
Tea-camellia family		
Gordonia (Carolina bay)	scarce	SE Asia and SE N America
Heath family		
Rhododendron	rare	N hemisphere
aff. *Arbutus*	rare	extinct
Linden family		
Tilia (linden)	rare	N temperate
Hydrangea family		
Hydrangea	rare	N temperate
Virginia-willow family		
Itea (Virginia willow)	scarce	E Asia, E N America
Currant family		
Ribes	rare	N hemisphere
Rose family		
Spiraea (bridal wreath)	rare	N temperate
Crataegus (hawthorn)	rare	N temperate
Malus (apple)	rare	N temperate
Rubus (blackberry)	rare	N and S hemispheres
Prunus (cherry)	scarce	N hemisphere
Photinia (toyon)	scarce	E Asia, S N America
aff. *Sorbus*	scarce	extinct
aff. *Prunus* (cherry)	scarce	extinct
Sumac family		
Rhus (sumac)	scarce	N hemisphere
Soapberry family		
Bohlenia	scarce	extinct genus
Koelreuterua (golden rain tree)	rare	E Asia
Maple family		
Acer (maple)	rare	N hemisphere
aff. *Acer*	scarce	extinct
Dogwood family		
Cornus (dogwood)	rare	N and S temperate
Olax family		
Schoepfia	rare	tropical, subtropical
Unknown affinity		
Republica	rare	extinct genus

species have modern representatives in these forests. But the modern Asian forests also contain many plants that are poorly represented or not found in the Republic flora—for example, oak (*Quercus*), beech (*Fagus*), and rhododendron. The Republic flora also contains numerous extinct genera (*Macginitiea, Plafkeria, Barghoornia*). In Table 1 we list elements of the Republic flora and indicate their present status.

After Republic time, other genera of poorly represented families were added to the highland temperate flora—Oregon grape, willow, redbud, and ash. Therefore, we believe the Republic flora represents a very early stage in the evolution of modern temperate forests. Plate 1 on the next three pages illustrates selected leaves found at Republic and that were used in the CLAMP analysis.

Among the Republic specimens there are tens of species of the rose family, including members of all four subfamilies. Many of these species remain undescribed. The arrangement of veins in one type of Republic rose leaf is probably a primitive type for the family. Other leaves seem to resemble the hawthorn, others are somewhat like *Photinia*. And still others seem to combine characters that are found in more than one modern genus, which suggests that Eocene species gave rise to these genera or they have characteristics that are intermediate between the original rose ancestor and a modern genus. The Republic flora is proving to be im-

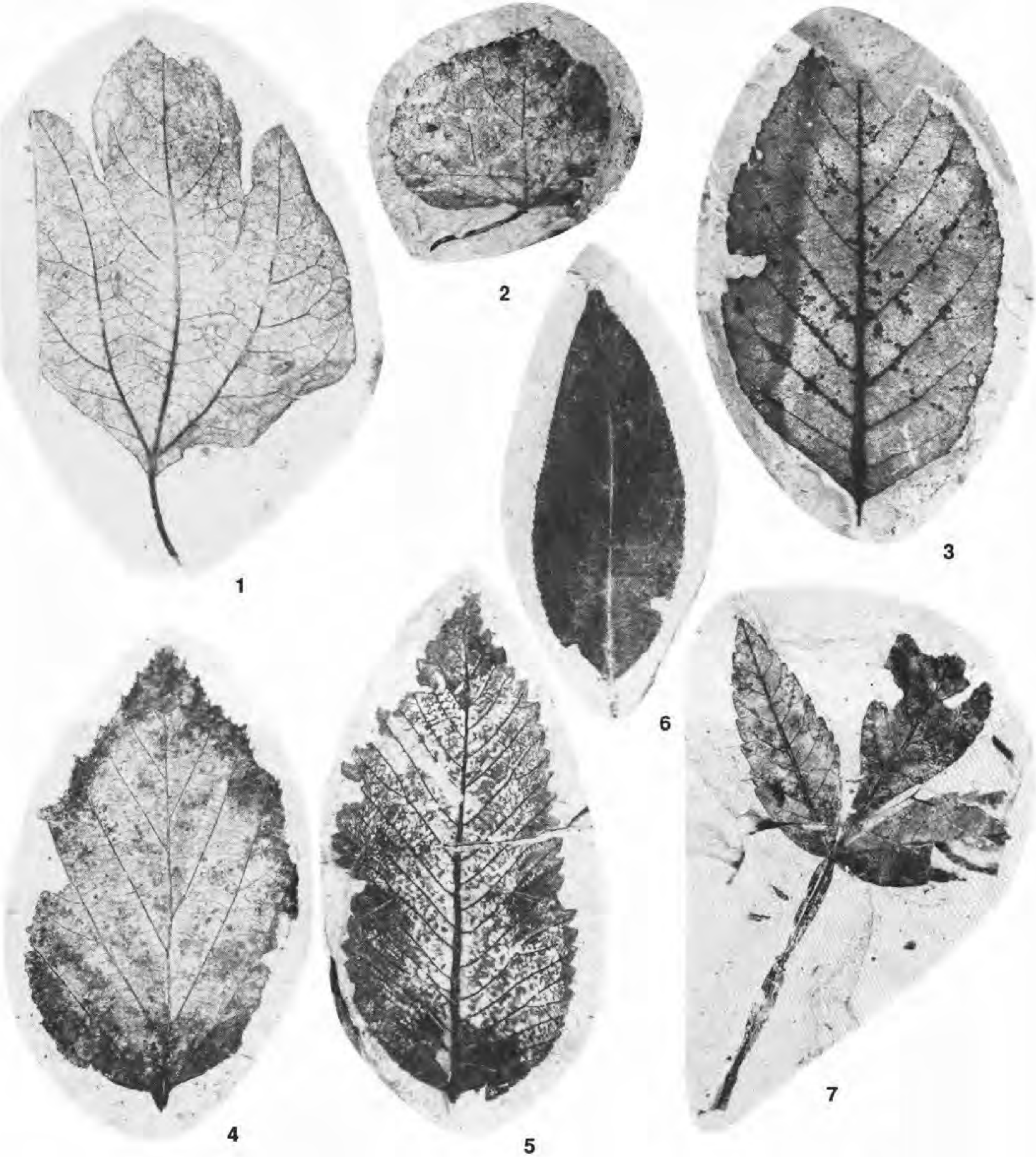

Plate 1. Leaves of plants in the Republic flora. Leaves of most temperate trees and shrubs have many, regularly and closely spaced marginal teeth (nos. 2-7, 10, 13, 16, 17), and the teeth tend to be sharply pointed. Lobed leaves (nos. 1, 10, 14) are also common among temperate plants. In contrast, leaves of most subtropical to tropical trees and shrubs are large, have no teeth, or if teeth are present, they are distantly and irregularly spaced and rounded (as in no. 12); these leaves also have attenuated, narrow tips, called drip-tips (nos. 11, 12). The subtropical to tropical characteristics are rare among the Republic leaves. Unless otherwise indicated, all photos are X 1. **1.** *Sassafras* (this leaf may be lobed, as in the photo, or unlobed); Family Lauraceae. **2.** *Joffrea*, related to the modern katsura; Family Cercidiphyllaceae. **3.** *Alnus* (alder); Family Betulaceae. **4.** *Betula* (paper birch); Family Betulaceae. **5.** *Ulmus* (elm); Family Ulmaceae. **6.** *Itea* (Virginia willow); Family Iteaceae. **7.** *Rhus* (sumac); Family Anacardiaceae; this is a compound leaf, that is, it has more than one leaflet, and it has a winged extension of the leaf stalk, or rachis. With the exception of *Betula*, all these leaves are abundant to common at Republic.

Plate 1. Leaves of plants in the Republic flora (continued). **8.** *Cornus* (dogwood); Family Cornaceae. **9**. A new genus belonging to the Family Loranthaceae (mistletoes); no other fossil leaves of the mistletoes are known. **10.** A new genus related to *Physocarpus* (ninebark). **11.** A new genus of the Family Meliaceae (mahogany family); this family is tropical to subtropical today, and the leaves have no teeth and can have a pronounced drip-tip, as in this Republic specimen. X 0.93. **12.** *Gordonia* (Carolina bay); Family Theaceae; this family is predominantly subtropical and, as in other subtropical leaves that are toothed, the teeth are rounded and irregularly and distantly spaced. X 0.93. **13.** A new genus related to *Sorbus* (mountain ash). Numbers 10 and 13 are members of the Family Rosaceae.

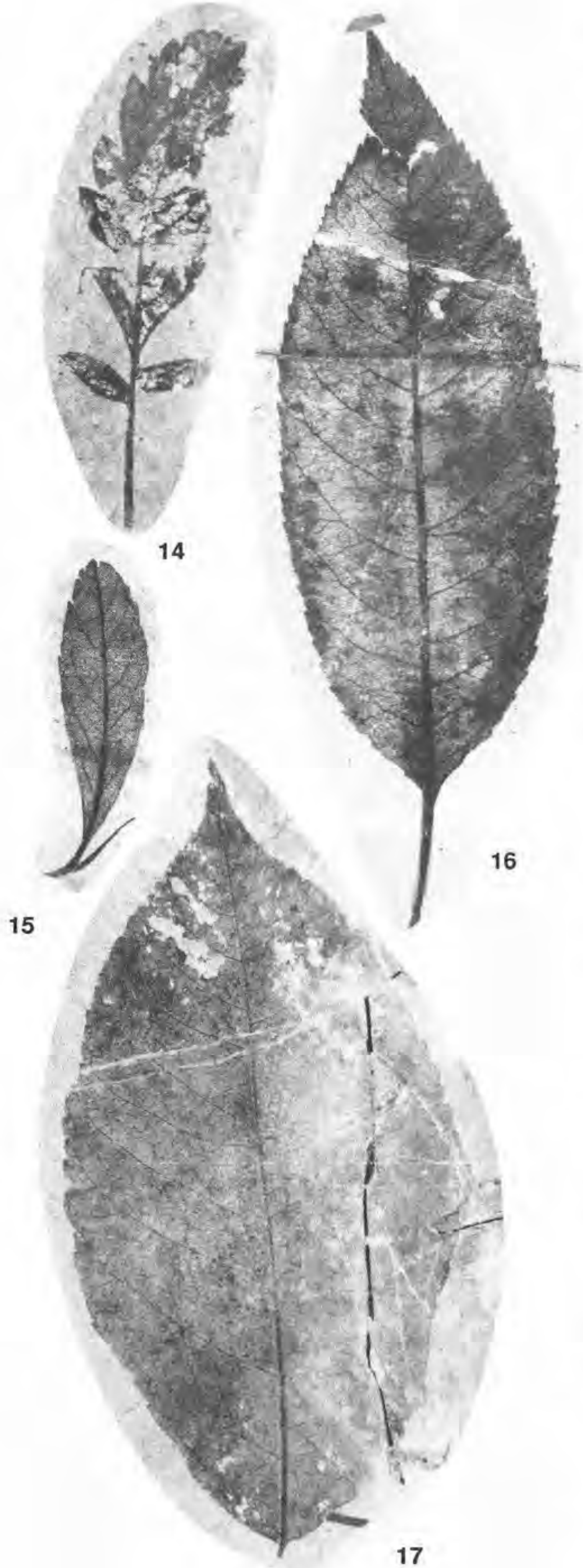

Plate 1. Leaves of plants in the Republic flora (continued). **14.** A new genus related to *Crataegus* (hawthorn). **15.** A new genus related to *Spiraea* (bridal-wreath); unlike modern *Spiraea*, the Republic genus has the primitive character of stipules, which are leaf-like structures that enclose the leaf bud and are located at the base of the leaf stalk. **16.** *Photinia* (toyon or christmas-berry). **17.** *Prunus* (cherry). These plants are also members of the Family Rosaceae.

portant in understand how modern members of the rose family are related. The name of the site's interpretive center, Stonerose, was taken from these fossils.

Because new species of plants (and rare animal forms) are still being found at Republic, it is important that visitors understand the potential value of their finds. Many leaf fossils preserve the vein structures well. Each leaf form contributes to our understanding of both paleoenvironment and evolutionary trends. We recommend a visit to the Stonerose Interpretive Center so as to get an overview of the plant forms found to date. We hope that fossils will be brought to the center so that plants can be identified and specimens of new or rare plants can be saved for study.

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Highlights of the Volcanic Ash and Aviation Safety Symposium

By Patrick T. Pringle

The First International Symposium on Volcanic Ash and Aviation Safety convened in Seattle July 8 through 12. The meeting was sponsored by the Air Line Pilots Association, the Air Transportation Association of America, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS). Cosponsors included the Aerospace Industries Association of America, the American Institute of Aeronautics and Astronautics, the Flight Safety Foundation, the International Association of Volcanology and Chemistry of the Earth's Interior, and the National Transportation Safety Board. Twenty-three nations were represented at the meeting.

Although the meeting was engendered by the aircraft/ash plume encounters at Mount St. Helens (1980), Indonesia's Galunggung volcano (1982), and Alaska's Redoubt volcano (1989), it gained additional impetus from 15 jumbo-jet encounters with eruption plumes of Philippine volcano Pinatubo several weeks prior to the meeting. (See cover photo.) A special session on the Pinatubo eruption took place on the first evening of the conference.

Luncheon speakers included **Dallas Peck**, Director of the USGS, **Zygmund Przedpelski** of the General Electric Corporation, and **Eric Moody**, who piloted the British Airways 747 that encountered an ash cloud from Galunggung volcano in Indonesia in 1982. (That plane "glided" more than 20,000 ft vertically before power was regained.)

The following paragraphs review the field trips and highlights of sessions. Affiliations are included only for speakers (bold lettering). The symposium was dedicated to Maurice and Katia Krafft and Harry Glicken, volcanologists who perished at Unzen volcano in Japan on June 3, and to Kazuaki Nakamura, Denis Westercamp, Johannes Matahelumual, and K. Kusumadinata, other volcanologists who died this year.

Field Trips

Many conference attendees participated in the pre-conference field trip to the FAA's Air Traffic Control Center (ATCC) in Auburn and the Boeing Airplane Co. factory in Renton where Boeing 737 and 757 aircraft are assembled. The ATCC, one of 20 regional centers in the conterminous United States, is responsible for monitoring and communicating with air traffic in a 300,000 mi^2 area in the Pacific Northwest.

A post-conference field trip to Mount St. Helens, led by **Steven Brantley** (USGS), visited Bear Meadows, Meta Lake, Harmony Falls, and Windy Ridge interpretive areas.

Redoubt Eruptions

The opening session centered on aircraft interactions with ash plumes from Redoubt volcano, 110 mi southwest of Anchorage. The most noteworthy ash cloud/aircraft interaction during the Redoubt activity was that of the December 15 KLM flight, which lost power in all four engines and then dropped nearly 12,000 ft before regaining power.

Table 1. Major volcanoes whose eruptions have been associated with aviation-safety incidents.

Year of Eruption	Volcano	Country
1944	Vesuvius	Italy
1955, 1976, 1986	Augustine	USA (Alaska)
1973	Asama	Japan
1975, 1986	Sakurajima	Japan
1977	Usu	Japan
1980	Mount St. Helens	USA
1982	Galunggung	Indonesia
1982	El Chichon	Mexico
1983	Colo (Una Una)	Indonesia
1983, 1985	Soputan	Indonesia
1985	Nevado del Ruiz	Columbia
1989	Redoubt	USA (Alaska)
1991	Pinatubo	Philippines

Tom Miller and J. N. Davies of the USGS Alaska Volcano Observatory (AVO) discussed the eruptive history of Redoubt volcano and described the 1989–1990 eruptive events. Photographs of one eruption show the ash column rising off a pyroclastic flow, illustrating that the origin of the column is not necessarily the central vent. Miller provided an overview of the types of eruptions and corresponding eruption return intervals that could be expected from Alaskan volcanoes.

Ernest Campbell of the Boeing Commercial Airplane Group gave a detailed account of the KLM/ash cloud encounter, of impairments to the aircraft's control system during the emergency, and of damage to the Boeing 747-400 aircraft. Total cost to put the plane back in service was $80 million.

Zygmund Przedpelski of the General Electric Corporation and **Thomas Casedevall** (USGS) discussed details of engine deterioration due to ash ingestion. They conducted tests to analyze damage sustained by different components of jet engines and used petrographic thin sections and scanning electron microscope and electron microprobe techniques to evaluate the results. Because the principal components of volcanic ash (volatile-poor glass and minerals) are unlikely to melt at temperatures below 900°–1,000°C, engine power can be reduced to minimal settings to lower engine temperature and reduce the likelihood of ash melting in the engine during an ash cloud/aircraft encounter.

Charles Criswell of the FAA's Alaska Region described the setting of Mount Redoubt in the midst of a route complex connecting the Orient, Europe, eastern North America, and the west coast of North America. This coincidence of flight routes illustrated one of the major reasons for concern about aircraft/ash interactions—that the routes that traverse and/or are linked to routes traversing the Pacific rim also traverse geographic regions hosting an abundance of volcanoes. Criswell compared aircraft-control center operating procedures and types of communications during and after the Redoubt incident and noted the current difficulties in getting digital information into the cockpit.

Peter Hobbs of the University of Washington Atmospheric Sciences Department reported on lidar detection of ash plumes and the distribution of volcanic emissions. Lidar uses wavelengths of 1 and 0.5 microns, much shorter than radar, and hence can "see" smaller particles. Radar uses 1-mm wavelengths, which results in possible confusion of meteorological and eruptive phenomena because that wavelength is close to the diameter of rain droplets.

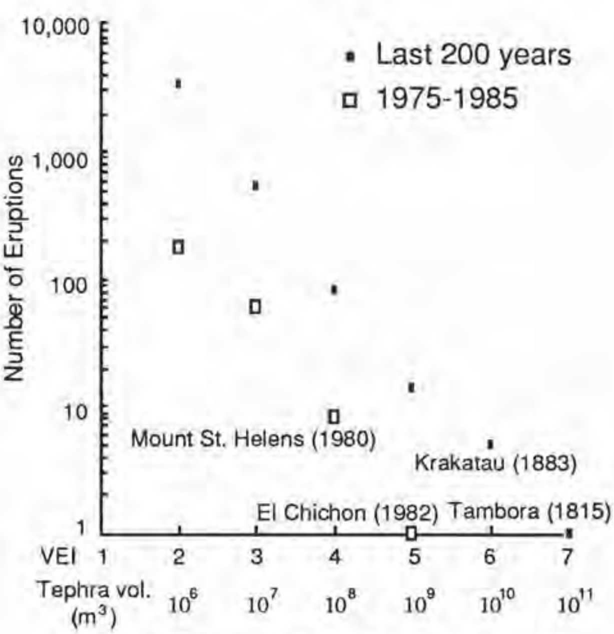

Figure 1. Log-normal distribution showing the frequency of volcanic eruptions of different VEI groups over the 200-year period 1490–1990 and over the decade 1975–1985 (modified from Simkin and others, 1981). VEI, "Volcanic Explosivity Index", is a measure of the magnitude of an explosive eruption (Newhall and Self, 1982). VEI is roughly proportional to tephra volume.

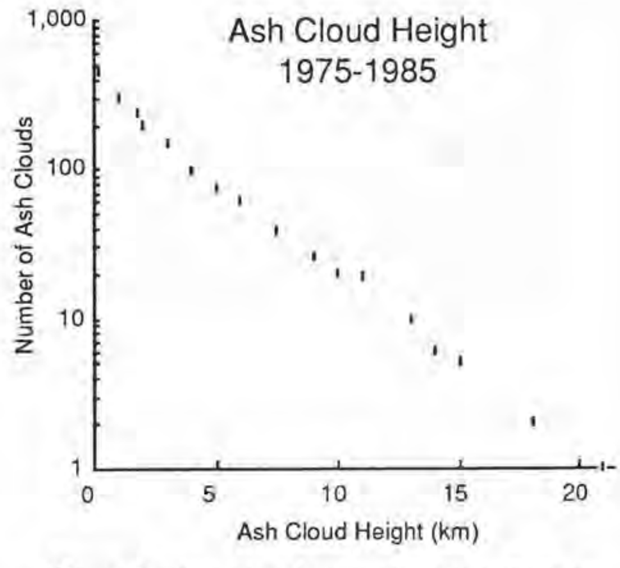

Figure 2. Log-normal regression curve showing the number of ash clouds reaching a certain altitude between 1975 and 1985 (modified from Simkin and others, 1981).

Edward Haeseker of Alaska Airlines described the difficulties faced by airlines and air travelers because the Redoubt eruptions occurred during the peak of the Christmas season travel. Haeseker noted that Alaska Airlines was unable to get information about the ash clouds in time to benefit their flights.

Volcanoes And Ash Clouds

Tom Simkin of the Smithsonian Institution summarized the occurrence and geographic distribution of volcanic eruptions around the world during various time intervals (Table 1, p. 25). Using data compiled by the Smithsonian for 1975 to 1985, he gave a perspective of the relation between eruption frequency and volume, and between eruption-cloud height and frequency of occurrence for volcanoes worldwide (Figs. 1 and 2).

Steven Self and George Walker of the Department of Geology and Geophysics at the University of Hawaii focussed on the characteristics and dynamics of eruption columns (Fig. 3) and divided these columns into groups based on height. He suggested that vulcanian eruptions (explosive eruptions producing much ash and hot blocks) were the most common type and large enough to cause problems with aircraft.

Steven Sparks of Bristol University, United Kingdom, discussed the nature of ash dispersion downwind from the vent. In order to be able to predict the particle concentrations downwind, he combined laboratory experiments with field data and developed models for plume distribution. However, he suggested that new knowledge of atmospheric-diffusion and particle-aggregation processes would further modify future models.

Grant Heiken of Los Alamos National Laboratory in New Mexico discussed the nature of volcanic ash and controls on its formation. **Thomas Casedevall** of the USGS elaborated on the gases and aerosols that make up volcanic eruption clouds.

Donald Swanson of the USGS summarized the strengths and weaknesses of the current state of volcano monitoring. He noted that while we can foresee eruptions, (1) there are too many volcanoes and too few volcanologists, (2) false alarms and failed eruptions continue to make predictive efforts troublesome (especially where large populations must be evacuated), and (3) the size and destructiveness of eruptions cannot be assessed with consistency. "Failed eruptions" have occurred in recent years at Phlegreaen Fields in Italy, Long Valley Caldera in California, and at Rabaul in New Guinea. In those complex volcanoes, high seismicity, deformation, and changes in gas discharge suggested the onset of eruptive activity, but no eruption occurred. Swanson suggested that seismic precursors are still the best (deformation tools having proven reliability only in dealing with the repeated behavior at Mount St. Helens) and that hazards maps and close media contacts are necessities for effective response to volcanic disasters.

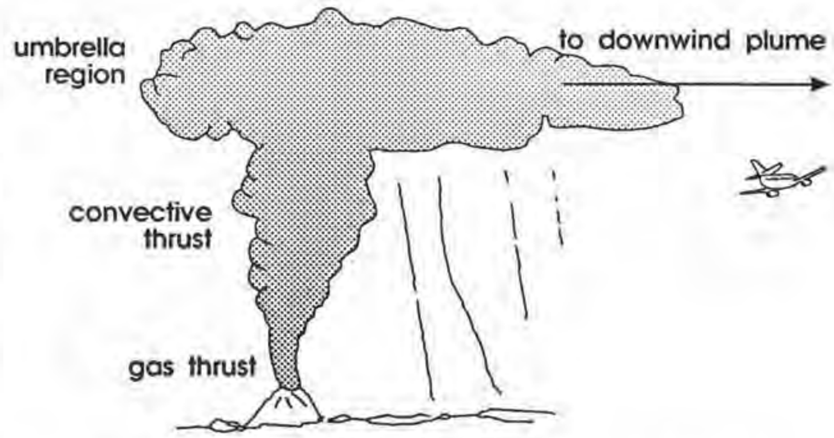

Figure 3. Characteristics of volcanic eruption columns (redrawn from Self and Walker, 1991).

Damage and Impacts

Michael Dunn of the Calspan Advanced Technology Center discussed damage to gas turbine engines and elaborated on potential damage mechanisms such as erosion of the compressor (and other rotating equipment), glassification of ash, deposition on fuel nozzles, deterioration of engine control systems, and contamination of oil and fuel supplies. Dunn noted that if engine operating temperature is higher than about 1,100°C, glassification and deposition will occur on the nozzle guide veins, choking fuel supplies.

Alan Weaver of Pratt and Whitney talked about the perception of relative risk with respect to volcanic-ash ingestion. He noted that the increased flight range and efficiency that go along with higher inlet temperatures enhance the threat of ash ingestion.

David Bailey of the Grant County Airport (Washington) related how the airport was able, by trial and error, to cope with and ultimately dispose of more than 3 cm of Mount St. Helens ash in 1980. Due to low precipitation in central Washington (6-7 in./yr), snowplows could not be used—dust-sized ash contaminated the machines and flowed around the blades. Lawn sprinklers finally were used to wet down the ash, which was then graded and hauled off by front-end loaders. It took 30 days to fully restore operations at the airport. Performance problems with vehicles and removal equipment were minimized by keeping air filters 3-4 ft above the ground and by covering air intakes with panty-hose dipped in oil.

John Labadie of JAYCOR provided an overview of techniques to mitigate of the effects of volcanic ash on aircraft operating and support systems. The 1980 Mount St. Helens ash maintained a high static charge two to three days after the eruption. The biggest problem for electronic systems was that the ash was invasive, making computers extremely vulnerable.

Communications and Procedures

Jim Evans of the Weather Sensing Group at Massachusetts Institute of Technology stressed that volcanic ash cloud hazards should be treated as a weather hazard and that maximum advantage should be taken of the weather information dissemination system under development by the FAA and National Weather Service.

R. W. Johnson of the Bureau of Mineral Resources in Canberra, Australia, summarized the problems of coping with aircraft/ash cloud interactions in Australia and the history of known encounters of aircraft with ash plumes (Table 1).

Meteorology and Ash Cloud Tracking

Both **Anthony Mostek** and **Gary Hufford** of NOAA/National Weather Service talked about the limitations of NOAA's ability to relay information during the 1989 Redoubt eruption and of the attempts to improve forecasting of plume movement via the Alaska Volcano Project. This project consists of developing new observing capabilities (C-band radar to help distinguish steam from ash emissions), new computer and communications equipment (including a wind profiler to provide continuous (real-time) wind reports to forecasters in Anchorage and for numerical models), and studies to enhance the numerical modelling system.

Thomas Schlatter discussed how the current difficulty in predicting the lower stratospheric wind field has inhibited our abilities to track ash-plume movement. Increasing availability of digital terrain data will allow refinement of the model for topographic surface roughness. A lack of current temperature data is a major obstacle to improved tracking. A new trajectory model will be developed to accommodate the anticipated "real time" data received from aircraft.

Detection and Tracking

A. J. Prata and Ian Barton of CSIRO, Division of Atmospheric Research, Australia, talked about the theoretical and experimental detection and discrimination of volcanic ash clouds using infrared radiometry. One ground-based problem is masking of the signal by water-vapor effects. Further, ash and sulfuric acid have nearly identical infrared signatures, making discrimination of these two emissions components difficult.

Michael Matson of NOAA/NESDIS in Washington, D.C., evaluated the current and future applicability of satellites for tracking ash plumes. Meteorological satellites use thermal and infrared sensors to detect ash clouds. The main advantage of satellites is large spatial coverage—the entire western hemisphere can be covered in 30 min. However, the problems of tracking ash plumes cannot be solved by satellites alone. Plume altitude and trajectory estimation require the use of additional technology. Modelers need to know the altitude of the plume to get the trajectory right, and they need better discrimination algorithms to enhance multispectral images operationally with fewer errors. Additional radiosonde data would help to assess plume location and trajectory.

William Rose and Alex Kostinski of the Department of Geology and Geological Engineering at Michigan Technological University provided an overview of the use of radar remote sensing of volcanic clouds. Ground-based radar systems can contribute much useful information including duration of eruption, rate of ascent of the ash plume, ashfall locations and times, and particle concentrations. Rose compared the better sensitivity of the higher powered (5,000 kW) Auburn, Washington, radar facility with that of the 230 kW facility at the Portland (Oregon) International Airport. Height limitations with regard to detection must be considered because they are so important to dispersion models—the July 22, 1980, plume from Mount St. Helens extended above the top of the radar. Rose suggested that Doppler radar might be employed to detect ash fallout and determine particle-size distributions in ash clouds, and that polarimetric techniques could be used to provide additional information. Cheaper portable radar units and the ability to change wavelengths of the radar (especially to a shorter wavelength) could also help with the discrimination problem.

Arlin Krueger of NASA's Earth Science Directorate discussed volcanic hazards detection using the Total Ozone Mapping Spectrometer. Although originally designed to measure ozone, it also can detect sulfur dioxide, which absorbs sunlight in a spectral range similar to that of ozone. Data-processing techniques can then separate the two gaseous components.

Special Session on the Pinatubo Eruption in the Philippines

One of the emotional highlights of the symposium was the evening session on the eruption of Pinatubo volcano in the Philippines. The scale of the June 15 eruption, one of the two largest eruptions this century, drew worldwide attention. American interest was particularly keen because of the volcano's proximity to two large military installations, Subik Bay Naval Base to the southeast and Clark Air Force Base to the northeast of the volcano.

Chris Newhall (USGS) and **Edward Wolfe**, Chief Scientist at Cascades Volcano Observatory (CVO), provided an overview of the events leading up to the climactic eruption of June 15. Numerous USGS scientists, including a contingent from CVO, cooperated with Philippine Institute of Volcanology and Seismology (PHIVOCLS) to establish volcanic monitoring and to prepare a preliminary volcanic hazards analysis around the volcano in April and May, shortly after seismic activity began. Because of their efforts, more than 200,000 people were successfully evacuated before the June 15 eruptive events. **Perla de Los Reyes** of PHIVOLCS provided a detailed account of how and when air traffic was disrupted by the eruption.

Poster Sessions

More than 50 posters were presented in sessions on topics including ash cloud damage and impacts, communications and procedures, meteorology and ash cloud monitoring, and detection and tracking of ash clouds. Before each session, authors were permitted to give a 3-min presentation summarizing their poster.

Steven Brantley of the CVO premiered a video tape on volcanic hazards that he had prepared with Maurice Krafft and Chris Newhall. Their video dramatically shows the impact of various volcanic processes using a combination of animation and film footage.

Catherine Hickson of the Geological Survey of Canada provided an overview of Holocene volcanism in British Columbia and the Yukon. She noted that a sizeable eruptive event (30 km^3) occurred only 1,200 years ago in the Canadian Cordillera.

William Scott of CVO and **Robert McGimsey** of the AVO evaluated the grain-size characteristics of the Mount Redoubt tephra deposits, noting that the polymodal grain-size characteristics of the ash might reflect the sizes of crystals in the eruption cloud.

Chris Jonientz-Trisler of the University of Washington, along with Bobbie Myers and John Power of the USGS, have developed criteria to discriminate volcanic explosions from other volcanic events.

Stephen McNutt of Sacramento, Calif., noted that volcanic-tremor amplitudes are empirically related to eruption explosivity. Therefore, tremor amplitudes of an eruption could be used to estimate its size; likewise, tremor duration could be used to estimate the eruption duration.

Yoshiro Sawada, Shizuoka Meteorological Observatory, Japan, demonstrated use of infrared images from the Geostationary Meteorological Satellite (GMS) to detect widely dispersed ash clouds caused by big eruptions. Detection rate is low (14%), mostly because of atmospheric cloud cover and resolution limitations of ground-based stations for smaller eruption clouds. However, large explosions are more easily detected, and the eruption temperature and intensity of the explosion can be estimated.

Bobbie Myers of CVO and George Theisin of the U.S. Forest Service provided a detailed description of the volcanic hazard notification procedures used at Mount St. Helens during the 1980-1986 eruptive events.

Summary

Probably the most fundamental challenge in tackling the volcanic ash cloud/aviation safety problem is improving communication among scientists, airlines, and air crews. However, this communication must be combined with an improved understanding of the hazards and agreements on who will take responsibility for alerting air crews about ash cloud hazards. Standards for reporting real-time ash-cloud conditions will likely be developed on a worldwide basis. Although several speakers stressed that reports of current conditions only (and not predictions of future/imminent eruptive activity) were needed, some anticipation of probable ash-plume hazards in a flight path will be helpful to air crews.

In general, there is a need for mutual understanding of the terminology used by, and bureaucratic functions of, the various disciplines involved. This appears to be a widespread problem in the applied sciences, and explanation and dialogue are important functions of symposiums like this one.

How much will future research and development be hampered by funding uncertainties? This issue is important because technological problems abound in areas ranging from ash cloud modeling to detection and tracking. Trackers can ascertain where an ash plume started, but they do not know what threshold concentrations effectively delimit where/when the plume is no longer a hazard. Existing communications networks and satellite systems could be used in conjunction with personal computer hardware and the Geographic Information System to locate the volcano, determine eruption status, analyze wind and other meteorological data, analyze the plume trajectory, and overlay air routes to delineate hazardous areas. Following interpretation of the data, uncomplicated messages still must be relayed to pilots in a timely fashion.

The USGS (in particular Thomas Casedevall and Chris Newhall) deserves much credit for this well-organized and well-attended symposium. Planning is underway for a future symposium.

References

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Self, Stephen; Walker, G. P. L., 1991, Ash clouds—Conditions in the eruption column [abstract]. *In* Casedevall, T. J. (editor), First International Symposium on Volcanic Ash and Aviation Safety: U.S. Geological Survey Circular 1065, p. 40.

Simkin, T.; Siegert, L.; McClelland, L.; Bridge, D.; Newhall, C.; Latter, J. H., 1981, Volcanoes of the world—A regional directory of volcanism during the last 10,000 years: Hutchison Ross Publishing Company, 232 p.

Last Map Celebrated

A ceremony to mark completion of the topographic mapping of the State of Washington by the U.S. Geological Survey (USGS) was held in Gov. Gardner's Conference Room on October 1. USGS Director Dallas Peck attended.

The final product in the map series is known as the "Mazama Map"; it covers parts of the Okanogan National Forest and Pasayten Wilderness. The Division of Geology and Earth Resources and its predecessors made financial contributions to this long-term effort from 1909 to about 1980.

At the ceremony, the USGS presented Gov. Gardner with a certificate recognizing the completion of the mapping, a framed original 1897 map of Seattle (also used as the background for the certificate), and a framed "last map" of the Mazama area.

Volcano News Erupts Again

Volcano News was an interdisciplinary forum where volcanophiles of all stripes—professional and amateur, "hard" and "soft" scientists, alike—could exchange information. *Volcano News* unfortunately became extinct when editor-publisher, Chuck Wood, became involved in editing *Volcanoes of North America*.

Janet Cullen Tanaka, a former contributing associate editor of *Volcano News* is planning the publication of a new interdisciplinary volcano newsletter to cover all facets of volcano studies from geophysics to emergency management. Persons interested in contributing articles and/or subscribing should contact Janet as soon as possible at P.O. Box 405, Issaquah, WA 98027-0405 or call 206/392-7858 between 10:00 a.m. and 10:00 p.m. PDT.

USSR Trip Promotes Exchange of Seismic Research Information

by Raymond Lasmanis

During April of 1990, the Division hosted the Fourth Annual Workshop on Earthquake Hazards in the Puget Sound and Portland Regions. At that time, we were able to invite the Vice President of the Uzbek SSR Academy of Sciences, Professor Tursun Rashidovich Rashidov (Fig. 1), to attend this Seattle meeting. He presented a lecture titled "Problems of Underground Structure Seismodynamics". Also present was Professor Bekhzah S. Yuldashev, Director of the Uzbek Institute of Nuclear Physics. (See Washington Geologic Newsletter, vol. 18, no. 2, p. 20.)

On September 14, 1990, Deputy Supervisor Stan Biles, State Geologist Ray Lasmanis, and Environmental Geology Section Manager Tim Walsh were invited by the Uzbek Academy of Sciences to visit the Republic of Uzbekistan in the Soviet Union (Fig. 2). The Division's federal National Earthquake Hazards Reduction Program grant was amended to cover travel costs to Moscow, and Professor Rashidov, on behalf of the Academy, offered to cover our costs during the stay in Uzbekistan.

Figure 1. Tursun R. Rashidov, Vice President of the Uzbek SSR Academy of Sciences, with Cretaceous petrified wood (species belonging to the Taxodiaceae) from Tashkent.

Figure 2. Uzbekistan and its setting in the U.S.S.R. Major cities visited are shown.

The trip was planned for June 1991 with the purpose of holding discussions to develop a scientific exchange program. Specifically, the agenda included items of mutual interest relating to seismic risk and mitigation.

We arrived in Tashkent, Uzbekistan, on June 4 and were greeted by a high-ranking delegation headed by Rashidov. During subsequent days, visits were arranged to various institutes where we had fruitful discussions with directors and staff. The following institutes and organizations were visited:

- Institute of Mechanics and Seismoresistance of Structures
- Institute of Geology and Geophysics
- Institute of Seismology
- Institute of Nuclear Physics
- Uzbek SSR Academy of Sciences
- Union of Scientific and Engineering Societies of USSR
- Science Education Center (Geological Museum)

We were also given the opportunity to present lectures to the Academy and a joint scientific and engineering society meeting. Stan Biles presented an overview of the Department of Natural Resources, Ray Lasmanis reviewed the geology and mineral resources of Washington, and Tim Walsh presented a lecture on geologic hazards (including seismic risk).

There was an opportunity to visit sites of historic and cultural significance. In Tashkent, a sister city of Seattle, we saw an impressive monument dedicated to the survivors of the devastating earthquake of April 26, 1966 (Fig. 3); Lenin Square; the public market; Moslem Friday Mosque, dating from the 16th century; and the Applied Arts Museum housed in the former Russian ambassador's residence dating from 1850.

Our hosts provided air transportation to Urgench; from there we drove to Khiva. The mayor of Khiva and the city architect guided us through the ancient inner city, Ichan Qala, declared a world heritage site by UNESCO. (See Fig. 4.) A flight the following day took us to Samarkand, the location of architectural treasures such as: the Shah-e-Zindeh site (constructed between 1360 and 1434); the Gur Emir mausoleum (1434); Registan, a site containing the madrasas, or complexes of buildings housing religious institutions (1417-1420); Shir Dar (1619-1636), Tilla Kari (1646-1660); and a 15th century observatory. Samarkand is a sister city of Olympia. Both Khiva and Samarkand were major cities on the ancient Silk Route; these cities were used as headquarters by Alexander the Great and Ghengis Kahn during their military campaigns.

Figure 3. Monument in downtown Tashkent dedicated to the survivors of the devastating earthquake of April 26, 1966. The quake had a magnitude of 5, but destroyed 28,000 buildings, including 200 hospitals and clinics (Bulletin of the Seismological Society of America, v.56, no. 5, p. 1192).

Figure 4. From left: Ray Lasmanis, Tim Walsh (on camel), and Stan Biles, at Ichan Qala (royal court), the inner walled city at Khiva.

Time spent at the Institute of Seismology was enlightening. The Institute was established after the 1966 Tashkent earthquake to conduct basic and applied research in geological engineering for construction sites. In particular, earthquake wave amplification research is carried out for the loess soils that mantle the Tashkent basin. Of special interest is the earthquake forecast program housed in the Hydrology Section of the Institute. The prediction program uses 13 deep wells located throughout Uzbekistan. These are monitored daily for radon and helium emissions, water levels and pressures, electromagnetic fields, acoustic emissions, and other data. We were given the opportunity to visit the site of a 2,500-m-deep well near Tashkent in which two high-pressure artesian aquifers are isolated for measurement purposes. In the 25 years that the program has been operating, the Institute has successfully predicted five earthquakes, although there have also been false

Figure 5. Almalyk porphyry copper pit, the largest mine in the U.S.S.R. The mine was operated in the 12th century and rediscovered by re-entering old workings in 1926.

alarms. On May 17, 1976, a visiting USGS scientist witnessed a successful 3-day prediction for a location in western Uzbekistan.

Tours of new construction and industrial sites included the modern Tashkent subway system and a field trip to Charvak Dam and Lake in the Tien Shan Range. One day was spent in the Almalyk porphyry copper district. We were shown the largest open-pit porphyry copper mines in the Soviet Union (Fig. 5). The deposit has a length of 3.5 km, a width of 2.5 km, and a depth of 1 km, with reserves of 3 billion metric tons of ore averaging 0.5 percent copper as well as other minerals.

At the end of our stay, agreement was reached between the Department of Natural Resources and the following organizations: the Uzbek Republican Association of Scientific and Engineering Societies of the USSR, Uzbek Academy of Sciences, and the Institute of Mechanics and Seismoresistance of Structures. The agreement is to provide for scientific and cultural exchange opportunities. The specific items are:

1. Facilitate opportunities for post-graduate work in earth sciences, including seismic, structural, and engineering geology.
2. Facilitate access to technology, including software, sand and gravel removal, seismic wave propagation theory, and earthquake and seismic hazard prediction methodology.
3. Facilitate communication with scientific and cultural institutions.
4. Jointly sponsor and implement conferences of mutual interest.
5. Facilitate a joint scientists exchange program.
6. Share scientific samples, studies, and papers of mutual concern.
7. Investigate opportunities for joint geochemical and trace element studies of mineral deposits.

Professor Yuldashev visited Washington again in late August, and communications continue with the Uzbek scientists. ⚒

1991 Geological Projects, Washington Colleges and Universities

This list is taken from material submitted by press time by the geology departments of the state's colleges and universities. Names in parentheses with the faculty projects are student collaborators unless otherwise noted; with student projects, they are faculty collaborators unless otherwise noted. Affiliations other than with the pertinent college or university are bracketed. Some projects involve areas outside Washington.

CENTRAL WASHINGTON UNIVERSITY

Faculty projects

Geologic thin skinned model for Yakima Fold Belt—*Robert D. Bentley and Haufu Lu [Nanjing University, Peoples Republic of China]*

Flow-thickness variations across Yakima Fold Belt—*Robert D. Bentley (John Kieling, Chrissie Phelps, and Martyne Smith)*

Guidebook to Yakima folds in Yakima Canyon area—*Robert D. Bentley and Jack E. Powell*

Evolution of Selah Butte anticlinal ridge—Robert D. Bentley (Andrew Miner)

Geology of Cleman Mountain area—*Robert D. Bentley and Jack E. Powell (Steve Jensvold)*

Geologic map of Yakima East quadrangle—*Robert D. Bentley, Jack E. Powell and Newell Campbell*

Propagated fault folds in Yakima folds—*Robert D. Bentley, Haufu Lu [Nanjing University, Peoples Republic of China]* and Jack E. Powell

Geologic evolution of Burbank Valley area—*Robert D. Bentley and Haufu Lu [Nanjing University, Peoples Republic of China] (Andrew Miner)*

Was timing of deformation of Yakima folds episodic?—*Robert D. Bentley and Jack E. Powell*

Ellensburg Basin with 1.5 km of latest Miocene sedimentary fill - contractional wrench: a "squeeze down" basin—*Robert D. Bentley, Jack E. Powell and Haufu Lu [Nanjing University, Peoples Republic of China] (Ronald Owens)*

Microprobe study of Frenchman Springs basalt plagioclase phenocrysts—*James R. Hinthorne, Robert D. Bentley, and Jack E. Powell*

Construction of global transect along 117 degrees in Washington and Oregon—*Steven E. Farkas*

Digitizing of 1:100,000 geologic maps: the Wenatchee sheet—*Jack E. Powell*

Student project

Geology of the Ryegrass sanitary landfill site, Kittitas County—*Gerda Smeltzer (Robert D. Bentley)*

EASTERN WASHINGTON UNIVERSITY

Faculty Projects

Mineralogy of the Golden Horn batholith, North Cascades, Washington—*Russell C. Boggs*

Structural states of feldspars as an indicator of sedimentary provenance—*Russell C. Boggs*

Mineralogy of the Sawtooth batholith, Idaho—*Russell C. Boggs*

Geomorphic mapping of Blue Creek to evaluate the potential for enhancing fish habitats—*John P. Buchanan*

Hydrogeology of Long Lake, Spokane and Stevens Counties, Washington—*John P. Buchanan*

Radon gas distribution in cave systems in the Pacific Northwest—*John P. Buchanan*

Survey of karst features in the Pryor Mountains, Montana—*John P. Buchanan*

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington—*Ernest H. Gilmour*

Biostratigraphic studies of Pennsylvanian and Permian bryozoans in North America and Pakistan—*Ernest H. Gilmour*

Carbonate petrology and paleoecology of the Antler Peak Limestone, northeastern Nevada—*Ernest H. Gilmour*

Rare earth element geochemistry of gold deposits—*Mohammed Ikramuddin*

Distribution of immobile trace elements in hydrothermally altered rocks associated with various types of gold deposits—*Mohammed Ikramuddin*

Thallium—a potential guide to mineral deposits—*Mohammed Ikramuddin*

Geochemistry of sediment-hosted precious metals deposits—*Mohammed Ikramuddin*

Development of new analytical methods by inductively coupled argon plasma and electrothermal atomic absorption—*Mohammed Ikramuddin*

Hydrogeochemical and biogeochemical methods of exploration for gold and silver—*Mohammed Ikramuddin*

Geochemistry of volcanic rocks and its relationship to gold-silver mineralization—*Mohammed Ikramuddin*

Use of cesium as a guide to mineral deposits—*Mohammed Ikramuddin*

The use of boron in gold exploration—*Mohammed Ikramuddin*

Reconnaissance lithogeochemical survey of northwest Pakistan—*Mohammed Ikramuddin*

Study of toxic elements in environmental samples—*Mohammed Ikramuddin*

Chemical analysis of ultrapure electronic materials—*Mohammed Ikramuddin*

Glacial and catastrophic flood history of eastern Washington—*Eugene P. Kiver*

Quaternary map of northeastern Washington east of the Okanogan River—*Eugene P. Kiver*

Geology of national parks—Eugene P. Kiver

Structure and stratigraphy of the Middle Paleozoic Antler orogen in northwestern Nevada—*Linda B. McCollum*

Stratigraphy, sedimentology, and paleontology of the Cambrian System of the Great Basin—*Linda B. McCollum*

Paleozoic continental margin sedimentation in western U.S.—*Linda B. McCollum*

Transcurrent faulting and suspect terranes in the Great Basin—*Linda B. McCollum*

Alkaline igneous rocks and related precious metal deposits—*Felix E. Mutschler*

Space-time tectonic and magmatic maps of the Cordillera—*Felix E. Mutschler*

Compilation of computer data base of whole-rock chemical analyses of igneous rocks—*Felix E. Mutschler*

Styolites in igneous rocks—*James R. Snook*

Petrology of the Quartz Hill molybdenum deposit, Alaska—*James R. Snook*

Use of remanent magnetization direction to correlate air-fall ash deposits from Cascade volcanoes—*William K. Steele*

Mechanism of acquisition of remanent magnetization by airfall ash—*William K. Steele*

Magnetostratigraphy of Clarkia Miocene fossil site—William K. Steele [with University of Idaho]

Student projects

Computer exercises in pattern recognition applied to exploration for mineral deposits related to igneous rocks—*Glen R. Carter*

Saturated zone chemistry down-gradient from mine tailings ponds near Twisp, Washington—*Robert H. Lambeth*

Abundance and behavior of cesium, and selected trace elements in rock, soil, and water samples from the Republic area, northeast Washington—*Wilfred H. Little*

Structural states of alkali feldspar as an indicator of sedimentary provenance—*Mohammad Zafar*

Groundwater geochemistry down-gradient from a uranium mill tailings pond—*Ronald A. Stone*

Origin and mineralization of Colorado Plateau uranium-copper bearing breccia pipes—*J. Michael Faurote*

Geochemistry of igneous rocks from Newport and adjacent areas, northeastern Washington—*L. Christine Russell*

Alunite characterization of the Gold Quarry mine, Eureka County, Nevada—*Dean G. Heitt*

Biogeochemical methods of exploration for Archean gold deposits—*Richard B. Lestina*

Hydrology of Long Lake, Spokane and Stevens Counties, Washington—*Michael S. Johnson*

Hydrogeology of the Haripur Plain, Pakistan—*Christopher T. Jones*

Rare earth element geochemistry of volcanic-hosted gold deposits—*Calvin A. Landrus*

Fenestrate bryozoans of the Toroweap Formation, southern Nevada—*Miriam E. McColloch*

Platinum-group elements in alkaline igneous rocks—*Thomas C. Mooney*

Formulation of a finite-difference groundwater flow model for the Spokane Valley aquifer—*Iain A. Olness*

Gallium in Carlin-type gold deposits—*Philip A. Owens*

Trace element pollution from sulfide deposits in Hunters Creek, Stevens County, Washington—*Fazli Rabbi*

PACIFIC LUTHERAN UNIVERSITY

Faculty Project

Palynology and depositional environments of Pleistocene sea cliff deposits north of Kalaloch, Washington, using optical and SEM techniques—S. R. Benham

TACOMA COMMUNITY COLLEGE

Faculty project

Roadside geology of Mount Rainier National Park—*J. H. Hyde*

UNIVERSITY OF WASHINGTON

Faculty projects

The Chesaw fault: A terrane boundary in Okanogan and Ferry Counties, Washington—*Eric S. Cheney (Michael G. Rasmussen and Martin G. Miller)*

Regional sequence stratigraphy of the Leavenworth fold belt, central Washington—*Eric S. Cheney and Richard J. Stewart*

Rapid chemical changes in the oceans near the Cretaceous/Tertiary boundary—*Bruce K. Nelson*

Fluid-rock interaction in subduction zones: the Franciscan Complex and the Austrian Alps—*Bruce K. Nelson*

Proterozoic anorogenic granitic magmatism in the midcontinent of North America—*Bruce K. Nelson*

Early crustal history of the Brooks Range, Alaska—*Bruce K. Nelson*

Isotopic study of the provenance of sediments in the Methow-Tyaughton basin—*Bruce K. Nelson*

Student projects

Use of cosmogenic isotopes for determining the exposure age and erosion of granitic rocks—*Paul Bierman*

Evaluation of rock varnish dating techniques [USGS NEHRP Research]—*Paul Bierman and Alan Gillespie*

Geology and origin of the Overlook gold deposit, Ferry County, Washington—*Michael G. Rasmussen*

Pb isotopic variations in sulfides of the Stillwater Complex, Montana—*Mark Thurber*

WASHINGTON STATE UNIVERSITY

Faculty projects

Exploration targets for the next century—metals in the metasomatic environment—*Lawrence D. Meinert*

Geologic and geohydrologic site characterization studies, Hanford Site, Washington—*David R. Gaylord and Eileen P. Poeter [Colorado School of Mines and Technology]*

Eolian morphology, sedimentology, and paleoclimatic significance, Hanford Site, Washington—*David R. Gaylord*

Sedimentology and stratigraphy of middle Eocene volcanogenic deposits, northeastern Washington and southern British Columbia—*David R. Gaylord*

Biostratigraphic analysis of three potential mid-Carboniferous boundary stratotypes in the Great Basin—*Gary D. Webster and Larry E. Davis*

Early Carboniferous crinoid faunas of the western United States (includes materials of Kinderhookian and Osagean age from MT, UT, ID and NV)—*Gary D. Webster*

Permian crinoids of Western Australia—*Gary D. Webster*

Bibliography and index of Paleozoic crinoids—*Gary D. Webster*

Annotated bibliography of Carboniferous conodonts—*Gary D. Webster and Carl B. Rexroad [Indiana Geological Survey]*

The significance of orogen-parallel lineations—*A. John Watkinson*

Refold geometries observed in the Loch Monar region, Scotland—*A. John Watkinson*

Refold analysis of multiply deformed mines and mining districts—*Richard L. Thiessen and A. John Watkinson*

Geophysical investigations of the cratonic margin in the Pacific Northwest—*Richard L. Thiessen*

Structural analysis of the central Columbia Plateau utilizing radar, Landsat, digital topography, and magnetic data bases—*Richard L. Thiessen*

A three-dimensional computer analysis of modelling system for remote sensing-structural geologic problems—*Jay R. Eliason*

Deformation along the Olympic/Wallowa Lineament, Oregon and Washington—*Peter R. Hooper*

The Columbia River basalts in the Lewiston Basin and along the Blue Mountains uplift (Oregon and Washington)—*Peter R. Hooper*

Primitive basalt flows in the Pacific Northwest.—*Peter R. Hooper (David G. Bailey and Richard M. Conrey)*

Paleomagnetism of volcanics in the Pacific Northwest—*Peter R. Hooper and William K. Steele [Eastern Washington University] (David G. Bailey, Richard M. Conrey, Kevin M. Urbanczyk, and Sandra P. Lilligren)*

Alkali basalts and ultramafic nodules of eastern China—*Fan Qicheng [Institute of Geology, Beijing, China] and Peter R. Hooper*

Alkali basalts of the Harrats of Saudi Arabia—*Victor E. Camp [U.S. Geological Survey] and Peter R. Hooper*

Deccan basalts—Peter R. Hooper and John Mahoney [University of Hawaii] *(John E. Beane)*

Prineville Basalt—*Peter R. Hooper, William K. Steele [Eastern Washington University], Terry Tolan, and Gary Smith (Richard M. Conrey, David G. Bailey, Kevin M. Urbanczyk)*

Age and determination of Cascade tephras in the Pacific Northwest—*F. F. Foit, Jr.*

Crystal chemistry of the tourmaline group—*F. F. Foit, Jr.*

High temperature gold-quartz veins in distal portions of porphyry copper districts—*Lawrence D. Meinert (John Link)*

Isotopic tracking of mineralizing fluids in skarn deposits—*Lawrence D. Meinert (Brian Zimmerman)*

Carbon cycling in vadose zones—*C. Kent Keller*

Age-dating dissolved inorganic carbon and dissolved organic carbon in groundwaters—*C. Kent Keller*

Structural evolution of metamorphic core complexes, northeast Washington—*A. John Watkinson*

Student projects

Geology and geochemistry of gold skarn mineralization in the McCoy mining district, Lander County, Nevada—*Jeffrey W. Brooks*

Geology of the Tillicum gold skarn camp, British Columbia—*Dean M. Peterson*

Gold skarn mineralization in the Fortitude deposit, Lander County, Nevada—*Greg L. Myers*

Gold skarn mineralization in clastic host rocks, Beal mine, Montana—*Kurt M. Wilkie*

Regional stratigraphy and sedimentology of the upper Sanpoil Volcanics and Klondike Mountain Formation in the Republic, First Thought, and Toroda Creek grabens, Washington and southern British Columbia—*James D. Suydam*

Sedimentology and stratigraphy of upper Sanpoil Volcanics and the Klondike Mountain Formation, Republic mining district—*Scott M. Price*

Sedimentology, stratigraphy and paleoclimatic implications of eolian deposits on the Hanford Site, Washington—*Larry D. Stetler*

Sedimentology and geoarchaeology of eolian deposits on the Hanford Site, Washington—*Grant D. Smith*

Stratigraphy and sedimentology of the O'Brien Creek Formation, northeastern Washington and southern British Columbia—*Jeffrey M. Matthews*

Stratigraphy, sedimentology, and depositional history of the Upper Cretaceous Beaverhead Conglomerate, McKnight Canyon, southwest Montana—*Holly J. Corner*

Kinematics and strain in the Lincoln gneiss dome, northeast Washington—*Jay P. Busch (A. John Watkinson)*

Fracture patterns and fold related strain using examples from the Yakima Fold Belt, Washington and the Montana fold and thrust belt—*Sarah M. Koerber (A. John Watkinson)*

Geologic analysis of a portion of the Weatherbee Formation, northeastern Oregon—*Rebecca Myers*

Correlation of fractures observed using a televiewer in the Cajon Pass DOSSEC drill hole with ones determined from Geologic Spatial Analysis applied to topographic data bases—*Mark Ader*

Structural analysis of the West Idaho suture zone—*David E. Blake*

Identification of range front fault scarps using digital topography data bases and application to the Wasatch front, Utah—*Douglas S. Neves*

Determination of the three-dimensional orientation and location of faults using earthquake foci and application to the Puget Sound—*Eric Rieken*

Syenites around the Idaho batholith, Idaho—*D. Kate Schalck*

Colville batholith and Sanpoil Volcanics—*Laureen J. Wagoner (Peter R. Hooper)*

The volcanic rocks of the eastern Clarno—*Kevin M. Urbanczyk and Sandra P. Lilligren (Peter R. Hooper)*

The Eckler Mt. Formation, Columbia River basalt gorge in Oregon, Washington, and Idaho—*Beth A. Gillespie (Peter R. Hooper)*

Relation between volcanism and tectonics in the Vale area, eastern Oregon—*Kate Lees (Peter R. Hooper)*

Dissolved organic carbon in vadose-zone pore water—*Richard Crum*

Bulk gas-phase diffusion coefficients in unsaturated loess—*Diane Foster*

Distribution of environmental tritium and groundwater recharge in the Palouse Formation—*Rachel O'Brien*

Foraminifera and conodont biostratigraphy and carbonate microfacies of Early Carboniferous shelf to basin sediments, north-central Wyoming to southeastern Idaho—*Aram Derewetzky and Chen Xiaobing (Gary D. Webster)*

WESTERN WASHINGTON UNIVERSITY

Faculty projects

Petrogenesis of the Crescent basalts and related rocks in the Coast Range Volcanic Province—*R. Scott Babcock*

Magmatic evolution of the North Cascades—*R. Scott Babcock*

Petrogenesis of the Fifes Peak Formation, central Cascades—*R. Scott Babcock*

Laser-Ar dating of tephra and paleomagnetism of early Pleistocene sediments in the Puget Lowland—*Don J. Easterbrook*

Thermoluminescence dating of middle Pleistocene sediments in the Puget Lowland—*Don J. Easterbrook (Glenn W. Berger)*

Advance and recession of the Cordilleran ice sheet and relationships to glaciomarine deposition—*Don J. Easterbrook*

Causes of debris torrents in northwest Washington—*Don J. Easterbrook*

Effects of logging on flooding in Whatcom County—*Don J. Easterbrook*

Effect of seawalls on beaches in Puget Sound—*Maurice L. Schwartz and T. Terich [WWU Geography Department]*

Sources, depositional environments, and tectonics of the peripheral sedimentary rocks of the Crescent terrane, northern Olympic Peninsula—*Christopher A. Suczek*

Student projects

Effects of 1989 and 1990 storms on Canyon Creek, Whatcom County—*Mark Ballerini*

Effects of dredging on the Nooksack River, Whatcom County—*Roger Bertschi*

Late Pleistocene marine terraces, glaciomarine drift, and late Vashon transition sediments—*Cindy Carlstad*

Effects of the 1989 and 1990 storms on Gallup Creek, Whatcom County—*Melanie Carpenter*

Historic fluctuations of glaciers on Mount Baker—*Joel Harper*

Glacier Creek flooding, Whatcom County—*Carla Cary*

Net shore-drift (longshore transport) mapping of the coastlines of San Juan, southern Snohomish, southern Island and southeastern Jefferson Counties—*Jim Johannessen*

Structure and petrology of the Eldorado Peak area, North Cascades, Washington—*Dan McShane*

Hydrostratigraphy and potential problems of seawater intrusion on northern Camano Island—*Lloyd Stevens*

Paleogeographic reconstruction of the Crescent terrane on the Olympic Peninsula—*Andrew Warnock* ⚒

USGS Starts Water Assessment of the Columbia Plateau

A long-term, comprehensive assessment of the water quality of the central Columbia plateau is being launched by the U.S. Geological Survey. The plateau is a 19,000-mi² basin, mostly in eastern Washington, drained by Crab Creek and the Palouse River. The project is one of 20 being initiated this year as part of a National Water Quality Assessment.

The long-term goals of NAWQA are to describe the status and trends in the quality of a large, representative part of the nation's surface- and ground-water resources and to provide a sound, scientific understanding of natural and human factors affecting these resources.

"One goal of the assessment is to provide water managers and users with a more complete snapshot of current water-quality conditions and problems in the regions," said Sandy (Alex K.) Williamson, a USGS hydrologist in Tacoma, who was recently named chief of the project.

"But even more important is the need to go beyond the snapshot to define the long-term trends in water quality in terms that will allow water managers to design long-term solutions to real problems," Williamson said. "We will work first with state, local, and federal agencies to take the pulse of the surface- and ground-water resources in the plateau. Then, we will develop an assessment program needed to build an understanding of the hydrologic health of the basin, that will, in turn, allow managers to make more effective water management decisions for the future."

Two immediate priorities for the central Columbia plateau assessment are:

- Formation of a liaison committee of representatives from state and local water-resources agencies, universities in Washington and Idaho, and other federal agencies.
- A detailed review of the hydrologic and related biologic information already collected or being collected, as part of a first-year effort to develop a practical assessment plan.

Water-quality issues discussed at the first meeting of the committee, held May 29 at Moses Lake, included:

- Elevated concentrations of nutrients and trace organic compounds in surface and ground waters
- Eutrophic conditions and nuisance aquatic plants in some streams and lakes
- Elevated concentrations of sodium in surface and ground waters in areas irrigated with ground water
- Erosion of soil caused by rainfall and snowmelt, especially on frozen ground
- Steambed deposition of fine sediment that covers spawning gravels and causes dissolved-oxygen depletion
- Elevated temperatures, pH and concentrations of ammonia and bacteria in surface water

NAWQA was started in 1986 at seven sites around the country to test its assessment methods. One of the sites was the Yakima River basin in eastern Washington.

The full-scale national program began in fiscal year 1991 with the selection of 20 study sites. Each of these 20 projects will consist of an intensive 4- to 5-year phase of data collection and analysis. In fiscal year 1994, 20 more projects will be started, with the final 20 projects to begin in fiscal year 1997, for a total of 60 projects covering a large part of the United States.

This rotational strategy will provide consistent information on a perennial basis that will be integrated to describe the quality of the nation's water resources. At the end of the first cycle of 60 intensive studies in three groups, the first 20 study units will be studied again to detect trends that may have developed. ⚒

(Modified from a USGS press release dated August 2, 1991)

Selected Additions to the Library of the Division of Geology and Earth Resources

May 1991 through July 1991

THESES

Ashford, Paul G., 1988, Geological hazard assessment of a residential development in West Vancouver, British Columbia: University of British Columbia Bachelor of Applied Science thesis, 66 p., 1 plate.

Barker, Sally E., 1988, Magma body geometry at Mount St. Helens inferred from the stress field associated with post-eruptive earthquakes: University of Washington Master of Science thesis, 76 p.

Beale, Harriet, 1990, Relative rise in sea-level during the late Holocene at six salt marshes in the Puget Basin, Washington: Western Washington University Master of Science thesis, 157 p.

Bodle, Tom R., 1990, The relation of earthquake intensity to surface geology and elevation in western Washington State: University of Washington Master of Science thesis, 119 p.

Brandon, Mark Thomas, 1984, Deformational processes affecting unlithified sediments at active margins—A field study and a structural model: University of Washington Doctor of Philosophy thesis, 159 p.

Burger, Roy William, 1984, Source mechanism of the May 18, 1980 St. Helens eruption from regional surface waves: Pennsylvania State University Master of Science thesis, 72 p.

Campbell, A. R., 1991, Petrology and petrogenesis of the Lost Peak and Monument Peak stocks, Okanogan County, Washington: University of Washington Master of Science thesis, 136 p., 1 plate.

Caress, David William, 1989, Some aspects of the structure and evolution of oceanic spreading centers: University of California, San Diego, Doctor of Philosophy thesis, 120 p.

Chambers, Richard L., 1971, Sedimentation in glacial Lake Missoula: University of Montana Master of Science thesis, 100 p.

Croasdale, Duncan Alexander, 1989, A small scale translational rock failure affecting the basal failure surface of the 1965 Hope slide: University of British Columbia Bachelor of Science thesis, 1 v., 2 plates.

Denton, Alexander W. S., 1986, Tectonics and sediment geochemistry of Tuzo Wilson seamounts, northeast Pacific Ocean: University of British Columbia Master of Science thesis, 183 p.

Dewhurst, Warren T., 1988, The simultaneous inversion of vector and total field aeromagnetic data using Bayesian inference—A case study from the Cobb Offset of the Juan de Fuca Ridge: Colorado School of Mines Doctor of Philosophy thesis, 249 p.

Eissler, Holly K., 1986, Investigations of earthquakes and other seismic sources in regions of volcanism: California Institute of Technology Doctor of Philosophy thesis, 174 p.

Feeney, Tracey, 1989, The petrology, morphology and tectonics of Explorer Seamount: University of British Columbia Bachelor of Science thesis, 55 p., 1 plate.

Ganoe, Steven J., 1983, Investigation of P_n wave propagation in Oregon: Oregon State University Master of Science thesis, 97 p.

Gardiner, Mark A., 1988, Hydrothermal reaction of groundwater with basalt from the entablature of the Cohassett flow, Grande Ronde formation, Hanford, Washington—The effect of the introduction of fresh solution to the system at 200 degrees and 300 degrees C, and 30 MPa: Temple University Master of Arts thesis, 152 p.

Hamill, Gary, 1982, Quaternary interpretation of southwest Tofino Basin, Pacific margin, Canada: University of Calgary Master of Science thesis, 148 p., 9 plates. (Note: DGER copy reproduced from microfiche; plates are dismembered and bound with the book.)

Johnson, David Andrew Lothian, 1987, Crustal structure and seismicity of the northern Gorda Ridge: University of Washington Master of Science thesis, 120 p.

Jones, P. R., III, 1975, Microearthquake studies of the Blanco fracture zone and Gorda Ridge using sonobuoy arrays: Oregon State University Master of Science thesis, 94 p.

Keach, R. W., II, 1986, Cenozoic active margin and shallow Cascades structure—COCORP results from western Oregon: Cornell University Master of Science thesis, 51 p.

Klitgord, Kim Donald, 1974, Near-bottom geophysical surveys and their implications on the crustal generation process, sea floor spreading history of the Pacific and the geomagnetic time scale—0 to 6 M.y.b.p.: University of California, San Diego, Doctor of Philosophy thesis, 177 p.

Knapp, John Stafford, Jr., 1982, Seismicity, crustal structure, and tectonics near the northern termination of the San Andreas fault: University of Washington Doctor of Philosophy thesis, 316 p.

Korn, Rosemary A., 1986, A comparison of the hydrothermal stability of the Columbia Plateau basalts from the Umtanum and Cohassett flows at 100 degrees, 200 degrees, and 300 degrees, and at 30 MPa: Temple University Master of Arts thesis, 126 p.

Korner, Karen, 1989, Design response spectra for Washington State bridges: Washington State University Master of Science thesis, 166 p.

Laesecke, Ronald F., 1989, Factors causing instability of rock slopes along the Vancouver–Squamish highway in south-western British Columbia: University of British Columbia Bachelor of Applied Science thesis, 86 p.

Leybourne, Matthew Iain, 1988, Volcanism and geochemistry of parts of the Endeavour segment of the Juan de Fuca Ridge system and associated seamounts: Acadia University Master of Science thesis, 177 p.

Li, Zhenlin, 1990, Longshore grain sorting and beach-placer formation adjacent to the Columbia River: Oregon State University Doctor of Philosophy thesis, 232 p.

Lisowski, Michael, 1985, Geodetic strain measurements in central Vancouver Island: University of British Columbia Master of Science thesis, 100 p.

Longtine, Mark William, 1991, Mid- to Late Cretaceous structural, metamorphic, and magmatic evolution of the Sloan Peak area, North Cascades, Washington: University of Texas at Austin Master of Arts thesis, 139 p., 2 plates.

Lowes, Brian Edward, 1972, Metamorphic petrology and structural geology of the area east of Harrison Lake, British Columbia: University of Washington Doctor of Philosophy thesis, 162 p.

McInelly, Galan Wells, 1989, Holocene and late-Pleistocene tectonic deformation in the Cape Arago–Bandon region of coastal Oregon as deduced from marine wave-cut platforms: Western Washington University Master of Science thesis, 66 p.

McKenna, Gordon Thomas, 1987, Evidence of large scale mass wasting on the Fraser River delta front at Sand Heads, British Columbia: University of British Columbia Bachelor of Applied Science thesis, 62 p., 1 plate.

Moore, Elizabeth L., 1983, Hydrothermal interaction of Columbia River basalt from the Umtanum formation with its coexisting groundwater: Temple University Master of Arts thesis, 89 p.

Moran, Jean Elizabeth, 1986, Heat flow and the thermal evolution of Cascadia Basin: University of Washington Master of Science thesis, 96 p.

Nicol, Doug, 1987, The feasibility and technical design of a proposed Squamish Highway tunnel: University of British Columbia Bachelor of Applied Science thesis, 71 p.

Phipps, James Benjamin, 1974, Sediments and tectonics of the Gorda-Juan de Fuca plate: Oregon State University Doctor of Philosophy thesis, 118 p.

Reddy, Douglas Gerald, 1989, Geology of the Indian River area, southwestern British Columbia: University of British Columbia Master of Science thesis, 166 p., 5 plates.

Shoemaker, Craig Alan, 1984, A relocation of earthquakes in the area of the Gorda Rise: Southern Illinois University Master of Science thesis, 111 p.

Solano-Borrego, A. E., 1982, Microseismicity on the Gorda Ridge: Oregon State University Master of Science thesis, 76 p.

Solano-Borrego, Ariel E., 1984, Crustal structure and seismicity of the Gorda Ridge: Oregon State University Doctor of Philosophy thesis, 185 p.

Stephens, Ernest, Jr., 1958, Intensity distribution study and fault plane solution for the Cape Mendocino, California, earthquakes of October 11, 1956: University of Wyoming Master of Arts thesis, 54 p., 1 plate.

Stoddard, Paul Richard, 1989, Kinematic studies—Ridge evolution, Gorda plate, and Deccan traps: Northwestern University Doctor of Philosophy thesis, 106 p.

Thrasher, Glenn P., 1977, Median valley crustal structure and sea floor spreading at the Gorda Ridge, 42 degrees N latitude: Oregon State University Master of Science thesis, 67 p.

Umhoefer, Paul John, 1989, Stratigraphy and tectonic setting of the upper Cadwallader terrane and overlying Relay Mountain Group, and the Cretaceous to Eocene structural evolution of the eastern Tyaughton basin, British Columbia: University of Washington Doctor of Philosophy thesis, 186 p.

Walters, Lori Kathleen, 1987, A geological interpretation of LITHOPROBE seismic reflection profile 3, southern Vancouver Island, B.C.: University of British Columbia Bachelor of Science thesis, 39 p., 5 plates.

Wei, Ching-Ling, 1990, Studies of marine scavenging by naturally occurring radionuclides: University of Washington Doctor of Philosophy thesis, 199 p.

U.S. GEOLOGICAL SURVEY REPORTS

Published Reports

Lee, F. T.; Abel, J. F., Jr., 1983, Subsidence from underground mining—Environmental analysis and planning considerations: U.S. Geological Survey Circular 876, 28 p.

Stover, C. W.; Brewer, L. R., 1991, United States earthquakes, 1985: U.S. Geological Survey Bulletin 1954, 170 p.

Sun, J. T., editor, 1985, USGS coastal research, studies, and maps—A source of information for coastal decisionmaking: U.S. Geological Survey Circular 883, 80 p.

U.S. Geological Survey, 1985, Strong-motion program report, January-December, 1982: U.S. Geological Survey Circular 965, 22 p.

Open-File Reports and Water-Resources Investigations Reports

Drost, B. W.; Schurr, K. M.; Lum, W. E., II, 1989, Selected ground-water information for the Pasco Basin and adjacent areas, Washington, 1986-1989: U.S. Geological Survey Open-File Report 89-228, 91 p.

Ebbert, J. C.; Payne, K. L., 1985, The quality of water in the principal aquifers of southwestern Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4093, 59 p., 5 plates.

Evarts, R. C.; Ashley, R. P., 1991, Preliminary geologic map of the Lakeview Peak quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 91-289, 35 p., 1 plate.

Luttrell, G. W.; Hubert, M. L.; Murdock, C. R., compilers, 1990, GEONAMES data base of geologic names of the United States through 1988, [part M—WA, OR, ID]: U.S. Geological Survey Open-File Report 90-466-M, 10 p., 1 floppy disk.

McCarthy, K. A.; Anderson, D. B., 1990, Ground-water data for the Portland Basin, Oregon and Washington: U.S. Geological Survey Open-File Report 90-126, 56 p., 1 plate.

Stanley, W. D.; Gwilliam, W. J.; Latham, Gary; Westhusing, Keith, 1991, Are hydrocarbon source rocks buried beneath volcanic flows in the southern Washington Cascades?: U.S. Geological Survey Open-File Report 91-119, 32 p.

Swanson, D. A., 1991, Geologic map of the Tower Rock quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 91-314, 26 p., 2 plates.

Turney, G. L., 1990, Quality of ground water in Clark County, Washington, 1988: U.S. Geological Survey Water-Resources Investigations Report 90-4149, 97 p.

GEOLOGY AND MINERAL RESOURCES OF WASHINGTON (and related topics)

Day, S. M.; Stevens, J. L.; Barker, T. G., 1988, Ground motion simulations for thrust earthquakes beneath western Washington; Final report: S-Cubed [La Jolla, Calif.] SSS-R-87-8801 [under contract to Washington Public Power Supply System], 1 v.

Higgins, J. D.; Fragaszy, R. J.; Beard, L. D., 1988, Seismic zonation for highway bridge design: Washington Department of Transportation WA-RD 172.1, 155 p.

Kennedy/Jenks/Chilton, 1990, Earthquake loss estimation modeling of the Seattle water system: Kennedy/Jenks/Chilton [under contract to U.S. Geological Survey], 1 v.

King County Department of Planning and Community Development, 1988, Final environmental impact statement, proposed rezone, Kangley sand and gravel mine and aggregate processing facility: King County Department of Planning and Community Development, 1 v.

Klarin, P. N.; Branch, K. M.; Hershman, M. J.; Grant, T. F., 1990, Sea level rise policy alteratives study—Vol. 1, Alternative policy responses for accelerated sea level rise and their implications; Vol. 2, An analytical review of state and federal coastal management systems and policy responses to sea level rise: Washington Department of Ecology 90-40, 1 v.

Lindsey, Kevin A., 1991, Revised stratigraphy for the Ringold Formation, Hanford site, south-central Washington: Westinghouse Hanford Company WHC-SD-EN-EE-004, 12 p.

Mason County Department of General Services, 1991, Draft environmental statement—Johns Prairie site, sand and gravel excavation and barge-loading facility: Mason County Department of General Services, 2 v.

Preuss, Jane; Hebenstreit, G. T., 1990, Integrated hazard assessment for a coastal community—Grays Harbor, Washington: Science Applications International Corporation [McLean, Va.], 36 p.

Scawthorn, Charles, 1990, Inventory and post-earthquake functionality of emergency response resources—Fire service operations in the Puget Sound area: EQE, Inc. [San Francisco; under contract to U.S. Geological Survey], 1 v.

Tilling, R. I.; Topinka, Lyn; Swanson, D. A., 1984, rev. 1990, Eruptions of Mount St. Helens—Past, present, and future: U.S. Geological Survey, 56 p.

University of Washington Geophysics Program, 1991, Quarterly network report 91-A on seismicity of Washington and northern Oregon, January 1 through March 31, 1991: University of Washington Geophysics Program, 22 p.

Wahlstrom, R.; Rogers, G. C., 1990, Relocation of earthquakes offshore Vancouver Island: Geological Survey of Canada Open File 2288, 63 p.

Washington Department of Ecology, 1991, Washington State mine waste program analysis and development: Washington Department of Ecology, 1 v.

A Note from the Burke Museum at the University of Washington

A new taxon from the middle Eocene fossil flora at Princeton, BC, has been named for the museum's Affiliate Curators of Paleobotany, Jack Wolfe and Wes Wehr. The new name is *Wehrwolfea striata*, but there's no information yet about its reaction to full moons.

LOCATION OF MAIN OFFICE

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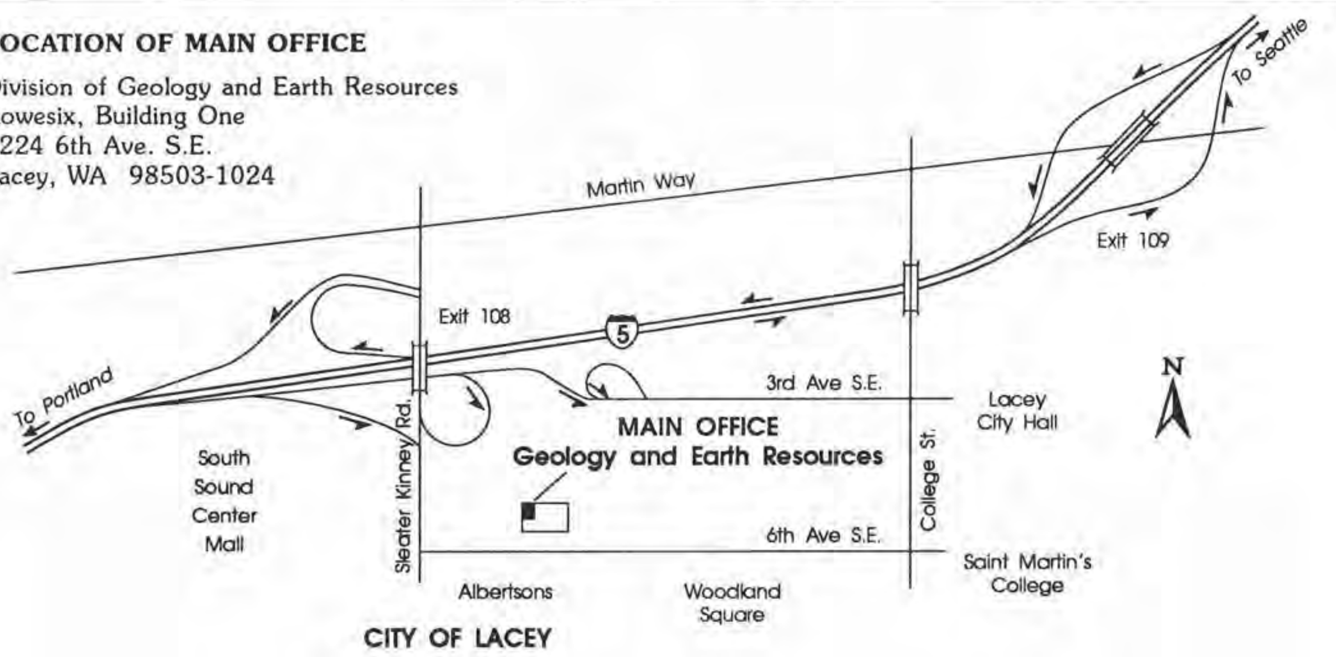

New Division Releases

The three sheets and accompanying pamphlet for the **Geologic map of Washington—Northeast Quadrant**, our **GM-39** at 1:250,000 scale, have been published. Folded sheets and the pamphlet in an envelope cost $7.42 + .58 (tax for Washington residents only) = $8.00. A limited supply of the publication with unfolded copies of the sheets is also available at $9.28 + .72 = $10.00. A topographic base map for the quadrant (**TM-2**) is also available separately: folded ($1.86 + .14 = $2.00) or flat ($3.25 + .35 = $3.50). Unfolded copies of both publications are mailed in tubes.

Open File Report 91-5, A compilation of reflection and refraction seismic data for western Washington and adjacent offshore areas, by W. S. Lingley, Jr., Linden Rhoads, S. P. Palmer, and C. F. T. Harris. This 9-page report briefly describes data available to the public from the Division's collection and shows the locations of tracklines on a 1:500,00-scale map ($.93 + .07 tax = $1.00). Disc versions of the plate are available as files in .DWG and .DXT formats.

The **Washington State Issue of *Rocks & Minerals*** (v. 66, no. 4), devoted to geologic features of the state, contains articles about zeolites, petrified wood, and fossil crabs, as well as descriptions of minerals from selected claims and mines. Also included are a list of collecting sites for agates and a list of geology, mineral, and fossil collections and displays in Washington. The lead article, by Raymond Lasmanis, is a discussion of the state's geology by physiographic province; it includes a page-size geologic map (1 in. = approx. 60 mi). The Division has a supply of issues for sale at $2.32 + .18 tax = $2.50.

The Association of Engineering Geologists Bulletin for August features an article by R. W. Galster and W. T. Laprade about **engineering aspects of the geology of Seattle**. The 67-p. article also features a generalized geologic map of the Seattle area (5 in. = 4 mi).

Please add $1 to each order for postage and handling. Our mailing address is given on p. 2 of this publication. We would appreciate having your Zip Code and the four-digit extension for your address with your correspondence. ⚒

Smithsonian Research Fellowships and Internships Available for 1992–1993

The Smithsonian Institution has announced its research fellowships for 1992-1993 in the following earth sciences: meteoritics, mineralogy, paleobiology, petrology, planetary geology, sedimentology, and volcanology. Fellowships are also available in the areas of: history of science and technology, social and cultural history, history of art, anthropology, biological sciences, and materials analysis (archaeometry and conservation science).

Applications are due January 15, 1992. Stipends supporting these awards are $26,000 per year plus allowances for senior postdoctoral fellows; $13,000 per year plus allowances for predoctoral fellows, and $3,000 for graduate students for the ten-week tenure period. Pre-, post-, and senior postdoctoral stipends are prorated on a monthly basis for periods of less than twelve months.

Awards are based on merit. Smithsonian fellowships are open to all qualified individuals without reference to race, color, religion, sex, national origin, age, or condition of handicap of any applicant. For more information an application forms, write: Smithsonian Institution, Office of Fellowships and Grants, Suite 7300, 955 L'Enfant Plaza, Washington, D.C. 20560. Please indicate the particular area in which you propose to conduct research and give the dates of degrees received or expected.

Smithsonian Minority Internship Program

Internships, offered through the Office of Fellowships and Grants, are available for students to participate in research or museum-related activities for periods of nine to twelve weeks during the summer, fall, and spring. U.S. minority undergraduate and graduate students are invited to apply. The appointment carries a stipend of $250 per week for undergraduate and $300 per week for graduate students, and may provide a travel allowance. For applications and deadline information, write: Smithsonian Institution, Office of Fellowships and Grants, Suite 7300, 955 L'Enfant Plaza, Washington, D.C. 20560. ⚒

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